CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

A Study of Input and Output Field Quantification in Heavy Civil Construction

By

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Abstract

Aknowledgements

I appreciate the time given by the engineers who shared copies of their spreadsheets, assisted me with developing techniques of tracking, and explained the details of quantification knowledge.

In particular, thank you to Ron Dukeshier, Darryl Goodson, Bob Stallard, Russell Clough, and Paul Teicholz for taking the time to share their time and experiences in heavy construction. I thank my thesis adviser Professor Martin Fischer for guidance and patience, and my Masters adviser Professor Bob Tatum for his encouragement to continue with my graduate studies and how to look at heavy construction from a research view. Thank you to the instructors at California State University Chico that let a homeless student attend their classes, as well as the Economics Professors at the University of Nevada Reno that let a field engineer hide in their classes from his supervisors, and the Sierra College lecturers that let a laborer sit in their classes. These instructors showed patience beyond the requirement of their roles.

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1 Introduction

If you ask enough heavy construction superintendents, the consensus will tell you that achieving the project stakeholder objectives is independent of project controls. For this reason, most superintendents have no interest in anything more than a superficial project planning. The independence of objectives from controls is the overarching problem addressed by this thesis. Specifically within project controls, I will look at the role of quantities as feedback of actual project status. The current prevailing theories for project planning rely on model-based and sesor-based closed loops replanning. After completing this study, one of my conclusions is that a field engineer, on a heavy construction project, following the quantification processes presented in this thesis, currently has the ability to measure quantities within +/-5% of the actual (accuracy), 75% of the time (precision), for 99% of the project activities (complete), with seven features of context – and to do this you will need one field engineer for every six to eight million dollars of contract value. Based on the prevailing process of detailed planning, replan forecasts should have at best a similar performance.

I also found that the degree of planning quality is insufficient to coordinate weekly field operations. The quality is sufficient to create plans at a component level of detail – useable for monthly planning at the project level. This means that most large civil projects do not have field level plans. The result of constructing large projects without detailed plans is wasted resources, both in the time spent attempting to plan and from uncoordinated activities. Plans that do not reflect reality lead to expectations that do not align with reality. Often, the difference makes no difference[1], as I will show evidence of in this thesis. There are those rare cases when the gap between expectation and reality is more than an annoyance, in the worst case it can result in serious injuries, massive environmental damage, and widespread impacts on the community.

These extreme cases are the target of this thesis. My target audience is researchers who can use this document as a compilation of the existing quantification processes for project monitoring.

The meta-goal of construction engineering research is sustainability. This thesis advances sustainability specifically through looking closely at the replanner theory for the feedback of actual quantities from the sensory to the model. I focus on project monitoring[2], which is one of

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[1] On one of the projects studied, the ReTRAC project, of thirteen locations, by mistake, one was not included in the schedule, the project engineering team never noticed, I found the error after the fact when I used the project documents for a civil VDC case study.

[2] Additional monitoring contributes to historical libraries, regulatory compliance reports, community impact mediations, and maintenance triggers.

the four sub-tasks of project control[3]. The other three control tasks are establishment of metrics, data analysis, and corrective actions (CPM 4th Edition Chapters 9 & 10)[4]. Since these tasks are dependent on the correct representation of measurement context features, I perceive them as secondary to quantities collection[5].

Within replanning, there is a gap in construction-engineering project-monitoring quantificiation knowledge. There is not a publication, or a group of publications, that captures the quantification knowledge. This gap limits the knowledge of researchers and limits practitioners' knowledge sharing. Through this thesis, I address this gap in knowledge through studying, observing, and synthesizing the current published theories and practiced knowledge.

This thesis stops and does not discuss sensor-based monitoring methods[6] outside of a summary discussion. Also, model-based integrated technologies that facilitate project monitoring, such as integrated scope-time-cost models[7], are not a focus of this thesis.

As a preliminary step to this thesis, in early 2007, I distributed a questionnaire through email. The responses indicated that quantification methods are evolving to incorporate new hardware - both processing and sensing - and software technologies. Therefore, now is a key time to capture construction engineering and management practices - as they have existed prior to the introduction of new technologies - and the associated methods.

Further, this thesis covers both the quantities and the context features of the quantity. Covering the quantification topic as a whole created too broad a topic for a thesis, resulting in a long document. As this thesis neared completion, it became clear to me that construction engineers and managers should perceive quantities and context features as two topics.

The reader will learn the concepts behind replanning and the need to monitor, how field engineers monitor construction projects, and the remaining gaps in knowledge. The methods may be universal to the construction industry, including residential, commercial, specialty subcontractors, industrial, and heavy civil; distinct differences in organization structures between these industries means that these methods cannot be applied strictly universally. Specifically, I have validated that these methods apply to the *lump sum profit-at-risk* contract

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[3] Such as billing, productivity monitoring, scheduling, cost and resource forecasting, and quality monitoring.
[4] These other controls are not included in this study.
[5] There are methods of deriving quantities through percentage of completion and using start / finish dates; these are not the same as determining the schedule activity percentage of completion and establishing the start / finish dates.
[6] Such as: RFID, 3D-imaging, digital imaging, barcode, ultra wide-band (UWB), e-invoice, object character recognition (OCR), global positioning satellites (GPS), on-board sensors (OBS), and hand held computers (HHC).
[7] Open-source source code and data exchange (file formats) is, in my experience, critical to integration.

with percentage completion progress payments, *self-performed*[8]*, heavy civil* industry, representative of vertically integrated heavy construction companies[9].

Throughout this thesis, I refer to 'field engineers.' The field engineers in this case are *'design-build'* field engineers. Design-build means that they are responsible for design engineering during early phases of the project and then transition into construction engineering and management with responsibility for redesign and detail design as needed to build. The field engineer's role encompasses what is broadly thought of as the 'project engineer' role in smaller (< $250M) civil works construction, and the 'project manager' in building (vertical) construction. I do not know why the title 'field engineer' is used to encompass such a broad scope of responsibility but this is the tradition I observed. For context, the design-build project engineer is a 'senior' field engineer and fulfills a supervisory role of the other field engineers. The 'project manager' in design-build is the most senior position on the project and responsible for all aspects of the project, divided into three supervisory roles, craft supervision (construction manager), design and field engineering (project engineer), and clerical (business manager). During the course of this thesis, it became clear to me that there is confusion about the title *field engineer* due to the use of the title for a wide range of responsibilities. In design-build heavy construction, the field engineer has a high degree of responsibility and directly assists the field trades: the core responsibility revolves around replanning.

The following chapters outline the state of quantities collection as it exists early in the 21st century. In the first chapter, I review tacit knowledge and literature from researchers, industry organizations, standards organizations, textbooks, and reference books, I then synthesized these into the current knowledgebase. Through the second chapter (Quantities Purpose) I investigate practiced quantities collection methods through pre-survey, questionnaire, and interview survey methods. The third chapter presents my ethnographic study of quantities collection. That chapter is a collection of manual methods the observed field engineers considered the industry practice, from all indications having existed for two to five millennia as tacit knowledge. The fourth chapter contains my findings from a post-project review of several case studies and a cross-case analysis of the literature review, survey, and field observations.

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[8] Self-performed differs from direct hire in that self-performed are employed by the prime contractor and are not simply sourced from a partner or joint venture contractor, they are prime contractor employees supervised by prime contractor supervisors and directly tied to the prime contractors engineering team.

[9] Examples of vertically integrated companies and their scope in $2007 billion (US) are: Bechtel ($27B), Fluor ($22B), Jacobs ($11B), KBR ($11B), URS ($10B), Shaw ($7B), Foster Wheeler ($7B), Perini ($6B), Kiewit ($5B), Quanta Service ($4B), CH2MHill ($4B), Granite Construction ($3B), and numerous heavy civil contractors with less than 1 billion annual revenue such as Orion Marine Group (<.5B) and Sterling Construction (<.5B). The revenue presented is for international and domestic work. For comparison, this list of companies represents 1/5th of 1% of global gross domestic product (GDP 2008).

These chapters are the culmination of over two years of research. If this thesis helps with developing and implementing a model-based project replanning system, it will change how field engineers see the quantification process. From my current lab-based case studies, I can see that *open source*[10] development code and open source interoperable file formats will be pragmatically necessary for implementing model-based project replanning. Further, I envision sensor-based feedback technology will be necessary to feed into the model-based replanners. As established customs and traditions, the existing practices will continue to coexist with model-based and sensor-based systems. Therefore, this thesis advances the formal definition of quantitifcation with an expected use with model-based integrated scope-time-cost replanners and sensor-based current state feedback methods to form a closed loop system.

[10] Open Source defined http://en.wikipedia.org/wiki/Open_source.

2 Quantities Purpose

> *"Nothing matters except the quantities [for takeoff remaining to completion, and time and quantities reported to-date][11]. You can manipulate unit cost and production rates all you want, but they don't mean anything if the quantities are wrong."*
> Ron Dukeshier - project manager; instructions for preparing the 2006 Reno Transportation Rail Access Corridor (ReTRAC) forecast

The key issue that forms the need for quantities collection is the inability to measure the degree of return on an investment expected from a given replan alternative. By this, I mean return on investment from the economic standpoint that includes externalities and other hidden costs. Return on investment is a broad measure of both the direct cost and benefit as well as the externalities of the cost and benefit. When externalities are added to the direct cost – the return on investment is often very different. An example of these externalities that are often not accounted for in the construction bid cost are impacts due to construction operations, most often in the form of environmental contamination, worker injuries, and community disruptions. It is from this standpoint that I call for the need to measure the degree of return on investment – so we build in a way that is beneficial. To measure return on investment we must be able to measure our costs and forecast costs, so then those who measure the benefit have a comparison. The measurement of return on investment continues throughout the project cycle – during the project-forecasts the measure of success is if the return for the contractor is positive or negative compared to the expectation, this is project controls. The ability to forecast expectation is important with for-profit organizations as well as not-for-profit organizations – both have the logistics of coordinating the application of applied resources (economic resources) and measuring the current state. Construction engineers and academics do not dispute the need for project control, it is simply good accounting to fulfill expectations reasonably closely; field engineers dispute the methods. To-date the method of affecting project success is a focus on planning prior to the project notice to proceed. Several project contract types have tried an innovative method by combining the project design, planning, and construction stages with interesting results illustrated by a 2009 Las Vegas news piece titled:

> *"The 'Wild Ass Guess' Method of Construction – how Las Vegas developers build huge casinos before they've even finished all the blueprints – and the human carnage and financial waste that results".*
> Liz Benston - Las Vegas Sun

'Carnage' is not what the developers of the design-build method wanted: Design-build is the construction method the journalist is referencing. The intuitive solution is to plan projects with

[11] Permission to use quote granted by Ron; he clarified the intent in meaning, included here in brackets.

finer and deeper detail prior to construction[12]. Planning has issues since actual conditions are not what planners expected, intentions change, and the ability to change plans as conditions change and present opportunities is a way to reduce project waste. There are projects where design-build was not a problem and the slack in planning appears to have avoided human carnage and financial waste. In full disclosure, both design-build projects I am familiar with had problems: The ReTRAC project, for which I was a field engineer, had a high injury rate – it was human carnage. The US20 project in Oregon – though I did not work on the project I followed the progress through news reports – is an example of financial waste, it was environmental carnage. The solution that is the theory I investigate in this thesis is to match the construction engineering resources to the project risk to provide a purposeful degree of monitoring and control to the project[13]. There are two primary approaches to project control, one is changing the method used to construct the project and the other is to change the amount of resources applied to the project. For example, if the earthwork temporary retaining structures have failed – the choice is to either use a different method of retaining the earth or apply more resources to rebuild the retaining structures when they fail – or build them better if a lack of resources during the intitial construction affected quality. Changing the applied resources for monitoring is an issue because construction-engineering resources erode the project margin and it is unknown if it provides a project control benefit[14].

In this chapter, I cover six topics. First, I present the definition of quantities. I follow this with the background of quantities, going back to the first texts that introduce the concept of quantities. After defining quantities and looking at the historical context I present four sources of quantities knowledge: the results of an online survey, my ethnographic experience, integrated project planning theory, and a literature review of publications. The sum of this chapter sets the foundation for the rest of this thesis for the purpose of quantities.

[12] This approach is characterized by ontology research that adds finer levels of detail and deeper detail to project representation – the topic of CIFE research from the late ‘80s to the early 2000s.
[13] This is a tie-in with professor Levitts sim vision work – the material in this thesis should allow for a better estimating of the oversight resources needed.
[14] Possibly construction engineers provide a data collection benefit for learning for the next project, as evidence in litigation, and demonstrating that a legal fiduciary responsibility has been met.

2.1 Quantities Defined

Before looking at the purposes of quantities I want to establish what I mean by quantity. My use of the term quantity is not consistent with the standard accepted meaning. For me quantity is notation representing the position on an indexical series that begins with negative infinity and ends with infinity. For example, three is the third index position in the series from zero to infinity. I use this abstract definition of quantity to separate the close association most have between quantity and unit of measure: my quantity is initially unitless. The unit of measure is a feature of the quantity, other unit examples are count, length, area, volume, and weight. In my application, all quantities have a feature for unit of measure – I consider the percentage the unit of measure for ratios, without this modification the ratio is dimensionless. In construction, cost is not considered a quantity; I modify quantity to include cost with a unit of measure of the currency represented. To me, cost is a quantity of applied resource at that specific point in time in that specific economy. For example, I see one cubic yard of concrete an equivalent quantity of concrete as $70 ($2000) of concrete in Reno Nevada.

Based on logic, in construction there are three quantity subtypes, these are scope, time, and cost. Scope in the simplest concept is the physical space consumed by a component that will be constructed: in the example above, one cubic yard. Realistically, construction is more than building things, there is demolition scope, temporary scope such as falsework, and modified scope such as soil stabilization. Many construction engineers and managers think of scope as the material. The time is the duration it takes to construct a component such as the one cubic yard cement cube. Time is important since it is the duration of constructing the scope – for example, one cubic yard requires one day to construct. For that hour, the physical space, material, and (what I will present next) the cost that must be applied to construct the cube are occupied. For that day, the space, time, and cost cannot be used for another purpose. The last is cost – this is the representation of the resources applied to construct the component. The applied resources have what economist call scarcity and has a cost to obtain, these are space, labor, equipment, material, haul (Leland Stanford's core interest as we will see), and for economist what they call the cost of capital. In construction, we usually ignore the cost of space and leave this to the real estate experts and we ignore capital and leave this to economists to debate. Each of these three subtypes needs a quantity to form a complete project plan. The constructor needs to know the scope of the project, the duration of the project, and the cost of the project. From these three quantities the constructor's pragmatics are satisfied with a product criteria, a schedule, and a budget. There are two forms of quantities, there are input quantities and output quantities. Input quantities are the material, labor, and scope of modification necessary to complete a product. The inputs are necessary to plan for construction. The output quantity is the completed product in statusable (billable) chunks. The output is necessary to demonstrate completion of scope and receive compensation. The output serves a second function and that is a measurable production rate. The overlap between chunks of product measured for production and chunks measured for credit overlap but are not at the same level of detail – the breakdown of the product deviates and is not a perfect fit. The credit for product production is not within the scope of this thesis. The measurement of output as a measure of current production and used as an input to the planning process is the focus of this thesis. There is an applied resource feature added to breakdown structure to represent organizational – usually simply an ‘in’ or ‘out’ feature: organizationally, am I building or are you building, if you then termed the subcontractor. The applied resources are labor (L), equipment (E), material (M), haul (H), and subcontractor (S). The following bullets present the relation of each quantity subtype to the applied resources – there are not strict definitions, they cover 99% of the conditions actually encountered in heavy construction:

- Resources (cost) – L/E/M/H/S
- Hours (time) – L/E/H
- Physical space (scope) – Material

These three subtypes must be planned using a combination of endogenous calculations and exogenous measurements related into a model representation of the project plan. The endogenous measures are relations that are defined through a formula relationship. The exogenous measures are the inputs to the endogenous and are measured from outside the model – often from the real world. The exogenous measures are usually defined by the inability to derive these from formulas. For efficiency, the goal is to keep the exogenous measures to a minimum.

With the definition of what I see as the scope of the quantities topic I will now look at the historical use of quantities in construction.

2.2 Background

With my definition of quantities established, in this section I present a short history of planning. Through the history, I introduce five aspects of planning: why planning is important, the tacit knowledge aspects of planning, the tradeoff between brute force and theoretical knowledge, the source of planning quantities, and the background to quantity theory in construction.

The traditional storyline often repeated for the origins of construction engineering and management is as follows: The initial driver for ways to measure field performance was the massive manufacturing scale up during the World War Two militarization of the United States economy. In the continued post-war militarization, new project-based products such as missiles (Fondahl, 1961) required equally new methods to manage. These project-based products became the genesis of new ways of thinking about planning. The practitioners from the post-war years became the early researchers that looked for applications to the construction industry. Now, half a century later these methods permeate the project form of manufacturing. Of the project-based manufacturing industries, construction is often the last holdout of traditional methods and the slowest to adopt new methods.

Professor John Fondahl helped introduce the project management Critical Path Method (CPM) to the construction industry in 1961 (Fondahl, 1961). Not developed for construction specifically, CPM was adapted from the 1950's Program Evaluation Research Task (PERT) analysis used in the ballistic missile industry and the Project Planning and Scheduling System used by the US Navy on submarine projects (Critical Path Method). Like construction projects, missiles and submarines are a large, complex, constrained duration production product. As such, the transferability of project management methods is straightforward due to the shared terminology and concepts as a sub-domain of the industrial engineering field. Beyond the introduction of critical path scheduling – there have been few innovations that have gained widespread adoption in the construction field. Even the critical path aspect of project scheduling is ignored – during my ethnography I never saw any attention given to the critical path function of the electronic scheduling tool.

The construction industry has reasons not to implement new tools or processes prematurely; it is a dynamic and difficult to predict environment that must adapt to production of a unique and often one-of-a-kind product. Therefore, the methods used in construction are skewed towards adaptable robust tools and processes that rely on knowledge easily transferred through learning by doing. Of the construction industries, the heavy civil industry is stereotypical of the extreme skew toward robust processes – nearly every project is one of a kind. Human intensive and manual processes are robust and adaptable. Heavy construction field engineers need maximum reliability and so do not attempt automated methods that have proved themselves in other industries. The drawbacks of the reliance on the manual process are human bias and diligence. I assume human limitations are the limiting factor to the current quantity of quantification[15]: +/- 5% accuracy, 75% precision (standard deviation of repeatability), and a 99% complete project quantification with seven context features.

In the 3rd century BC, Greek masons inscribed to scale the plans into the project's stonework, converting the plan measurement to field measurement using a compass (Nova, 2008). In the 1st century BC, Vitruvi discusses representing what he will build by drawing for the owner the plan, elevation, and isometric views (Vitruvius). Project documents such as drawings, have evolved since then to form an integrated combination made of the breakdown structure nomenclature for context features, the specifications, the scope drawings, the relational functions, the bills of material[16], the time schedules, the cost estimates, and the efficiency and quality analysis tools. The recent addition of the machine computer provides for the repeatable representation of the integrated project plan and the parametric relationship computations necessary for the interconnected components.

Project planning is necessary so that construction engineers can prepare for anticipated events prior to their effects becoming apparent. A premeditated arrangement allows the work-crews to focus on the work at hand and assume the labor, equipment, material, haul, and capital resources will be available when needed. Vitruvi established the relevance of project management as specifically the quality, scope, and cost components. Time, or the sequence and schedule of work, is a notable omission, though Vitruvi implicitly represents time as a component of cost[17]. Vitruvi makes no mention of the sequence of work – though he demonstrates sequence in his clear explanation of floor tile instalation. If Vitruvi did not discuss time because price represents the labor and equipment time components then it is not an omission. However, the omission also indicates that at that time the significance of the time-variable is minimal, possibly, because construction engineers of that era could not control the time component. Further, in Vitruvi's time, the concept of time itself is at the beginning of popular acceptance. This is evidenced by Vitruvi's complaint that his day is divided into increasingly smaller blocks of time due to the increasing use of the sundial. Most likely Vitruvi did not use production as a function of time as it is understand today. While popularly known for proportion, as Vitruvi describes theory, he signaled the significance of project management by including it as the sixth principle of architecture, that is, *economy*.

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[15] Based on cumulative conclusion from this thesis.
[16] Includes additive, subtractive, and transformative quantities.
[17] I assume, the cost of work was paid on a unit cost bases, for example, per linear foot of masonry wall, this cost has an implicit productivity built in to be profitable. Dividing an assumed daily living wage by unit cost provides the productivity per day, therefore making it redundant to state.

> *"Economy denotes the proper management of materials and of site, as well as a thrifty balancing of cost and common sense in the construction of works. This will be observed if, in the first place, the [construction engineer][18] does not demand things[19] which cannot be found[20] or made ready[21] without great expense."*
> Vitruvi, 1st Century B.C.

Vitruvi does not give us a name for construction engineers in his day – Vitruvi wrote for the architect, the master builder. Somewhere between Vitruvi's time and now, the core builder that embodies most of the characteristics Vitruvi called the architect is the heavy construction field engineer, in particular the design-build field engineer; these are design-buildiers on the same level as vitruvi's architect. Field engineers are educated in construction engineering and management (CEM) and on graduation are considered construction engineers or construction managers depending on the specific program of study – little to no difference. Field engineers learn project management knowledge two ways: that is by learning from experience or by learning theory in a classroom. *Tacit knowledge* is a characteristic attribute of the construction process: knowledge is difficult to gain without field experience (Woo et al., 2004; Kivrak et al., 2008; Peterson et al, 2010). Though everyone would agree with Vitruvi that management and thriftiness are variables, it is to the reader to understand through their tacit knowledge what management and thriftiness means in practice. With reflection on field experience, it appears that as presented by Vitruvi *economy* is matching resources to local conditions. Matching project demands to the local resource supply results in the least waste of resources (Clough et al, 2000), contemporarily called *sustainable* (Hill and Bowen, 1997). In pursuit of minimized waste - also known as maximizing profit - the project is modeled and the calculations are made for resource demands of labor, equipment, material, specialty skills, transportation, capital, and time (Kerzner, 2009). To me the difference between profit driven and sustainability driven optimization is the inclusion of economic externalities in the definition of sustainability. In the context of waste, leveling the applied resources quantity demand with regional quantity supply is what *economy* means in practice. For example, a project plan requires 80,000 man-hours per month, but the local available labor resource is 50,000 man-hours per month. Either the field engineer will apply additional resources to import labor from surrounding regions - needing a reason to justify the additional resources applied - or the project plan will conform to the regional supply.

The second component, the balance of cost with commonsense, implies that these are exchangeable. Commonsense could be an ad-hoc intuition or discretion, seemingly

[18] The concept of an architect at that time is similar to the sum of what today is perceive as the field of engineering.
[19] labor, equipment, & material.
[20] Local labor, equipment, and material.
[21] Labor skills modification, equipment fabrication, & material processing.

contradictory interpretations. In the context Vitruvi uses the term - *thrifty balancing of cost and commonsense* - means that knowledge can replace cost. Knowledge is expensive and so there is a balance between the application of brute strength[22] - expensive not for knowledge but due to search duration - and a knowledgeable shortcut - expensive in knowledge but allows a shorter search - to come to the answer. Clearly, students need to learn project management theory through courses and tacit knowledge through practice. A field practitioner achieves a solution through a brute force implementation of tacit knowledge that a student finds through an implementation of theory knowledge; similarly, a tacit intuition shortcuts a brute force application of theory. In addition, practical knowledge bridges gaps in theory and an intuition from theory bridges gaps in practical knowledge, see Figure 1.

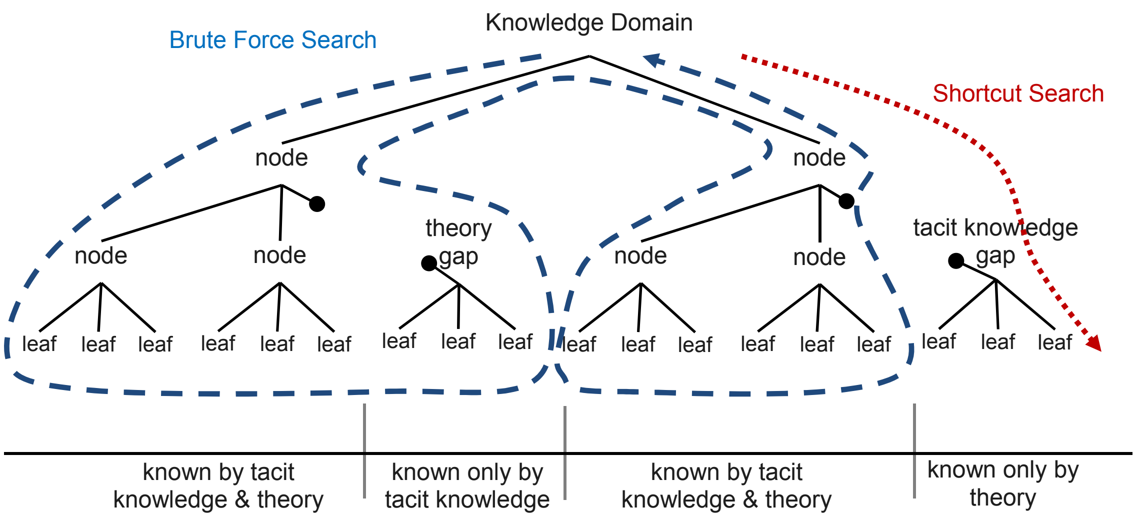

Figure 1 Field engineers parse the knowledge domain with two methods, by brute force or a shortcut to an anticipated result. The tradeoff is the completeness of the search for the duration of the search. The brute force search can bridge gaps in theory and the shortcut search can bridge gaps in practical knowledge.

A review of the practical methods of defining project quantities prior to the technology revolution in the second half of the 20th century has not provided definitive resources. Project scope takeoffs without electronic aids originate with a scaled 2D drawing and takeoff scale[23]. Manual takeoff is time consuming[24] and provides an assumed accuracy of 10% due to scale reading errors[25]. In practice, two engineers takeoff the same items and then reconcile a *bill of*

[22] Used here in both the typical meaning and as used in programming - to try every conceivable possibility.
[23] Today these scaled rulers are a triangular shape with differing scaling on each face, for example ¼" = 1'.
[24] Unkown number of hours per plan sheet.
[25] Industry rule of thumb tough me while in the estimating office.

quantities[26]. The bill of quantities lists the material[27] for a project or portion of a project. As the project progresses, the field engineer represents the project progress for each week by coloring-in with pencils a plan set pinned to the wall, Figure 51 on page 265. From the colored regions, the field engineer makes a scaled takeoff to derive the weekly reported quantities. During my ethnographic study on the ReTRAC project (introduced in next chapter), I observed the field engineers and the project manager use the plan coloring method; the project manager had for over 30 years and so the method must predate 1970. Possibly scaled quantity takeoff methods have been constant since stonemasons in the 3rd century BC used scaled plans inscribed in stone to dimension columns (Nova, 2008). Roman architects[28] starting in the late Hellenistic period (~100 BC) used scaled drawings (Jones, 2003). The scaled scope takeoff and coloring-in methods of monitoring project progress based on the takeoff and scaled plans could have followed shortly thereafter. Vitruvi in De Architectura describes the drafting of a *groundplan* drawing with compass and rule (1st century BC), lending evidence of the existence of scaled drawings from which it is a short step to derive quantities from the drawing and another short step to color-in the drawing to represent completion of components. Vitruvi does not specifically discuss the plan takeoff or coloring-in drawings so he may not have used these methods. An improvement to the takeoff process occurred with the development of takeoff digitizers during the late 1980s[29]. The digitizer is a flat pad with an electronic grid; the takeoff technician places the plans over the grid, over which the technician moves a pickup device in the *xy* dimensions, therefore recording the plan dimensions. Throughout the 1990s as computer-aided drafting (CAD) became prevalent digitizers evolved into onscreen takeoff viewers, extending the concept of the digitizer to the computer monitor and mouse[30], and leading to the introduction of new methods to compliment the new technology.

Moving from background in practices to the expected practices in the future requires a look at the theories. A review of theory starts with the Center for Integrated Facility Engineering (CIFE) publication database; CIFE is an academic research center for Virtual Design and Construction (VDC) of architecture, engineering and construction (AEC) industry projects[31]. Past researchers at CIFE have laid the groundwork with a series of interconnected theories applicable to model-based quantity collection and control. Professor Akinci while a doctoral

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[26] In usage here this is the same as bill of material.
[27] In this case means additive, subtractive, and transformative objects.
[28] Differs from modern notion of an architect, these were *master builders.*
[29] Richard See, Stanford University Civil and Environmental Engineering Class CEE241, 2007 ppt presentation material.
[30] As of 2008, my casual observation shows that the heavy civil industry uses digitizers and the commercial building industry uses on-screen takeoff (OST): by 2015 the widespread move to BIM takeoff appears eminent in vertical construction while there are signs of wider adoption in horizontal construction.
[31] Center for Integrated Facility Engineering (CIFE) cife.stanford.edu Stanford University research center that studies the implementation of virtual technology to resolve built environment facility life cycle efficiency.

researcher (2000) developed methods for considering the risk of time-space (scope-time) conflicts using process models, therefore pushing the boundary of the project plans and schedule as a 4D model. Professor Staub-French's doctoral research, also during the late 1990's, looked at integrating model-based quantity take-off with estimating software tools. Staub-French's method relied on component features to drive the production rates, therefore representing the scope features as context in the integrated time and cost model. In recommending departing research to the 2002 thesis, Staub-French proposed finding mechanisms to update the process model based on actual progress performance, which is quantities collection. A few years later from the same research group Akbas suggests similar mechanisms for updating the schedule with actual progress measurements (2004).

I have now established the history and practice of planning through five aspects: Planning is important to avoid unintended events such as environmental contamination, injuries, and community impacts. Construction planning knowledge is tacit and is learned by doing. There is a fundamental tradeoff between brute force and theoretical knowledge – both are necessary for construction planning due to gaps in knowledge and theory. I have shown the traditional source of planning quantities - appearing to go back at least 2,000 years - that has continued to overlap the electronic tool developed during the last forty years and the projected model-based source that is replacing previous practices. The model-based project replanning practices bring a new role for quantities – though the model-based replanning topic is outside the scope of this thesis. The topic is important as a background to this thesis to understand that the integration of project planning places the quantities in a new role where before quantities could be ignored as a shortcut, they now are critical to the integrated model-based planner – making my study on quantities beneficial to the model-based replanner audience.

Next, I will present the purpose of quantities as found through survey, after that I will present the purpose of quantities as found through ethnographic observation, followed by a look at integrated planning theory, and last a look at the literature.

2.3 Survey Response to Purposes

Now that I have presented the background of quantities from a historical perspective, I will look at specific uses of quantities as given by practitioners through a survey. A core discovery through the survey is the distinctly different roles quantities fulfill in vertical and horizontal construction.

The results from a questionnaire survey I distributed in the winter of 2008 (Peterson & Fischer, 2009c) provides for the quantity tracking purposes for the (*BLS* classifications) heavy civil (237000), industrial, (236200) and building MEP (238220) industry segments. The purpose for quantities differs between the construction industries but the domain is definable, Table 1. The core difference between the heavy civil and building construction is the heavy civil industry uses quantities for production and equipment maintenance monitoring, 11% and 2% respectively more than the building industry. The survey found no use in the building industry of quantities for equipment maintenance. In return, the building industry uses quantities more for quality control. Other than these three differences, the survey found that the heavy civil and building construction sectors use quantities for the same purposes. My survey population cannot distinguish the degree of variation for the remaining domain of purposes and so the purposes are statistically equal between civil and building construction. The survey included a sample from other manufacturing industries such as shipbuilding, agriculture, timber, and plant manufacturing. From the survey responses: what makes the construction industry unique is that the product manufacturing is without automated process control, from literature: these other industries have introduced and improved automation throughout the past century.

Table 1 Building general contractors function similar to heavy construction management firms; these industries view quantities differently. Building general contractors monitor the quality of subcontracted work, and then negotiate project progress in *pencil draws*, because they do not have their own construction crews, there is not the degree of interest in the actual productivity that is found with heavy civil contractors. Reproduced from Peterson & Fischer, 2009c.

		Ratio of Total Users				
Purpose of Quantities	Example	Heavy Civil & Industrial	CI[32]	Building & MEP	CI	Gap
Sample Size (n)		*62*		*87*		
Population (BLS 2008-09) & Confidence Level		*35,000*	*95%*	*82,000*	*95%*	
Billing/Invoice	Progress payment	87%	8.4	81%	8.2	
Production Monitoring	Project control	85%	8.9	55%	10.4	11%
Schedule Forecast	Project plan	83%	9.3	71%	9.5	
Cost Forecast	Project control	77%	10.5	81%	8.2	
Historical Library	Estimating database	45%	12.4	40%	10.3	
Quality Control	Inspection	43%	12.3	62%	10.2	-3%
Resources Forecast	Supplies schedule	30%	11.4	38%	10.2	
Regulatory Compliance	Hazardous material removal	26%	10.9	30%	9.6	
Community Impact	Stakeholders / partnering	15%	8.9	11%	6.6	
Mass Balance Calc.	Material resources	13%	8.4	9%	6.0	
Maintenance	Equipment service	2%	3.5	0%		2%
Earned Value Mgmt.	Model-based plan updates	na		na		

With the historical and current purpose for quantities established, I will now provide the broader context and relationships of quantities as I found through my ethnographic observations.

[32] Confidence interval calculator: http://www.surveysystem.com/sscalc.htm

2.4 Ethnographic Observation of Purpose

For eighteen months I observed a large heavy construction project in the role of a field engineer. During that time, my understanding of quantities varied from that provided by the survey I present in the previous section. The most significance variance is with respect to schedule updates. During my ethnography, I did not see quantities take much of a role in the scheduling process. Though my observation depends on how I define concept of quantities - at the time of my ethnography the field engineers did not consider the percent completion values quantities with respect to the schedule. Now after researching this thesis I can see that the schedule percent complete and milestone I/0 values are a form of quantity.

2.4.1 Observed Purposes

The Reno Transportation Rail Access Corridor (ReTRAC) project was a lump sum competitively bid design-build contract put out for bid in 2001. The contract required the contractor to derive the monthly progress payment from measured percentage of completion for several thousand items aggregated into a predefined schedule of values representing the project as 24 billable components. The only quantities I observed specifically collected for a unit cost derived invoice - quantity * unit cost = billable amount - related to extra work completed during an emergency flood event the project loaned resources (2006 New Year flood) and the sale of boulders excavated from the project to the Lower Truckee River Restoration Project. On the ReTRAC project, I observed seven reasons for quantities:

1. progress billing
2. progress monitoring, Figure 2
3. cost forecasting
4. estimating historical database
5. regulatory [agency] reporting
6. change order billing (not found in survey)
7. subcontractor backcharge (not found in survey)

The following are examples of the expected duration until a return on quantities collection efforts, Table 2. For the short-term, defined here as <3 months, the quantities collected and reported on a weekly or monthly basis were for cost tracking and forecasting the next week's or month's resource requirements. Several quantities were for regulatory reporting and change order work, but these were specifically for known petroleum-contaminated soils the owners expected to encounter during excavations directly under the historic railroad tracks (Technical Memorandum). The mid-term, defined here as, 3-months to 1-year, the reason for putting an effort into quantities was the project quarterly revenue forecasting process and its impact on the revenue reporting of a publicly traded company. For the long-term, defined here as > 1 year, the quantities were collected for feedback to the regional division estimating database and for potential future litigation.

Table 2 Examples of purposes and expected duration to return for quantities collection.

Reason for quantities	Time to return on resources
Estimating Database Potential Litigation	Long term (>1 year)
Project Revenue Forecasting	Mid-term (3-months to 1 year)
Productivity Monitoring Forecasting Resource Requirements Regulatory Reporting Change Order Work	Short-term (<3 months)

2.4.2 Observed Depth of Purposes

For context, view the project monitoring level of detail as a repetitive cycle, Figure 2. For example, at the applied resource and method levels the field hand actually holding the implement that is causing work exerted onto the workface is monitoring their pace of work for those metrics they value. From my field experience the motivating factors are first their health, second their employment, third quality in work, fourth economy - material waste and equipment wear - and last productivity. Everyone wants a successful project so the field hand is trying to help the company "*make money.*" The sequence of monitoring for those metrics valued continues through the chain of stakeholders. These are - example is for self-performed work - the lead man, foreman, superintendent, construction manager, project manager, owner's representative, owner, public stakeholders, and the lending institution.

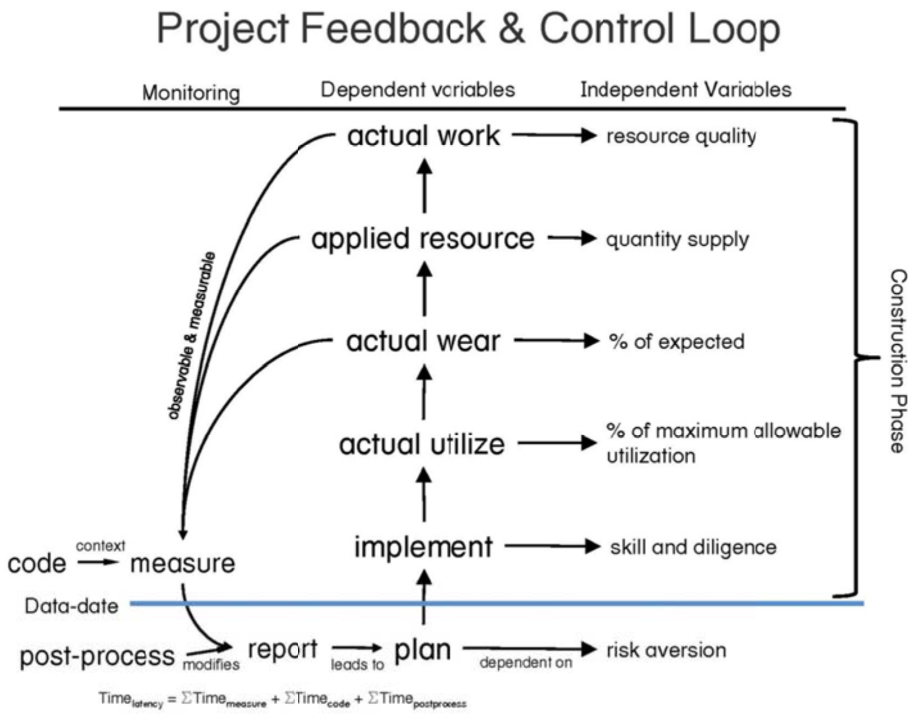

Figure 2 The quality of process monitoring is dependent on the quality of three independent variables: measurement, coding features to the measurement, and post process the measurement. With the measurement, this schema represents a closed loop of planning, feedback, and corrections. If *n* field engineers work in parallel then divide the time delay by *n*.

At each level, there is a reporting process. The field hand becomes fatigued if working too hard, the superintendent chastises the foreman if not on schedule, and the superintendent must represent their work at the scheduling meeting with the construction manager. The project manager of a self-performed heavy civil company maintains a depth of project monitoring three times as detailed of what the other stakeholders maintain. The owner's representative and the corporate projects manager both receive a monthly progress report, the monthly billing and project monthly report (PMR) respectively. The owner's representative and the projects manager submit a report to the owner and division management respectively at a regular interval, likely at a condensed level than what they received. The owner submits a report to the lending institution and the project's corporate office submits a quarterly report to the stockholders: the financial statements report. The presented sequence is an example, possibly the lending institution also receives a monthly progress report. Last, the lender, the project's corporate office, and the stockholders each submit a report to the U.S. Internal Revenue Service (IRS). The IRS report is the corporate income tax (Form 1120); the IRS aggregates the reported generation of value into the annual gross domestic product (GDP).

The reported values, for this year's GDP percentage over the previous year back down to the laborer feeling agitated and disoriented, then feeds back into analysis, the implementing of control, and a new round of monitoring, possibly for the laborer a walk to the ice water.

2.4.3 Summary of Ethnography

In this section, I looked at the purpose of quantities as I found through ethnographic observation. From the depth of context the ethnography provides, in addition to uses of quantities I could also discern sub-categories of purpose and the relationship of these categories. I found that quantities have latency and features at varying level of detail.

Next, I use the integrated planning theory to present the purpose of quantities.

2.5 Purpose Predicted by Integrated Theory

Here I will present the challenges found through theory that confront planning. First, planning and replanning outside the verbal consensus of the superintendents is nearly useless for anything further out than two weeks. For this reason, the theoretical push is for integration of replanning as a way to improve the quality of plans outside the 2-week forecast. Most of the theory development is intended to generate a buildable baseline plan prior to the start of the project. This plan must then be strictly adhered. I present the current state of integration planning theory, the components of integration and the purpose of each, and the use of integrated planning towards automated planning past the contract notice to proceed.

Construction status assessments are notoriously unreliable and labor intensive. Repeated findings by different researchers have contributed to the realization that project success is independent of project controls (Cheok et al., 2000; Sacks et al., 2005; Akinci et al., 2006; Navon, 2007; Rebolj et al., 2008; Skibniewski, & Jang, 2009). An analogy to current project control practice is an early 20th century doctor during the 1918 influenza pandemic (Human Virology at Stanford). The only benefit the doctor could hope to provide was to measure, relate the measurements with context features, and collect samples for future researchers. At that time - with the technology available - it was not possible to affect the pandemic or the outcome of an individual. In the same way, projects are like a virus, field engineers today can realistically only be expected to perform the same service as 20^{th} century doctors for future use in the estimating department or for research: they cannot affect the project outcome with project monitoring efforts. Uncertainties in the future uses of the quantitates results in some that will not be used, some collected at a level of detail too abstract to provide a depth of analysis, or some collected with insufficient contextual features. The quantitifcation plan requires features for reporting the project team's understanding of the project progress as well as reuse of the quantities; examples of quantification features:

- what to collect,
- at what level of detail,
- with what degree of accuracy
- how repeatable
- with what delay and,
- at what frequency

2.5.1 Technological & Professional Context

Since the introduction of critical path scheduling in1961, through incremental innovation of analysis methods such as CPM, project management methods are formally integrating points of the project management scope-time-cost triangle into integrated systems (Peterson &

Fischer, 2009a), Figure 3. Formal integration of the product model (scope) and process model (time) resulted in a new tool called a 4D model (Aalami et al., 1998). The adoption in the building industry of information models, specifically termed as Building Information Model (BIM) and in the civil industry, called a Civil Information Model (CIM), provides a new source of information such as quantities and the contextual features such as location, object type, and material type. Used as an electronic database, information models facilitate integration of scope-time-cost across the various efficiency analysis and graphical representation tools.

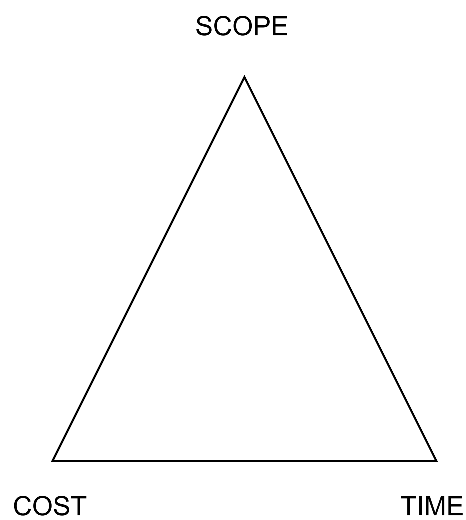

Figure 3 Integration of scope-time-cost results in a system of the product, process, and cost models. The process of finding the optimum solution for the valued factor is iterative and results in a circle integration through these three points as first proposed by Fischer and Kunz (1989).

Scope-cost, scope-time, and cost-time are the triad sides of the project management triangle. Determining these sides is the task of separate professions such as cost estimators, schedulers, and financiers. These professions rely on scattered sources such as product, process, cost, quality, efficiency analysis, and for direct and indirect specifications databases for: component, operation, production, and cost. Examples of these sources: AutoCAD 3D component model, RSMeans production database[33], US government Bureau of Labor Statistics[34], CalTrans specifications[35], and Parmley's Field Engineer's Manual (2002). Integration through an information model allows pulling these scattered knowledge sources together and in theory provides a greater degree of accuracy and consistency in calculating the

[33] CSI RSMeans www.rsmeans.com
[34] US government Bureau of Labor Statistics www.bls.gov
[35] Caltrans specifications www.dot.ca.gov/hq/esc/oe

resources necessary to construct a product. Integrating scope, time, and cost as the takeoff, schedule, and cost estimate or budget, with the geometric product model as a 4D model, provides a check of plans in a graphical format that communicates a broad context of information to the human mind.

2.5.2 Current (Baseline) Condition of Industry

The 2008 CFMA and 2007 CIFE survey results provide a baseline analysis of the use of takeoff, process, and cost tools. The use of these minimum project planning and monitoring tools is not universal as shown in the surveys. I did not find a publication for how to define the heavy civil population, for example by project, by company or a combination. Assuming a confidence interval of 9%, from <1% to 18% of heavy civil contractors rely on triangular scaled rulers for takeoffs, dry-erase white-board schedules, and paper notepad estimate. The rest use electronic software tools, intuitively 95% do project planning in a non-integrated way.

2.5.3 Repetitive Tasks

For contractors a paper-based scope-time-cost plan results in keying or the use of paper tables/chalk boards for each software tool not used, introducing a risk for human errors. Scope-time-cost planning tasks are tedious and prone to short cuts, the goal of optimizing project planning becomes lost, and soon the engineer cannot see the forest for the trees. A survey of Auburn University undergraduate building science students and industry professionals found that 85% of surveyed student have a medium interest starting-as or a career-in an estimating office and they disliked estimating tasks such as takeoff, scheduling, and pricing (Fuller & Kahn, 2003). If a poor attitude towards estimating tasks permeates the estimating departments and field engineer positions where new engineers start their careers, the results can be poor bid and project performance due to shortcuts. In the same way, engineers can become focused on insignificant but time-consuming tasks[36], these then will outweigh core tasks[37] of maximize productivity, minimize risk, and ensuring feasibility. The result is like an error-plagued estimate, poor results.

2.5.4 Scope-Time-Cost Defined

Project planning, scheduling, and execution depend on valuating and trading of project control factors to gain the optimum efficiency in resource utilization. As shown by the project management triangle in Figure 3, there are three project management process and control

[36] Calculating durations, make the forward pass and back pass, calculating free float and determining the critical path & total float.
[37] Such as: adjust production rates for climate & conditions, level resources, optimize process model logic, adjust location sequence, check laydown & workspace detection, and calculate cost effect from changes.

factors, these are scope-time-cost, and a fourth quality[38] (Max's) is implied to exist within the other three. Another relevant factor is efficiency, which cannot be 100%[39]. Scope, as given by the plans and specifications, is the work required, both implicit - i.e., temporary structures - and explicit, to finish a project. It seems logical that scope indicates the project benefit[40] and cost represents resources consumed (in addition to scarcity), therefore defining project viability. To obtain scope, a field engineer makes a takeoff. If done manually takeoff is an error prone, time-consuming process (Alder, 2006). Cost reflects the value of resource scarcity at a given time; economists call cost *price*. Cost is difficult to capture, due to the affecting variables such as production, resource demand, and the time value of money. Cost includes definition, associated externalities, design, fabrication, construction, operation, and demolition; the sum of costs is the *life cycle cost*. Quality and time are the last two factors. The quality factor reflects how resources are used and what specific grades of resources the project needs. Time is the duration to move, arrange, and assemble these resources. Quality and time affects cost because absent innovation, an increase in quality or a reduction in time will result in increased resource consumption, which is cost (Brucker et al., 1999). The tradeoff holds true as long as the project is operating at perfect efficiency - which is not possible - so in practice a field engineer can reduce duration and/or increase quality through an increase in efficiency: without an effect on cost.

2.5.5 Finding the Optimum Plan and Forecasting the Affect

Different curves present themselves in project characteristics that can alter the risk of inefficiencies, Figure 4. For example, a steep production curve implies there are resources applied at the same time, potentially resulting in workface congestion. As an alternative, the y-axis could be cost or represent the resources applied to the project. With the cost y-axis, absent innovation, applied resources can only be greater than a hypothetical perfectly efficient curve[41]. With a quantities y-axis, if the project is inefficient - say indirects are wasted - the in-place quantities may not differ from the efficient or inefficient plan.

Logically, as the project forecast moves further from the data-date the reliability diminishes. The forecast reliability increases as the contract completion date nears due to precedence logic forcing the conformance to the completion date. In addition, a shorter duration to forecast and the constrained domain of project scope makes it easier to forecast. The contractual completion date is a hard constraint and so does not move therefore removing speculation of

[38] This material is offered to individual readers who may use it freely in connection with their project work. It may not be used by commercial or non-commercial organizations without permission, www.maxwideman.com/
[39] Efficiency is the waste that does not result during implementation of the project plan.
[40] Return on investment.
[41] See Tatum 2005 for an in-depth discussion of field engineers and innovation.

favorable or unfavorable conditions and therefore dictating increased or decreased resources, depending on the project progress, to meet the completion date. There are multiple paths to achieve the same goal, though they are not equal in prudence. In a simplified scenario, what the field engineer does know are the contractual start and completion dates and the state of progress at these times, 0 and 1 respectively. There are multiple paths to project completion, though they are not equally efficient with resources, Figure 3. On the ReTRAC the field engineer, project engineer, and project managers were presented project production as three linear rates, these are to-date, three-month, and the previous week, Figure 61 page 348. The view of production as a slice in time presents an issue when forecasting the planned resource utilization. In addition, the field engineer must continually forecast and consider the quantity supply and quantity demand effect on price.

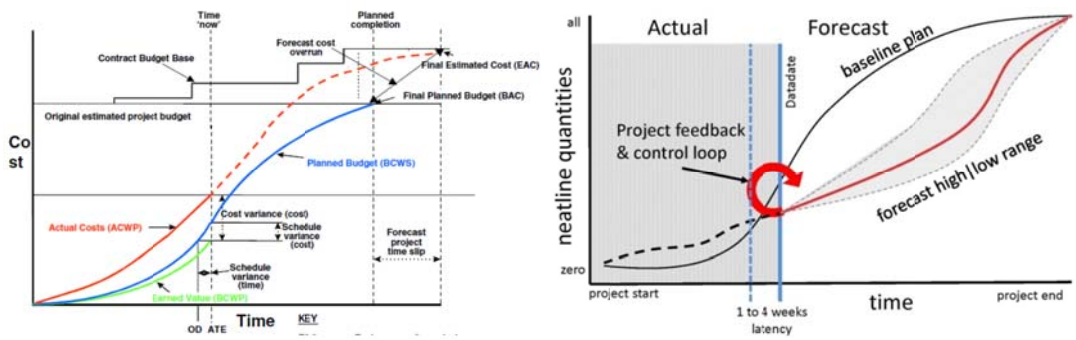

Figure 4 On the left is the Earned Value Management s-chart (APM, 2002). On the right, an expected production drives the project planning (Staub & Fischer, 1999; PM 6th *rolling plan*). The baseline production is dependent on applied resource factors, production modifiers, and chance occurrences; empirical feedback during the project reflects the actual conditions and production, therefore allows adjustments to the calculated plan.

Now that I have presented the purpose of quantities in integrated theory, I will next review the published purposes for quantities.

2.6 Published Evidence for Purpose

The published evidence I provide is from reference literature, and covers the purpose and the expected accuracy and inaccuracies, as well as from a published survey of professionals.

2.6.1 Purpose from Reference Literature

In the reference literature, the purpose for quantities collection from construction projects falls under three categories; these are the as-built, the forecasted expectation, and the auditing review. Before introducing those topics I will first review the feature set that as-built, forecasting, and auditing rely on.

2.6.1.1 Integration

The breakdown structure groups items in the estimate, budget, and expenditures with those having similar features (APM, 2002; AACE 20R-98, 2003). Each group is given a nomenclature to represent the features and this nomenclature becomes the means to relate work scope to schedule and costs (AACE 20R-98, 2003; CPM, 2000). With the nomenclature relating the context features of the associated quantity simplifies integrating accounting, cost reporting, and cost and schedule control (AACE 20R-98, 2003). From the integrated plan the feature set provides for performance and productivity measurement and analysis (AACE 20R-98, 2003). For example, the nomenclature allows mapping from one facet (usually reality) to another such as project estimating, financial accounting, and field cost accounting. The quantity takeoff is also applied the nomenclature but in my ethnographic experience, these are assigned after the quantity takeoff rather than applying a quantity takeoff to the nomenclature (CPM, 2000).

2.6.1.2 As-built

The texts treat the as-built topic as an implied phase between the project monitoring and the project estimating. The old question of the chicken and the egg – does the estimate come first and then there is an as-built or is there an as-built followed by an estimate for the next project. Where did the first cost estimate get the data for the estimate? It is the classic turtles all the way down problem.

2.6.1.3 Forecast

The forecast of expectations is what academically quantities are most often associated – usually taught as a quantity takeoff used for the project cost estimate that will be tendered as a competitive bid (Bartholomew, 2000). What is usually left for students to discover after graduation is that the estimating process does not end with the bid. The estimating process of large projects is repetitive. New forecasts are produced at regular intervals for the expectations to project completion (PMBOK Guide, 2008).

While the classic heavy construction estimating textbook by Bartholomew (Ch1, 2000) ignores quantities in project monitoring – a reasonable expectation since he is focused on pre-project estimating. Quantities form the basis of production rates, without good quantities, field engineers cannot reasonably forecast. Bartholomew (2000) shows us that relationship and the features field engineers need to group quantities. The Bartholomew text presents the detailed unit estimating[42] method, this method is what I saw used in the heavy construction industry. Possibly because of how estimating is taught, many field engineers see quantities as a billing topic not a planning topic. In the Bartholomew (2000) view as he presents in his text, planning is for cost purposes, these are conceptual, evaluating the cost of alternative plans, estimating the cost of a change in contract scope, and finding the damage to the contractor caused by a breach of contract.

Ostwald and McLaren present forecasting using statistical analysis approaches such as graphical analysis, single and multiple linear regression, correlation, indexes, moving averages and time series (Ch5, 2004).The methods are fundamentally similar to construction estimating – they begin with a *bill of material* (Ostwald & McLaren, Ch 8.3.1, p359). They present methods of estimating in more detail than construction texts and covered a broader domain of methods and industries. They place construction within the context of a broader domain of industries, see Table 3 for their comparison of construction with other industries (Ostwald & McLaren, Ch6, 2004). One distinction they make clearly is the difference for their comparison of construction with other industries between estimating and accounting; estimating involves unknowns, otherwise it is accounting (Ostwald & McLaren, Ch 5, 2004). The Bartholomew list of estimate types contrasts with those given by the Industrial Engineering Text: the main difference is the exclusion of Ostwald's and McLaren's advanced approaches from construction (Bartholomew, 2000).

[42] Unit estimating has subcategories of average, order of magnitude, lump sum, function, parameter, module, and factor.

Table 3 Industry attributes; the comparison with agriculture does not capture the nature of construction. In construction, the project-to-project location is variable but within the project, the location is fixed. Harvesting durations are equivalent to project activities and have similar changes in location, methods, and equipment (Ostwald & McLaren*, table 7.1*, 2004)

	Attributes			
Comparison Industry	Plant & Equipment	Location of Plant Site	Output of Industry	Relative Value of Output, Customer's View
Construction	Portable	Variable	Immobile and unique	Expensive
Agriculture	Mobile	Land fixed	Moves off the plant site and is numerous	Inexpensive
Information & Service	Transitional	Virtually anywhere	Temporary	Low price
Manufacturing	Fixed	Fixed	Moves off the plant site and is numerous	Cheap to expensive

A text that dives past the estimating topic and provides a more complex understanding of construction is the Clough, Sears, and Sears project management text (CPM 4th edition, 2002). In the preface, the authors present the construction management process as the five M's: Men (labor), Machine (equipment), Material (quality), Method (labor, equipment), and Money (scarcity of capital). They define field project management as monitoring *actual cost* and *progress of work* at periodic intervals against: a "budget" and "time schedule of operations" (CPM p17, 2000).

More advanced approaches to project planning use an integrated scope-time-cost (scope-schedule-cost) process such as the Project Management Institute (PMI) Earned Value Management (EVM) approach (PMBOK Guide, 2008). During the project phase the quantities are used for varying purposes dependent on the source: It is cost control, productivity measurement and analysis, and capitalization (depreciation) in the AACE 20R-9 (2003). Planning, scheduling, and project control on the Rocky Ridge project (Stevens, Titus, & Sanford, 2002). Back at the PMI it is scope management and two subtasks: schedule (PMBOK, Ch 6) and cost (PMBOK, Ch7).

2.6.1.4 Audit

Like all auditing, quantities suffer from the same problems as currency quantities such as the *offsetting error* (Auditing, 1912). After talking with Professor Winograd, I understand that problems with quantities are often rooted in issues of marginal objects[43]. A marginal object is the 'spork' of accounting – is it a fork or a spoon, it is both and neither. Misassociating the quantity with an account results in the need to not just audit the quantity values but also audit

[43] See Terry Winograd Understanding Computers and Cognition, 1987.

the quantity associations. An offsetting error is an error with an equal counterbalancing error: the accounts balance, producing a false positive. This error can affect quantities such as hours or cubic yards. The usually affected quantity unit of measure are the monetary values, such as dollar. This occurs because of the common movement of cash between accounts, creating range of positive and negative entries. The negative entries are not found with other units of measure at the same frequency and so do not present the same number of opportunities for an offsetting error.

Quantities provide the opportunity to audit with cross checks. The quantities provide control thresholds based on the percent variance from the baseline plan through rules of performance measurements (PMBOK Guide, Ch7, 2008). The PMBOK has the audit aligned with the work breakdown structure (WBS) for control points at a specific level of detail (PMBOK Guide, Ch7, 2008). The work breakdown structure is the relationship between work tasks broken into groups of similar features. The work breakdown structure is commons in construction and other project management fields – in this thesis I will abstract the work breakdown structure and use the generic feature breakdown structure because I am concerned with all the features for context and not just the work features.

2.6.2 Project Planning Accuracy

The 2003 National Cooperative Highway Research Program (NCHRP) report *Project Cost Estimating: A Synthesis of Highway Practice* (Schexnayder et al., 2003) reviews megaproject estimating. Since forecasting, as practiced in construction, is a specialized sub-group of estimating, then the methods given in the NCHRP report should also be applicable to project forecasting. One motivation for the report is the megaproject study by Professor Flyvbjerg[44] while at the Denmark Aalborg University Department of Development and Planning. Flyvbjerg did not find evidence of a correlation between cost escalation[45] and the year of construction - between 1910 and 2000. Instinctively, I think the lack of correlation evidence indicates there are causes of escalation that are not dependent on time-inspired Moore's law innovations, Figure 5.

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[44] See flyvbjerg.plan.aau.dk/
[45] Between the initial and forecasts cost estimate, and the final cost.

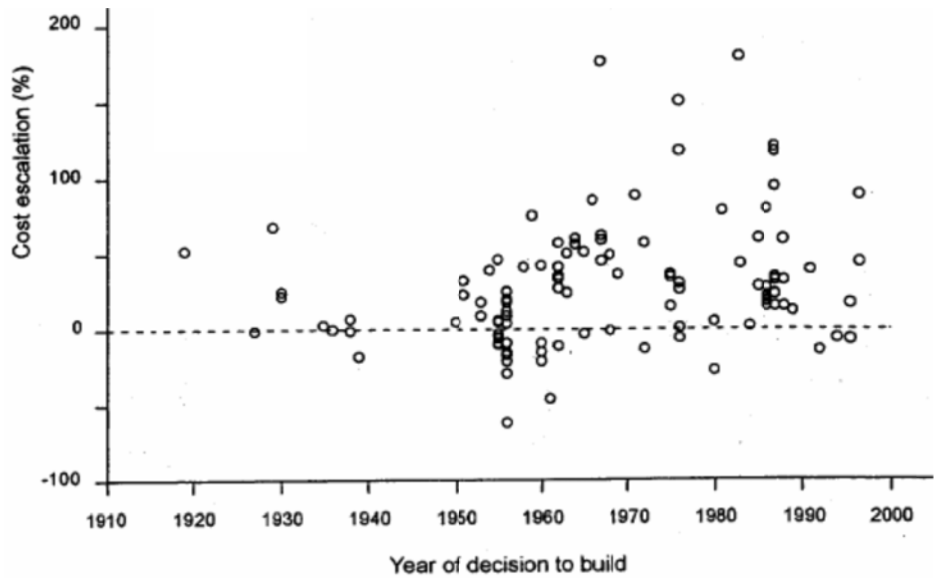

Figure 5 The Flyvbjerg megaproject study (2002) did not found evidence of a correlation between year of project and cost escalation; indicates there are causes of escalation not dependent on Moore's-law innovations. Graphic from NCHRP 2003.

The NCHRP *Challenges of Major Projects* report (NCHRP, Ch 4) identifies factors as potential causes of unexpected cost overruns [escalations]. The authors relied on four sources for unexpected overruns: a report published in 1986 by the Rand Corporation and authored by Edward Marrow, a 1973 article by L. Merewitz studying the Bay Area BART project that unfortunately is not available electronically. The report appears respected, fourteen authors and two United States government agencies have cited Merewitz: the US Army Corps of Engineers and the Bureau of Reclamation.

The NCHRP compiled a review of these sources and characterized unexpected escalations as either uncontrollable or controllable, see Table 4. One of the methods to change the controllable risks is to change the resources applied to schedule control. For example, changing the resources allocated to the quantification and the reforecasting that produces the schedule. It is difficult to know what the NCHRP authors intend – allocation of resources for schedule controls such as conformance to the schedule; it can mean many things.

Table 4 Resource (cost) escalation factors (NCHRP, 2003).

Uncontrollable	Controllable	Function
•inflation •scope change	•management •engineering survey (admin) •organization structure (admin) •contracting practices (admin) •professional skill (admin) •time dependent risk •exogenous factors (i.e., outside)	change accuracy of forecast with controls using: •change engineer resources •change schedule resources

2.6.3 Sources of Inaccuracy

While a graduate researcher, prior to research on risks of 4D time-space conflicts, Professor Akinci looked at uncontrollable project risk factors (Akinci & Fischer, 1998). Akinci's review covered a similar domain as the NCHRP report though relies on a different group of authors to present similar results. While the domain covers a wide range of factors affecting contractor's risk of cost overburden [escalation], a section concerning design and project-specific and contractor-specific factors fits within the topic of quantities.

For design and project-specific factors, Akinci reviews if project scope and complexity affect cost escalation. Akinci first defines the baseline accuracy of the estimate considered most reliable. By tradition the estimate submitted as their bid for the project is the most detailed cost estimate; accuracy range is +10% to -3% (Peurifoy & Oberlender, 1989), Table 5. Second, Akinci presents a difference between four empirical studies: those that find scope a risk and those that do not find scope a risk. Akinci hypothesizes that the known risks associated with the project size results in a correlation with the resources applied and so the risk of a cost escalation is changed. Akinci's literature review provides four components to the risk of cost escalation, these are (Rusteika & Boomer, 1992; Napier & Chang, 1988; as given by Akinci & Fischer, 1998):

- process visualization [communication of process state i.e., 4D]
- quantities estimate [accuracy]
- production rate [accuracy]
- unit cost rate [accuracy]

These risk components are at an abstracted level of detail the input to the NCHRP (2003) report call for improved schedule control. These are equal because the union of process visualizations, quantities estimates, production rates, and unit cost is the cost-loaded schedule. Once the field engineer updates the schedule with actual values from the project, it then becomes part of the project control. The quantities fulfill a key role in production rate and unit cost rate.

Table 5 Comparison of accuracy and precision expected for the project plan scope, time, and cost.

component	**error**	**stdev**	**high**	**low**	**research method**	**sample**	**source**
coding	5.5%	.5			case study		
coding	25%		50%	4%	survey	5	pre-experiment 2007
coding	8%		40% - 20%	8%			published
2D Onscreen QTO	27%	18	46%	3%	charrette		Alder 2006
3D BIM QTO	19%	19	51%	1%	charrette		Alder 2006
2-month schedule to actual	85%				case study		Peterson, Fischer, & Tutti
cost estimate (>1970)	10%				secondary	6	as cited in Liu & Zhu 2007[46]
[dam] parametric cost estimate	9%	6	17%	-13%	review		Walski & Pelliccia 1981
detailed cost estimate	10%				review		as cited in Akinci & Fischer 1998[47]
field measurement	70% not returned		7% (12%)	35% (>12%)	timecards	1month	Kiziltas & Akinci 2005
auditing invoice	6% internal error	92% *false negative*			case study	4years	Peterson & Fischer 2009

Next Akinci presents improvements to schedule control through four issues that affect the production rate, see Table 6. Akinci provides a new risk: the subcontractor. The variance between the findings for subcontractor risk may be due to the megaproject contractors self-preforming work and so there are not multitudes of subcontractors as a source of risk.

[46] See McCaffer, 1976; Flanagan & Norman, 1983; Morrison, 1984; Cheong, 1991; Gunner & Skitmore, 1999; Ling & Boo, 2001.
[47] See Peurifoy & Oberlender,1989.

Table 6 Akinci resource [cost] escalation factors added to the NCHRP factors.

Uncontrollable	Akinci 1998	NCHRP 2003	Controllable	Akinci 1998	NCHRP 2003
inflation		X	management		X
scope change		X	engineering survey (admin) | site conditions	X	X
subcontractor-generated	X		organization structure (admin)		X
			contracting practices (admin)		X
			professional skills (admin)		X
			time dependent risk | weather	X	X
			communication	X	
			project plan (estimate)	X	
			project scope	X	
			exogenous factors (outside influence) | client-generated	X	X
			schedule control resources | monitoring | feedback	X	X

Again, as presented in the NCHRP report, cost escalation occurs on projects for controllable and uncontrollable reasons. Monitoring of the project is necessary to recognize if there has been a change, if change is in the process of occurring, or if change will imminently occur. Akinci provides as an extension, empirical evidence that contractors change their controllable risk exposure by changing resources, possibly of process visualization, quantities estimates, production rates or unit cost. Akinci does not define if these resources apply to the monitoring process and the planning process. Mitigation of estimate error risk through project monitoring is not proposed by Akinci nor by the NCHRP report authors. Through monitoring errors in the estimate can be recognized, with the error corrections incorporated into a new revised estimate, this new estimate is called a forecast[48] and is the new plan to completion.

[48] This is consistent with theory proposed by Suchman, 1987.

2.6.4 Survey of Professionals

For additional and corroborating evidence of escalation factors, I reviewed two of the 23 published surveys I found during the literature search: Professor White's[49] (2002) survey of project managers and Professor Ogunlana's[50] (1991) survey of estimators. Both found the importance of quantities in the project feedback loop. I did not attempt a detailed synthesis of the 23 surveys, Table 7.

[49] Iowa State University www.ccee.iastate.edu/who-we-are/person/id/djwhite
[50] Formerly of the Asian Institute of Technology (AIT) and now of the Heriot Watt University in Scotland www.sbe.hw.ac.uk/staffprofiles/O/StephenOgunlana.htm

Table 7 A broad but shallow tabular review to give context for the completeness of this studies survey review. Literature that would have been nice to include are in bold. These publications are not included in the bibliography.

	Author	University	Year	Topic	n	Prominent Finding
1	**Navon et al.**	**Technion**	2003	**Feature set inferred from location**	**12**	**earthwork management control**
2	Chan & Tse	Hong Kong Polytech. Univ.	2003	Contractual cultural issues	90	inappropriate contractual arrangements
3	**Marshall**	**Lille School of Mgmt.**	2006	**Impact of EVM**	**148**	**EVM is a predictor of success**
4	**Frimpong et al.**	**Univ. of Tech. Sydney**	2003	**Issues - delay & cost**	**72**	**pay, manage, procure, technical, & escalation**
5	Long et al.	City Univ. of Hong Kong	2004	Issues - large project	109	main issue - time estimate accuracy
6	Assaf & Hejji	King Fahd University	2005	Issues - project delay	57	main issue – change order
7	**Thomas**	**NIST**	2000	**IT Impact (heavy industry)**	**297**	**IT & performance correlation**
8	Stewart	Griffith University	2007	IT in civil construction	82	IT benefit metrics and equation
9	Love & Irani	University of Joondalup	2004	IT in SME construction	126	indirect costs are considerable
10	Love et al.	University of Joondalup	2005	IT metric - empirical	126	discounted cash flows metric
11	Stewart & Mohamed	Griffith University	2003	IT value metric	108	operational perspective metric
12	Gilligan & Kunz	Stanford University	2007	IT VDC technology use	170	annual technology use increased
13	Ng et al.	Univ. of Hong Kong	2003	Labor demotivation	120	rework is demotivating
14	Chan et al.	Hong Kong Polytech.Univ.	2002	Partnering	78	improved relationship with client
15	Albert et al.	Hong Kong Polytech. Univ.	2003	Partnering implementation	108	commercial pressure compromises partnering atmosphere
16	Black et al.	West of Scotland Water	1999	Partnering success factors	78	communication, commitment, understanding roles, consistency and attitude
17	Chan et al.	Hong Kong Polytech. Univ.	2004	Partnering success factors	68	conflict resolution, share resources, define responsibilities, win-win, monitor process
18	Liu et al.	Hong Kong Polytech. Univ.	2002	PM knowledgebase barriers	187	lack of competent CS professionals
19	Zaghoul & Hartman	University of Calgary	2002	Risk allocation	300	trust agreements should be used
20	Akintoye & MacLeod	Glasgow Caledonian Univ.	1996	Risk analysis - empirical	37	Intuition
21	Lyons & Skitmore	Queensland Univ. of Tech.	2004	Risk management - empirical	44	Brain-storming during execution stage

The White survey looks at factors that affect project success [escalation] (White & Fortune, 2002); responses from 995 Information Technology (IT) project managers and five construction (project duration >2 years) project managers. The response rate is 24% and weighted towards the IT industry. Project managers noted 135 times that monitoring and feedback affects escalation, the mid-level frequency for the responses. The factor noted most frequently was an explicit objective (206 times) and the least frequent was ‘clear project boundary’ (two times). For operation factors the survey ranked monitoring and feedback as the first and second factors. These operation factors rank after factors outside the control of the field engineer, such as senior management support, leadership – clear goals and objectives - and communication. These factors correlates with the NCHRP (2003) findings and supports the suggestion to change schedule control resources to change the controllable factors, and is consistent with the risk factors found by Akinci (1998).

The Ogunlana survey (1991) looked at eight estimating offices to define estimate success [escalation] factors. The surveyed estimators believed the core factors are monitoring data and their personal expertise. Estimator expertise is not a factor in the White survey though the sum of the lower ranking factors found by White, are equivalent to estimator expertise, such as recognizing complexity, accounting for external influences, considering multiple views of project, and accessing talented people: termed professional skills in the NCHRP report (2003). The estimators gave four points of monitoring data context, Table 8. Ogunlana found these four points consistent with previous research published by McCaffer (1976, Loughborough University of Technology Ph.D. Thesis) and by Morrison & Stevens (1981, University of Reading, UK). These four points are:

- associated knowledge
- breakdown structure features
- monitoring accuracy
- time between schemes

Table 8 Four points of monitoring data context found by Ogunlana (1991).

data point	associated knowledge	context	accuracy	duration since measured
example 1	CAT handbook - grader	31.22.13	+/- 10%	7 years
example 2				
example n				

2.6.5 Summary of Published Purpose

These four sources – NCHRP, 2003; Akinci, 1998; White, 2002; and Ogunlana, 1991 – indicate that quantities are a core component of mitigating project escalation risk with improved schedule control and project monitoring, Table 9. Now that the need for project monitoring is established and the contributing factors, the next section will synthesize publications, explore the industry professionals’ opinions, and study ethnographic observations of quantities collection methods. The question is, how have these factors been implemented on construction projects since published and what has been the effect?

Table 9 Construction project escalation factors[51] and the purpose for quantities monitoring.

Uncontrollable	Ogunlana 1991	Akinci 1998	White 2002	NCHRP 2003	Controllable	Ogunlana 1991	Akinci 1998	White 2002	NCHRP 2003
inflation				X	management | leadership | support			X	X
scope change			X	X	engineering survey (admin) | site conditions		X		X
subcontractor		X			organization structure (admin)				X
					contracting practices (admin)				X
					professional skills (admin)	X		X	X
					time dependent risk | weather		X		X
					communication		X	X	
					project (plan) estimate		X		
					project scope		X		
					exogenous factors (i.e., outside) | client		X		X
					schedule control resources | monitoring | feedback	X	X	X	X
					monitoring context	X			

[51] A key question unanswered is how have these factors been implemented on construction projects since published and what has been the effect?

2.7 Summary of Quantities Purpose

In this section, I have shown the definition, background, and purpose of quantities. I showed the purpose through a survey, my ethnographic observations, from a review of integrated planning theory, and through a review of literature. Next, I present my research methodology.

With the underpinning purpose of this thesis established, I will now begin a study of the quantification process. First, I will present my research methodology to study quantification. After methodology, I will establish a problem case and through this case, I will then present my observations of quantification.

3 Research Methodology

3.1 Research Goals

This thesis is a part of Professor Fischer's *Center for Integrated Facility Engineering* (CIFE) research goals as presented in *Formalizing Construction Knowledge for Concurrent Performance-Based Design* (Fischer, 2006a). One of several concepts defined as CIFE goals is the concept of Self Aware Elements (SAE). The Self Aware Element (SAE) is abstracted into two follow-on concepts. The first is as the product, organization, and process model (POP) (Fischer, 2006b). The second is as the components, actions, resources, and sequence constraints (CARS) (Fischer et al., 1998). In preparation for automated methods as a solution at the trade level (Fischer, 2006) I need the knowledge for Self Aware Elements (SAE) to implement project independent monitoring methods.

My contribution is through the synthesizing and adding to the formalized knowledge of the quantification process. Someday, a self-aware process element with learning capacity will be able to see the project state. Quantification feedback (to see) is the input to the learning process, abstract the feedback process concept to machine learning applied to SAE and that is the specific meta-goal of this thesis. To implement learning to a self-aware element - a limiting factor to the concurrent application of learning on the project – then the researcher developing the learning component needs a guide of the baseline tradeoff between resource intensity and quality of feedback.

The research question that guides my investigation:

What is the current quantification topography in construction?

As a thesis investigation, the goal of contribution for this thesis is relaxed compared to the dissertation requirement for a contribution to science and practice. Regardless, these are the stated contributions of this thesis:

- Practice: Present the current process in construction to measure the context and quantity of the economic inputs, the current state, and the product output
- Science: Explain the framework, formalization, and methodology of the current process in construction to measure the context and quantity of the economic inputs, the current state, and the product output

The arguments I make to support my claim to practical and scientific contributions:

- Power: My ethnographic observations of a large design-build heavy construction structures project (ReTRAC) has a depth in understanding that shows that those observations capture a complete, detailed, and correct frame. I then support the power of that observation through open format expert interviews to fill several gaps in the ethnographic observations. I further confirmed the power of my observations through both a literature review and a questionnaire survey – neither found contradictory evidence.
- Generality: The application of the quantification process I observed on the ReTRAC project to a broader domain of construction is valid and I show this through a literature review and a questionnaire survey. I found that the methods I observed on the ReTRAC are the most commons approach to quantification and represents a full system that is an extreme example – vertical construction and smaller civil projects use a less detailed and rely on a lower quality approach to quantification.

For confidence, I validated my arguments through a bundle of the following methods:

- Literature Review
- Questionnaire Survey
- Open Format Interview of Experts
- Ethnography
- Case Study

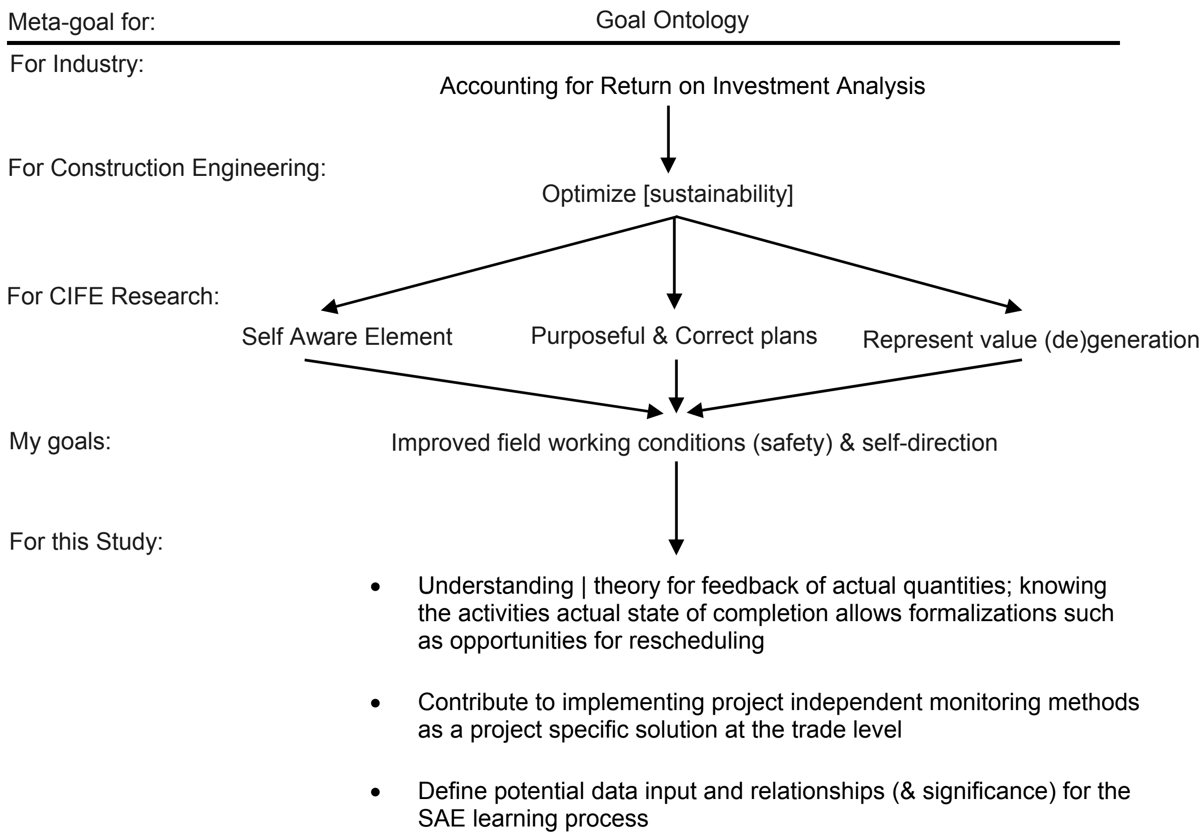

Figure 6 Goals of this thesis within broader goals

While I was a field engineer, the topic of project monitoring was an item of uncertainty, risk, and lack of definition. I perceived project monitoring as a task that was in the way of performing the field engineering tasks. To me, the field engineers most important task is to ensure the field hands have what they need to safely perform the task before them[52].

Rather than follow the CIFE *maximum anxiety principle,* “tackle the task that has the greatest uncertainty or risk or lack of definition,” I approach my studies for this thesis by exploiting the paths of least resistance and sidestepping the anxieties as gaps in knowledge. I will investigate an anxiety or gap in knowledge at a later-date as an in-depth research project.

In contribution to the CIFE broader impact goals, the goal of this thesis is to understand the process to ‘feedback’ the actual project state. Knowing the activities’ current state allows field

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52 They had resources allocated to the ice and water account - on warm days the ice is omitted due to its lethargic affect - and had resources to procure equipment needed for encountered conditions.

engineers to focus on other formalized concerns such as opportunities for rescheduling (Fischer, 2006). This thesis ties-in with climate change and the potential relocation of industrialized regions and associated resources. At CIFE, through my experience with estimating infrastructure construction I assisted Dr. Becker with his studies on the impact of climate change on port facitlities. From Dr. Becker's work I can see that the capacity to relocate industrialized regions in a historically short time-frame is beneficial (Becker et al., 2014). Last, throughout this thesis I used the formalized scientific process provided by the *CIFE horseshoe* to guide my studies and facilitate comparison to other research (Fischer, 2006), Table 10. To begin, a review of the research at the Center for Integrated Facility Engineering (CIFE) will give a review of core literature from where in the beginning of CIFE Paul Teicholz opened these practices as a research topic.

Table 10 The association of Fischer's CIFE horseshoe (2006) with sections of this thesis defining the problem - but not addressing the problem. The actual sequence is the step order.

Step	Process	Description	Applied	Reference
5	Problem Statement	Metric to define the problem	There is no project monitoring guide	page 25
5	Intuition	project-independent solution	monitoring methods	page 25
6	Context	larger picture of theory and practice	statement of purpose and storyline	page 25 and 197
7	Points of Departure	literature review	published knowledge	page 77
8	Research Question(s)	concise, feasible, testable; facilitates finding evidence for generality and power	what is the baseline civil project monitoring knowledge	page 65
2	Research			
	Research Method	quantitative or qualitative	qualitative meta-method	page 19
	Research Tasks	depends on research problem	ethnographic survey literature synthesis	page 88 page 274 page 37
	Research Plan	quality-scope-time-cost plan	ad-hoc & informal	
	Validation Method(s)	test of results (transparent)	expert panel of *n* for confidence interval *y* cross analysis of observed and survey with literature	NA page 298
3	Research Results	generality power	sample size & sources scope of application cross analysis	page 68 page 77
1	Contributions to Knowledge	extend prior work with new theory	methods guide monitoring level of detail monitoring sources monitoring relation	page 236 page 255 page 255 NA
4	Practical Significance / Impact	same metrics as used to define the problem (start here, i.e., vision)	Allows project monitoring plans to conform to the data constraints with a factor of safety	NA

3.2 The Research Question

I base my motivation for this thesis in my belief that field engineers should not burden field hands with quantities collection tasks. This belief comes from both my experience as a laborer and as a field engineer. The field engineers' primary purpose is to support the field hands to allow the field hands to focus on constructing the product. My belief has support, echoed by Dr. Saidi in his thesis (2002). In addition, I believe field crews need the resources to self-determine their work and working conditions; I explore this idea further as *Organization for Monitoring* on page 363 and I see empowered field crews as concepts of an *edge organization* as presented by Alberts and Hayes (2002)[53].

I have one research question: What is the current quantification topography in construction?

3.3 Intellectual Merit

This thesis provides documentation of the project monitoring process in the civil construction industry. This thesis is a record of knowledge for future researchers and field practitioners. Without this thesis, the only way to learn the processes is through trial, error, and knowledge transfer from established practitioners. The downside is that knowledge transfers are imperfect - often specific to the specific application at hand - can be incorrect, and knowledge is lost. The benefit is that the context of knowledge and depth of meaning passes from master to apprentice in a way researchers cannot replicate. To practitioners, this thesis is a reference. To researchers, this thesis adds to the greater body of project monitoring knowledge: (0) what field quantities are (1) where field engineers are with quantities collection practices, (2) where field engineers are going with these methods and (3) through intuition gained from this thesis I have suggestions for where research should go and what problems researchers need to solve. In support of the world mandate for a sustainable construction industry (Stone, 1996), this thesis strives to understand a source that affects the accuracy, consistency, and completeness of project control in the construction industry: the feedback of actual production quantities used for forecasting. Without reporting field quantities then project monitoring methods such as those I present in this thesis, cannot provide a sustainable forecast of what to expect and therefore results in waste.

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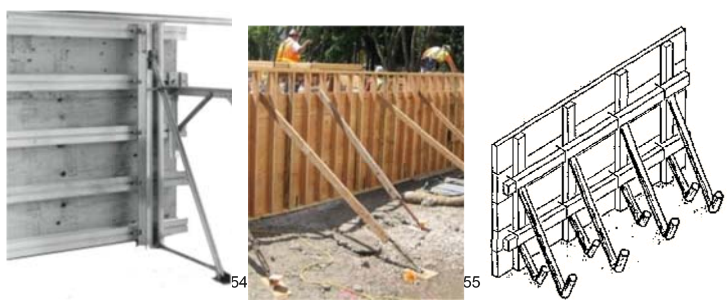
[53] The edge organization structure is characterized by the absence of a management hierarchy, replaced with support to facilitate availability of resources to non-managerial workers progressing towards an established goal with universal knowledge sharing. The core concept is that the decision-making capacity of the organization rests at its edge (bottom up) rather than conveyed from the top down.

3.4 Personal Motivation: Sensitivity to Context

The path that led me to consciously researching quantities began after conferral of my undergraduate degree. It began while I was a field engineer on the Reno Transportation Rail Access Corridor (ReTRAC) project. In the years before earning a degree in Construction Management, I worked as a tradesman on residential, commercial, and civil projects. These experiences provide me with my contextual understanding of project monitoring. During my years as a field hand, quantity tracking was not an issue; my task was to generate the work that the engineers tracked. The experience is invaluable – there are details in construction methods that affect the fundamental planning aspects. For example, what type of forms to build impacts what material to purchase, the crew to task with the work, and the time expectation for completion, see Figure 7. I can only speculate what methods the field engineers used to monitor those projects. My field engineer experience gave me the ability to intuitively know the progression of the work and monitor project progress, Figure 8.



[54] [55] [56]

Figure 7 The superintendent instructed the laborers to build forms for a 3ft thick bridge approach cross-section. He saw the design with strong back carpenter panels (left). As laborers, we had only built formwork for a 10" tall highway cross-section and did not have reference material. Based on 'Vitruvi' experience we built weak panel forms similar to framing a house wall (middle). A journeyman mason suggested a design using mason boards (right). Each design has a different resource-operation-method (Mourgues, 2008) requirement.

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[54] HI-LITE aluminum concrete support systems, last accessed 10/26/2015 http://www.hi-lite-systems.com/uploads/Image/Products/wall-02.jpg

[55] Unable to find through image search – unsourced image from web

[56] Building with pumice, last accessed 10/26/2015 http://www.appropedia.org/Original:Building_with_Pumice_7

Project-level monitoring:
Day Spa (1999)

Action-level monitoring:
Transportation Corridor
Realignment (2003)

Operation-level monitoring:
Transportation Corridor Reprofile
(2005)

Figure 8 The abstracted low, medium, and high levels of detail in project control, corresponding resource intensity, and monitoring methods. A specialty subcontractor with one payment [0/100]; a highway realignment project with milestones for core work packages; and a transportation access corridor where actual productivity was measured for both control and for planning of subsequent proposals.

Prior to the ReTRAC project, I was a roofing laborer for a year, then a tile laborer[57] for a year that lead to becoming a journeyman marble-setter for a year. With the millennium demise of the Silicon Valley dotcom industry - and their taste for lavishly tiled homes - I then journeymanned into the Laborers union for the next four years. During the two-year educational transition from a highway laborer to a field engineer, in-between courses I began and completed a residential *spec* house – slang for a house built speculating that it will sell rather than built on order. My courses tied the skills learned during the previous years as a field hand with the skills of scope, time, and cost learned in coursework. Attempts at monitoring my work progress so to reduce scope-creep, remain on time and on budget, provided a lesson in the balancing of resources between producing, monitoring, and planning. After 15 months on the ReTRAC project, I interned for several months each with a Bay Area civil works company, the commercial builder of the Jerry Yang & Akiko Yamazaki Environment & Energy Building, and the commercial builder of the Stanford Law School. If not for these three internships, I would not have perceived the significance of the level of detail of the ReTRAC project monitoring. The project level of monitoring observed at the *Bay Area* Granite Construction branch (regional projects), the Hathaway Dinwiddie Stanford University Y2E2 building, and the DOME Construction Stanford University Law School building are similar to the discipline level (an abstracted level) of monitoring observed on the ReTRAC project.

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[57] Laborers time counts as an apprenticeship to another trade, if I had remained with the Laborers union eventually I likely would have journeymanned into the concrete masons union.

Following the Y2E2 Building and Stanford Law school project I searched for a project that replicated the conditions I observed on the ReTRAC project. The purpose was to allow me to test the new Virtual Design and Construction style software tools and methods in a familiar environment. After talking with several prospective project teams I found one that uses many of the same approaches as I had seen on the ReTRAC as well as a comparable structures project. The biggest difference was the contract type difference from a lump sum percentage of completion reimbursement design build to a design, bid, build, unit cost reimbursement contract. From the perspective I worked the difference was minimal. This project is the $30 million three year Merced Highway 99 Overpass Project with RGW Construction. My experiences in Merced closely reflect my experiences in Reno so I do not separate the Merced project out in this thesis.

3.5 Research Methodology Plan

To support my methodology I will present the confidence expected from this methodology, the sample population, and an argument for generality.

3.5.1 Confidence

I use a cross validation approach relying on five sources of validation, each individually non-compelling, but when taken together, forms a compelling bundle of evidence. Relying on the literature review confidence interval of 16% with a sample of 29 does not provide confidence. Therefore, I include the analyses of the confidence interval for the field observation and the survey, Figure 9 and Table 11.

My field observations of the ReTRAC project represents .04% of U.S. heavy and civil engineering project revenue for 2005, resulting in a confidence interval of 1% @ 95% confidence, therefore a reliable sample. The questionnaire survey sample of 127 provides a confidence interval of 12%, comparable to the literature review sample. Resting on two samples provides a @15% CI, which does not instill confidence even with the observation supported by observing a large project.

Therefore, I added an open format interview of a senior cost engineer to capture niche scenarios and hidden topics (p88). The interview of one senior cost engineer is a 98% CI and functions as a reality check through an open interview format to catch anything obviously incorrect. The interviews mitigate the possibility the literature review, survey, and ethnographic cross approach left a knowledge gap. In addition to the open format interview, two additional interviews answer specific questions. Also, there is the initial open format interview of the project manager. The interview provided the opportunity to ask tacit practice or issue specific questions, for example, the *neat line* reported quantity practice. In the ethnography section of this thesis, I will go into detail with the neat line method.

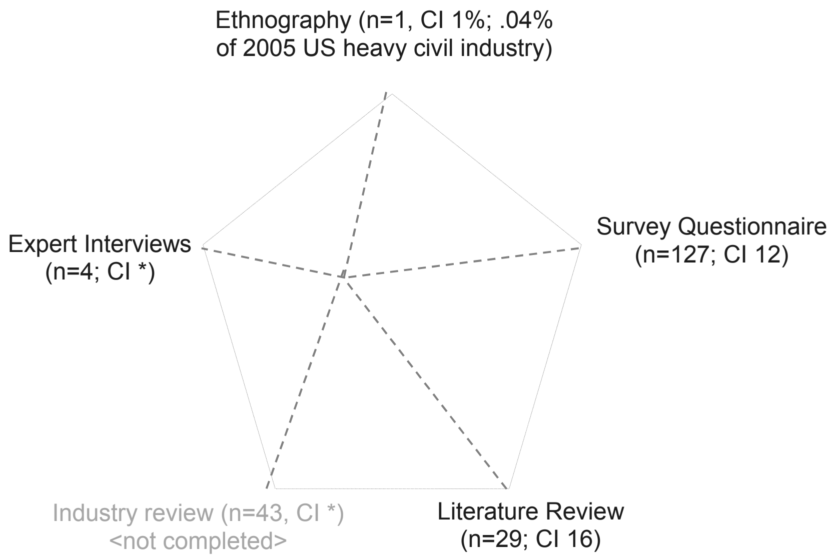

Figure 9 Due to the inability to find significance in one method; to build confidence I use five points of validation for this thesis. I did not replicate the process with a simulation or through a charrette due to my inability constrain the domain of study from the available knowledge prior to this thesis.

This thesis follows a progression from published knowledge to tacit knowledge. The published knowledge is a fragmented and scattered storage of construction quantities collection methods. The interviews provide the tacit components for the relationships of the knowledge fragments; a review of accepted practices forms a bridge between published practices and the observed practices. I present the tacit knowledge in sub-sections of ethnographic experience in project-level monitoring used by a heavy civil contractor and interviews of senior construction engineers.

The open format interviews, literature review, direct and indirect project observations, and questionnaire survey is the cross-validation subcomponents; the cross-validation gives confidence to this thesis. Last, given time, as a fifth source of validation, I wanted to distribute this thesis to a representative population of project monitoring professionals, therefore providing credibility from industry. I do not think I can find 43 professionals to review this thesis and provide feedback that I can include in the results, due to the difficulty in obtaining expert review, it is necessary to decide for yourself the validity of this thesis as the fifth source of validation. The penta-check validation is necessary in this thesis due to the small sample sizes on a topic that is tacit with gaps in documentation.

3.5.2 Population

I found the populations for the confidence using several methods. The population used for the industry and field observation[58] validation are based on the United States heavy and civil engineering revenue for 2006 (Corporate Source Book) and the assumption that each field engineer supports $10M of work-in-place per year[59]. Based on the total 2006 revenue of $220B then there should be 22,000 field engineers, 7,300 project engineers[60], and 2,400 project managers[61] employing the methods described in this thesis. The validation of this thesis does not include commercial and residential construction. While monitored similarly, though likely in an informal process, if validated it implies another 130,000 people tracking project progress, given 2006 construction revenue of 1.3 Trillion or 10% of US GDP.

The population for the questionnaire survey is from the number of degreed professionals working in the heavy civil industry (237000) as found by the US Bureau of Labor Statistics (BLS). The employment categories for 2006:

- engineers (17-2000)
- construction managers (11-9021)
- engineering managers (11-9041)
- agricultural managers (11-9010)
- industrial production managers (11-3051), and
- computer and information systems managers (11-3021)

The population of senior cost engineers is not easily quantifiable. In the heavy civil industry there are 12,000 cost estimators (13-1051), 6,000 civil engineers (17-2051) and 65 budget analysts (13-2031), the senior cost engineer is a mix of these three and then is *senior*. It appears the interviewed sample is of a small population, possibly equivalent to the number of companies represented, 14 known companies, and likely another 50 unknown (one for each state), equal to the budget analysts. The sample size of one eliminates the need to define the population since the confidence interval is 98% regardless of a population of 65 or 12,000. For a 95% CL sample with a CI of 15 requires 25 to 45 individual reviewers, while adding confidence, an open format review is not feasible without additional resources.

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[58] A conservative assumption is that only heavy civil contractors use the job cost accounting method, therefore excluding commercial specialty subcontractors from this study. With this assumption and the 2006 U.S. construction industry population (IRS corporate tax returns with net income), 17% of U.S. construction, and 27% of U.S. commercial and heavy construction use the job cost accounting practice.

[59] The annual figure is a rule of thumb that was used as a heuristic on the ReTRAC project.

[60] Assuming one project engineer per three field engineers, ReTRAC had a 5:1 ratio.

[61] Assuming one project manager per three project engineers, ReTRAC had a 1:1 ratio.

Table 11 The cross validation sources and confidence intervals. Individually these do not give confidence; synthesized and cross-analyzed gives confidence.

Source	Sample Size	CI @ 95% CL[62]	Population	Population Source	Sample for 5% CI @ 95% CL
Literature review	29	16%	300	guesstimate	
Pre-survey survey	27		34,000	BLS[63]	
Questionnaire survey	149	12%	34,000	BLS[64]	
Interviews	4	98%	65	BLS	
Ethnographic 2005	.05%	<1%	$220B	IRS[65] [66]	
Niche case study	6			Doc Count	
Industry review (incomplete)	43	15%	21,800	estimate	

An inductive argument: the following observation populations have been included as part of this thesis: literature (n=29), interview (n=4), pre-survey open questionnaire (n=27), online questionnaire (n = 149), ethnographic field observation (n=1), and lab case studies (n = 6). From this bundle of observation sources, I make the claim that the planning processes with respect to quantities that I present in this thesis is inclusive of heavy construction projects. Alternatively, I cannot claim that my search is perfectly complete. There is confidence, since I observed the same methods repeatedly; finding a new method, or variation has become infrequent and supports a declaration for an exhaustive search.

3.5.3 Argument for Generality

Intuitively, these methods are applicable outside construction and so apply to a larger population. The quantities collection process is a human-centric process that relies on a series of interactions between various actors and therefore has implicit rules and traditions with purposes or lack of purpose that are not transparent. The following sections will cover the domain of the study for each of the four approaches. After a discussion of the purposes quantities serve, the first section reviews and synthesize literature as secondary quantities research. I then identify the gaps in the literature and place emphasis on resolving these gaps through multiple survey methods and ethnographic field observations. The interviews are specific to several questions unanswered through field observations. After the literature, survey, and the observations, in the

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[62] Confidence intervals calculated with online calculator at www.surveysystem.com/sscalc.htm
[63] BLS – senior cost engineer ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/occ_pdf/occ_13-1051.pdf; ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/occ_pdf/occ_17-2051.pdf; ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/occ_pdf/occ_13-2031.pdf
[64] BLS – senior cost engineer ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/occ_pdf/occ_13-1051.pdf; ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/occ_pdf/occ_17-2051.pdf; ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/occ_pdf/occ_13-2031.pdf
[65] IRS - Corporate Source Book www.irs.gov/taxstats/bustaxstats/article/0,,id=149687,00.html
[66] BLS – Heavy and Civil www.bls.gov/oco/oco1001.htm

Selected Discussions chapter I review my findings that illustrate the aspects of quantities collection that are not easy to understand.

I searched for but did not find the origins of the large projects monitoring tradition in Western North America. There are references by John Fondahl to cold war projects in technologies with no precedent but there were large projects before the cold war. It is likely these practices have earlier origins. One of the large projects in Western North America is the Boulder (Hoover) Dam project on the Colorado River in the Black Canyon narrow. In the1930s, a joint venture[67] constructed the Boulder Dam project. The joint venture members were:

- Morrison-Knudsen Company of Boise, Idaho
- Utah Construction Company of Ogden, Utah
- Pacific Bridge Company of Portland, Oregon
- Henry J. Kaiser & W. A. Bechtel Company of Oakland, California
- MacDonald & Kahn Ltd. of Los Angeles
- J.F. Shea Company of Portland, Oregon

The founder of the Bechtel Company started in 1898 (29 years after the first major Western North America project[68] [69], 17 years after the second[70], and 10 years after the third, the Sweetwater Dam in Southern California[71] [72]) building rail and road corridors in the Western United States. The Boulder Dam project is a candidate project for the sharing and development of monitoring methods knowledge that then influenced field engineers in a broad geographical region. Those practices likely continue to those observable today. There is a civil contractor in the Western North America region that is known to have been influential on West coast civil contractors that exist today: Ball, Ball & Brosamer[73], known as the *3Bs* (Kilzer & Gathright). The 3Bs was the starting point for many west coast field engineers; it is possible that the practices they used to monitor projects spread with field engineers across companies in the region. Due to a tradition of several influential contractors the observed practices on the ReTRAC project – which appear consistent with practices at Ball, Ball & Brosamer - are likely representative of a larger group within the design-build, lump sum contract, self-performed demographic.

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[67]Hoover Dam design preparation and contracting http://en.wikipedia.org/wiki/Hoover_Dam#Design.2C_preparation_and_contracting

[68] Overland railroad http://en.wikipedia.org/wiki/First_Transcontinental_Railroad

[69] The precedence for project monitoring prior to this project is uncertain; the project was built by Cornish miners, Chinese laborers, and a group of dry goods merchants – one of these could be the source of the tradition. Referencing a late 18th century textbook on project management did not find these methods outside of payment by work units (piece work) therefore implying production rate. A rate that does not provide the resources needed to live is less than the average production.

[70] Southern Pacific Railroad http://en.wikipedia.org/wiki/Southern_Pacific_Railroad

[71] Richard A. Reynolds, Sweetwater Dam: Then and Now, August 2, 2008, http://homepage.mac.com/oldtownman/local/docs/doc238.pdf

[72] See http://legacy.signonsandiego.com/uniontrib/20080315/news_1sz15history.html

[73] See http://www.ballconco.com/about.htm

3.6 Introduction to Terminology

There are terms used in this thesis that because they are pragmatic and do not have academic origins the definition of the term and usage is inconsistent and heavily based in context. To clarify the meaning of these pragmatic terms I have used more concise terms in this thesis. Refer to Figure 10 during my discussion.

Throughout this thesis, I will use the term *cost code* – this term is a noun and is a term used by civil engineers that has a loose definition. The cost code is used to describe most any code that represents features of the work activities such as labor, equipment, material, and output progress. The code could represent the project, or location, or objects – there is a wide range that the term cost code can describe. In the strictest sense, cost code means the core code that represents the work discipline and the operation – then additional codes are concatenated to this core cost code. The other codes could have code names such as resource code, distribution code, location code, and project code. These add-on codes could just as easily be known as cost codes as well. I will use the cost code term to describe the core work operation code but there may be a few cases where I have used the term cost code to describe a code that encompasses all features.

A role that I will refer to throughout this thesis is the cost coder – the cost coder measures the features that give context to a quantity measurement and assigns these features to the quantity. As I will show later, the cost coder should always refer to the field engineer role but this is not strictly correct. Often foremen and clerical staff fill the role of the cost coder – usually at the discretion of the field engineer.

The cost coder codes the cost code, coding is a verb and describes the act of measuring and assigning the features of a quantity. The term coding is near universally understood to mean the act of assigning cost codes to a quantity such as timecard or material invoiced quantities.

As a note here, when I use the term quantity, I mean all quantities not just the quantities that are pragmatically known by this term. My definition of quantity includes date (month/day/year) and amounts of currencies – to me currency and date are units of measure. The reason for this is that defining all quantities and the features that give those quantities context in the same way allows for a simpler definition and use of the concepts.

The cost code represents features of a quantity. Every quantity has features; at the least they have the feature unit of measure. Often there are features such as date, project, responsible person, component constructed, and work operation. The features form a set and I will call this the feature set. I will also occasionally refer to the feature set as activity or cost code – they essentially mean the same thing: Cost code is the pragmatic term that is used in the field. The term activity is the intersection of scope, schedule, and cost – represented by the units of measures for physical quantity, time quantity, and currency quantity. When I do not refer to activity then I am not specifically referring to this intersection though in many cases I am also not specifically refereeing to the lack of this intersection. From here on, when I am discussing a work task I will use the term activity since I am talking about the work in an abstraction that includes the scope, time, and cost.

The nomenclature or naming of feature sets is accomplished using an encoding of a breakdown structure of feature groupings. The breakdown structure provides the relationship between the features. Each feature set named through the nomenclature is then an account. The sum of the accounts is known as the chart of accounts.

The context features grouping, the relationship given through the breakdown structure, and the nomenclature, is known as the ontology, see Figure 10.

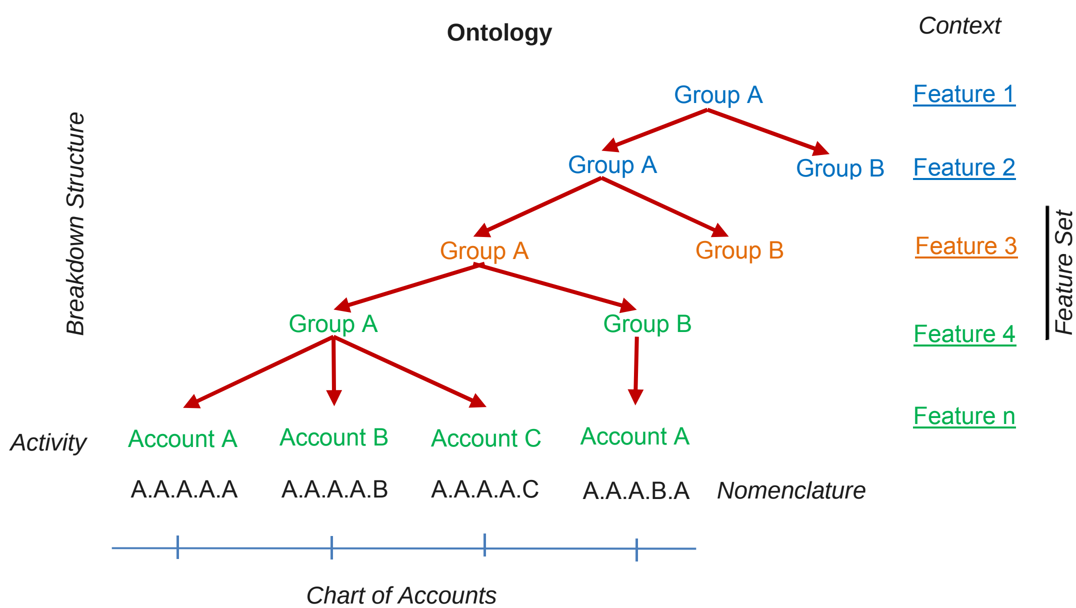

Figure 10 The account nomenclature is commonly referred to as the code – these codes are usually bundles of features (shown here as different colors) and so there are different types of codes that are concatenated into a larger code such as the project code, location code, object code, cost code, workmans comp code, and resource code. The list of the concatenated account codes is called the chart of account – though often this is the core 'cost codes' and the other codes types are kept in separate code lists and then concatenated to the core cost code.

3.7 Summary of Research Methodology

To support the research methodology I have presented the goals, questions, intellectual merit, my personal motivations, and my methodology plan. The methodology I use is based on capturing the pragmatic application of quantification and verify the relation of these pragmatic applications through the research literature. I systhesize these sources and show the confidence based on the sample size. Next, I will present the problem case.

4 Problem Case: Design-Build Rail Corridor Project

4.1 Problem Case Introduction

One conclusion of this thesis is that project monitoring is a tacit practice and the documentation available does not do it justice. If that is true then these practices have been passed-on for generations. It is possible that field engineers in the Western United States have used these methods since the earliest large infrastructure projects. One of the earliest is the 690-mile Overland Rail Corridor. As a field engineer I worked on the reconfiguration of a 3-mile section of the Overland corridor in Reno Nevada – that project was the Reno Transportation Rail Access Corridor (ReTRAC). In many aspects, the ReTRAC project is simply the completion of a section of the Overland Project that was never completed.

In this section, I will present these two rail projects. On that stretch of track, they are the same project constructed on the same rail alignment 150 years apart. I use this section of rail alignment to illustrate a long-term case example of project monitoring for heavy civil projects. The methods between the two projects do not differ by much. A specific ReTRAC issue was the removal of contaminated soils. These contaminated soils formed under the rail alignment during the 150 years of operation. Throughout this thesis, I will reference back to the Overland Route/ReTRAC project site – these contaminated soils form a specific case example.

In the following sections, I will provide an overview of the Overland transportation corridor from a historical perspective. Then I provide the regional demographics across the timeline of the transportation corridor. I will discuss issues that this historical corridor presents in the Reno Nevada basin now that it has been engulfed in an urban landscape. Last, I will introduce the ReTRAC project that addressed both the urban issues and the demographic issues that equally plagued the ReTRAC and the Overland project.

4.2 Transportation Corridor Demographic

The Western North America geography is dominated by the the 9,000 ft. Sierra Nevada Mountains. For the 1,000 miles of coastline from North of the Los Angeles Harbor to South of the Willamette River where Portland Oregon sits, there is one commercially usable mountain pass opposite a harbor. At 7,000 ft. (2,160m), located at the midpoint of the Sierra Nevada mountain range due east of a large inland harbor is Donnor Pass: barely suitable to slip through a rail alignment. A confluence of constraints combined to create the conditions necessary to equalize the risk this terrain obstacle provided with the monetary gain from realizing the opportunity.

The mountains divide a large bay from a large basin, called the *Great Basin* - encompassing the state of Nevada - in a wide river valley. The Great Basin is a high mountain desert 4,400 feet above sea level. The 190,000 square mile Great Basin Desert provides a second though equally challenging obstacle to travel. It is only the nearly impassable "Desert Route" through the Sonoran Desert inland from Los Angeles Harbor and the vast bog and river valley conditions to the north out of Portland that makes the combination of a high mountain pass and crossing the Great Basin look like the best of three bad options, Figure 11.

Figure 11 The 1857 G.K. Warren map indicates five potential routes from the Pacific Ocean to the eastern railroad heads in the Mississippi river valley (History of Railroads and Maps)[74]. The Overland route indicated by the dashed line was not on this map. Note that the original Northern California route followed the Feather River canyon.

At the dawn of industrialization, the Central Route - as it became known - was the most suitable for a commercial corridor. The corridor follows a pathway that ascends the western slopes' river canyons then drops down through a narrow pass and traverses through the solid granite Sierra Nevada Mountains into the Reno Nevada Basin. This path forms a transportation corridor from the large San Francisco Bay Harbor Eastwards towards the expansive deserts and mountains of the Western North America and into the broad grass prairie of the continents interior. Formed during the tectonic uplift of the Sierra Nevada this corridor for millennia

[74] Most of these routes were constructed: The Donner Pass route (<25 trains per day (Trains)) has cargo limitations due to the tunnel clearances (Donner Pass). The southerly route (100 trains per day), with its own transportation rail access corridor (the Alameda Corridor), and Feather River routes (15 trains per day) carry the bulk of double stacked cargo containers originating at west coast ports.

provided a transportation path to migrating animals, the Maidu people, and more recently Europeans moving westward in search of opportunities.

4.3 Transportation Corridor Historical Perspective

Entrepreneurs considered several paths to align the first rail corridor; each had issues that presented obstacles. The northern route passes through the Feather River canyon - inhospitable, desolate, and with unstable geography. The southern route passes through the then northern reaches of the recently independent Mexican Republic – also the home of the fiercely independent Yuma people – both a source of uncertainty. The central route – an established mule train path – presented only steep granite bluffs and High Sierra winter weather to resolve.

The rail transcontinental transportation project that passed through the future Reno site was constructed in nearly seven years between 1863 and 1869 (Golden Spike, 2003), Figure 12. Starting with the Pacific Railway Act of 1862 (First Transcontinental Railroad) projections for improvements in coast-to-coast transportation - then feasible by Conestoga wagon across the desert, by ship around the stormy Grand Cape Horn at the tip of South America, or by ship and a malaria plagued trip across Panama[75] - became an opportunity. The technology advances in engines predicate this opportunity. During the millenniums leading up to the 1862 act several key milestones establish the steam engine: The invention of the *aeolipile*[76] steam engine sometime before the end of the 1st century BC (Vitruvius). By 1712, *Newcomen* had embodied the expansion principles demonstrated by the aeolipile into a productive stream engine. Then progress moved at a quicker pace. In 1804, the first steam locomotive was demonstrated and in 1829 the first rail lines were operating (wiki>Steam engine). The first railroad used formerly horse drawn wagons modified to hold a steam boiler and to transfer the power to the wheels. Twenty-five years later in 1854 a compromise in the United States congress allowed the construction of the transcontinental railroad along a central route (then called a northerly route) rather than a southerly route (Kansas-Nebraska Act).

[75] One of the projects design engineers and early proponents died of malaria on the trip from California to Washington D.C. to deliver a project report to congress.

[76] During research for this paper I noticed that Hero of Alexandria, a 1st century AD Greek mathematician, was potentially incorrectly attributed as the inventor of the aeolipile. While searching for project monitoring methods, I noticed that this device was described by Vitruvi in De Architectura, a 1st century BC Roman treatise, 100 years before Hero.

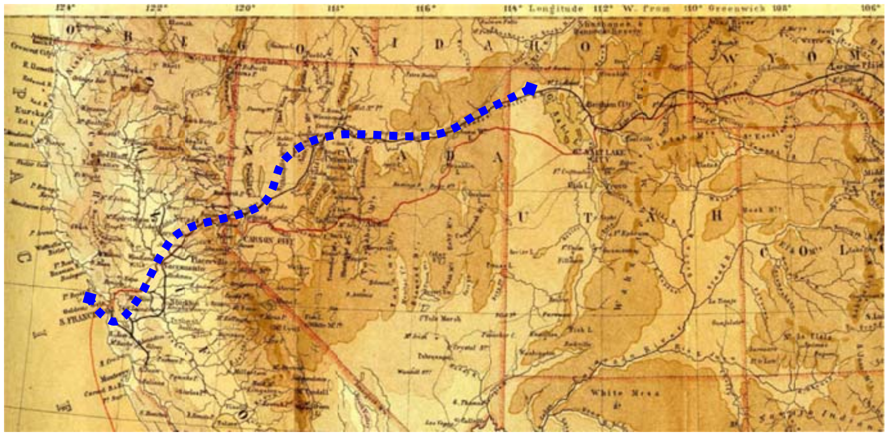

Figure 12 Located in downtown Reno Nevada the observed project is a 3.5-mile rail access corridor depressed below street grade, Table 38. The Central Pacific Railroad originally placed the rail tracks June 19th 1868 (waymarking.com), one year before completion of the Overland project[77].

Theodore Judah, a civil engineer, documented a potential rail alignment through the Sierra Nevada Mountains in 1860. He consequently formed the “Big Four” Construction, a group of Sacramento, California businessmen, to finance and construct the rail line (Theodore Judah). Eight years after approval of the central route, in 1862, the United States congress provided financing for the project. The construction of the Central Pacific Railroad Overland corridor began in January 1863, thirty years after the first commercially viable steam locomotives began operation. To help finance construction the Central Pacific Railroad subdivided and sold real estate on the Western edge of the Great Basin in what would become the city of Reno. During construction of the Overland route the project engineer maintained detailed quantities and seems to have had a project schedule. Prior to the rail bed the construction of predecessor subprojects was completed such as access roads, bridges, cuts, and fills. Later the project engineer related labor as the core problem he encountered, he did not mention planning nor coordination. The project engineer was pleased to have resolved the labor issue with immigrant Chinese labor (Lewis Metzler Clement). After five years of construction and a sixth year reconstructing Union Pacific[78] work[79] of a disputed quality, the rail lines were joined in 1869 (Pribonic, 2007), Figure 13 and Figure 14. At the completion of the construction ceremony, the Central Pacific president Leland Stanford[80] made a speech:

[77] Note the map’s incorrect location of the Nebraska – Kansas boarder at the 41st parallel north rather than the correct 40th parallel north established by the Kansas-Nebraska Act of 1854.

[78] The Union Pacific built the overland route heading west starting from the Mississippi railhead.

[79] The Central Pacific construction crews passed and built parallel to the Union Pacific lines with the plan to continue until they found what they could determine was track-bed of sufficient quality to tie into; after one year they were still looking.

[80] Leland Stanford is the founder of Leland Stanford Junior University.

"This line of rails, connecting the Atlantic and Pacific and affording to commerce a new transit, will prove, we trust, the speedy forerunner of increased facilities. The Pacific Railroad will, as soon as commerce shall begin fully to realize its advantages, demonstrate the necessity of rich improvements on railroading so as to render practicable the transportation of freights at much less rates than are possible under any system which has been thus far anywhere adopted.

The day is not far distant when three tracks will be found necessary to accommodate the commerce and travel which will seek a transit across this continent. Freight will then move only one way on each track, and at rates of speed that will answer the demands of cheapness and time. Cars and engines will be light or heavy, according to the speed required, and the weight to be transported.

In conclusion I will add that we hope to do, ultimately, what is now impossible on long lines transport coarse, heavy and cheap products for all distances at living rates to the trade. Now gentlemen, with your assistance we will proceed to lay the last tie and last rail and drive the last spike."

Leland Stanford, May 10, 1869 (Whitney, 1893)

Figure 13 On the left, Andrew J. Russell photographed "The meeting of the lines" (Golden spike). On the right, in the center of the crowd at Promontory Summit, Utah, Leland Stanford holds a silver maul in preparation to drive the last spike on May 10, 1869 (Hill, 1881), eleven months after placing rails through the future ReTRAC project site, and fifteen years before founding Stanford University in 1885. His son, the namesake of Leland Stanford Junior University will turn one in four days. Photograph from Pribonic, 2007.

Figure 14 The 18k (24k is pure gold) inscribed commemorative golden spike cast by the San Francisco firm Schulz, Fischer, and Mohrig (Johnson); currently displayed in the Stanford University[81] Cantor Arts Center.

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[81] Cantor Arts Center at the Stanford University museum.stanford.edu

The construction of a transportation corridor through this otherwise commercially infeasible pass provided for a concentration of commercial activity in that West Coast region. If not for this confluence, there would not be a San Francisco Bay Area, there would not be a Port of Oakland, there would not be a Stanford Leland Junior University, and there would not be Silicon Valley, the current technology hub of the world. Research on the west coast would be at the University of Los Angeles or the University of Washington in Seattle. The Bay Area would be rural and agricultural like the Monterey and Half-Moon Bay areas.

4.4 Issues with Urban Rail Corridor

In 2009, 140 years later, there are two rail lines in place and plans are still underway for coast-to-coast high-speed rail. The route taken by the Central Pacific has become a transportation corridor for both rail and highway commerce. Moving forward to the 20th century the towns and cities that grew along the rail line through California and into the inhospitable desert regions of Nevada and Utah, found themselves in conflict with freight trains carrying dangerous materials. By 1942, the United States Bureau of Public Roads recommended depressing below grade the rail line through downtown Reno. In 1996, the last of several studies addressing the Reno segment, listed six issues mitigated by a depressed corridor through the downtown core, these are: (1) hazardous spills, (2) pedestrian egress, (3) emergency vehicle egress, (4) public vehicle egress, (5) whistle noise, and (6) air quality (ReTRAC project history). An additional issue lay beneath the tracks. Over the course of 130 years of rail traffic and local industry, the ground had *hot-spots* of petroleum contamination. Possibly the contamination was from the locomotives and the cars they pulled, though no specific source was identified (memo appendix H, 2000).

4.5 Realignment of the Transportation Corridor

In response to the problems with the Overland corridor through Reno the decision was made and funding secured to realign. The purpose was to reprofile the rail under the city to mitigate the core danger that a large rail accident involving hazardous materials presented to the city. The trench will contain hazardous material in the event of a rail accident in the city core. The project was named the Reno Transportation Rail Access Corridor (ReTRAC). The ReTRAC project is a $180M (US2002) heavy construction project constructed between 2000 and 2007 in downtown Reno Nevada. The project site is a 3.5-mile original segment of the Overland Route, the first North American transcontinental railroad, also known as the *Pacific Railroad*[82].

Field engineers monitored the progress constructing both the original tracks and the realignment of those tracks. The previously mentioned contaminated soils are regulated by

[82] First North American Transcontinental Railroad http://en.wikipedia.org/wiki/First_Transcontinental_Railroad

government agencies. In addition to the quantities for project monitoring and replanning the contaminated soils were given their own account. A field engineer measured, recorded, and reported the volumes of contaminated soils excavated and how they were disposed.

The project is adjacent to an interstate highway alignment running east-west through the same transportation corridor as the rails and is adjacent a north-south highway that runs from the Los Angeles Harbor to Portland. The highway proximity provided good access to the site for haul trucks as well as delivery from adjacent metropolitan areas.

A large part of the project involves bulk earthwork and concrete that the project engineer had transported in haul trucks. Sourcing of these materials locally reduces applied resources allocated to haul. Local mines quarried and processed the cement, limestone, sand, and aggregate concrete components used to build the large retaining walls. The project estimators planned for the field engineers to stockpile the material excavated during the early project phases, process it on-site with a subcontractor, and short haul the graded material to the retaining walls for structural backfill.

A portable batch plant was located on site to provide a short haul of concrete to the project site. An issue arose in the summer heat due to the cement arriving hot from kiln processing. The delivery time from kiln to batch plant by rail was too fast and the fresh cement had not had time to cool. The hot cement then gained additional heat from the lime reaction with water – increasing the temperature and reducing the set time – the crews reported the concrete was flash setting. First, as a temporary solution, a crew of laborers manually feed ice blocks into the water tank that supplied the batch plant with water. Later, the construction manager added mechanical water chillers to the inlet water line.

The project engineer sourced additional concrete and earthwork material locally when project production outpaced the supply of the on-site facilities. Off-site hauls of earthwork material were from two facilities depending on the material type, each facility is 10 miles from the project site.

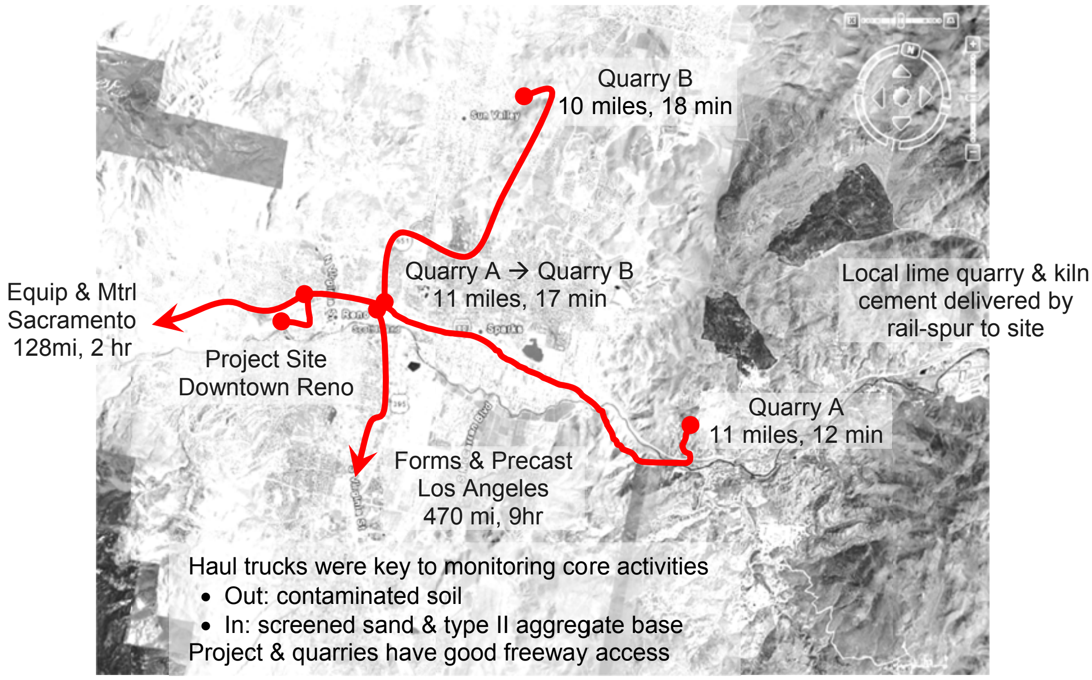

Figure 15 As an isolated metropolitan region there were good labor, equipment, and material resourced but also hard constraints: The bulk materials were available locally such as soil, aggregates, and cement. Cycle times dictated the bulk material balance for haul trucks and load-out equipment (CAT handbook). Material and equipment from outside the region required three days from request to actual use.

Local suppliers proved unable to supply the labor, material, and equipment quantity demand of the project at peak production. The field engineers sourced additional suppliers from the Sacramento Central Valley, a 2-hour 130-mile haul over the 7,000-foot mountain pass, or from the Los Angeles metropolitan region, a 9-hour 470-mile haul, long stretches of which are through the Mojave Desert. At peak production, 45,000 man-hours per month, the local labor supply could not meet the quantity demand; several laborers released the previous week for shirking work were dispatched back to the project in response to a request to the local labor union for their replacements. When asked, the union dispatcher responded that those were the only two people left in the hall.

With the exception of a couple engineers, the corporate regional office sourced the project's engineering and management staff from outside the region. Located three blocks from the project's east end is a university with both civil and mining engineering departments. I cannot determine if the use of staffing from outside the region was due to a tight local supply of construction professionals. The project was during the height of the housing boom. There were other large projects in the region under simultaneous construction. An online search for other large civil projects in the Reno basin found (1) the US-395 highway-widening project nicknamed the *Spaghetti bowl*, (2) a series of bridges constructed as part of the I-580 highway realignment project, and (3) a couple other midsized projects with a sum in scope equal to the ReTRAC project (NDOT news). It could have been the engineer resources in Reno were unable to meet the quantity demand at that time. Potentially it was a company policy to fill these slots from outside the project region to prevent conflicts of interest; evidenced by the lack of non-construction professionals hired locally – assuming that heavy construction is not a specialized profession.

Figure 16 On the left, the people of Reno Nevada turn out for the first train[83] (Reno ReTRAC). On the right, the first train passes through the rail access trench November 18th 2005, 3 years after construction began and 10 years after planning began; vertically altering the original rail alignment 137 years after it was first placed (Reno ReTRAC)[84].

4.6 Summary

I will describe the methods used to monitor contaminated soil excavation and other operations in the following three sections. These methods were likely developed on the first large projects and continued with successive generations through iconic projects such as Hoover Dam and across the projects construction format with facilities such as the Kaiser Steel ship production at Mare Island shipyard.

I will search for these methods through four separate approaches. First, a literature review synthesizes the existing knowledge that was a potential guide for the project engineers, then a survey of industry practitioners, and interviews with several engineers with direct influence on the methods used on the project, and last the ethnographic observations made through direct participation as a field engineer on the project.

[83] Reno Nevada ReTRAC project website, last accessed 2011. http://www.reno.gov/index.aspx?page=353
[84] Reno Nevada ReTRAC project website, last accessed 2011. http://www.reno.gov/Index.aspx?page=388

5 Observations

To present a holistic understanding of the problem, in this chapter I review reference and scientific literature, conduct follow-up surveys, and document my field observations. Initially I had planned to only review the literature as a means to cross-reference my ethnographic field experiences. During that process it became clear there were large gaps in the literature and what was there was not well validated – some seemed wrong. I had to expand the literature survey with surveys of industry practitioners. Between the literature survey, surveys of practitioners, and my ethnographic experience, I believe I have given a comprehensive presentation of the current state of heavy construction project monitoring.

5.1 Literature Survey

5.1.1 Methodology

The following sections offer a review and synthesis of publications with respect to quantities collection in construction. I reviewed 300 English language sources, of these 29 were relevant to quantities. To place quantities in construction in relation with the broader domain of project-based industries, I also reviewed a reference text from the industrial engineering field. In this section, I will introduce the topic sections, disclose gaps in my review, show my confidence in the review, and discuss limitations.

The review process was like seeking gold in the modern day Klondike. Just when a miner figures out, based on theory, where the gold must lie geographically and sinks a test borehole, they find a tunnel cavity left by a 19th century Klondike miner that also figured it out. Similarly, discoveries I made in ethnographic observation I then found published in literature.

I divided the literature review into three sections: reference sources, research sources, and internal company guidelines. The reference material presents status-quo monitoring methods: conservative practices peer reviewed by committee and suitable for reference in contractual agreements. The research sources then provide an idea of where the reference books will eventually be. In-turn the peer reviewed research publications provide confidence in the reference texts – I can see the logic behind what are often universally accepted but unchallenged pragmatics. Internal guidelines hold the heaviest weight, they are accepted practices – unlike reference guidelines and academic theory that may or may not have adherents.

Unfortunately, I failed to capture internal guidelines: the problem, internal guidelines are not publicly available. I did not find a single company with documented guidelines. My sample was small, a half-dozen heavy construction companies. The knowledge appears tacit and passed between practitioners through a learning-by-doing format. To fill this gap left by the missing guidelines, there are several sections after this literature review where I will present my ethnographic experience, interviews, and surveys that gather the tacit practices.

After reviewing reference publications, I will review research publications. Three of the researchers focus on sensor-based quantities collection. They included monitoring methods as a baseline to show process improvement provided by automation. Interestingly, these explain quantities collection in more detail than the reference texts. While the reference books seem to have large gaps – I will show in the subsequent sections that many of these gaps can be closed.

I use the confidence interval to test my literature review for completion. In Appendix D: Literature Not Reviewed is a table presenting a further 20 publications I reviewed but only in summary. I reviewed 29 sources in-depth, the authors each reviewed two or three sources. For example, the APM (2002) (p404) references ANSI/EIA-748 and though not part of my literature review, Humphrey's (2002) context is captured in the Senior Cost Engineer interview (p175). Therefore, the 29 sources could represent a broader 90 sources, see Figure 17. Compounding the review implies I actually captured 60 to 90 individual sources. Towards the end of my review, I stopped finding new knowledge and so I believe this review is completed to saturation and further researching is not likely to turn up more.

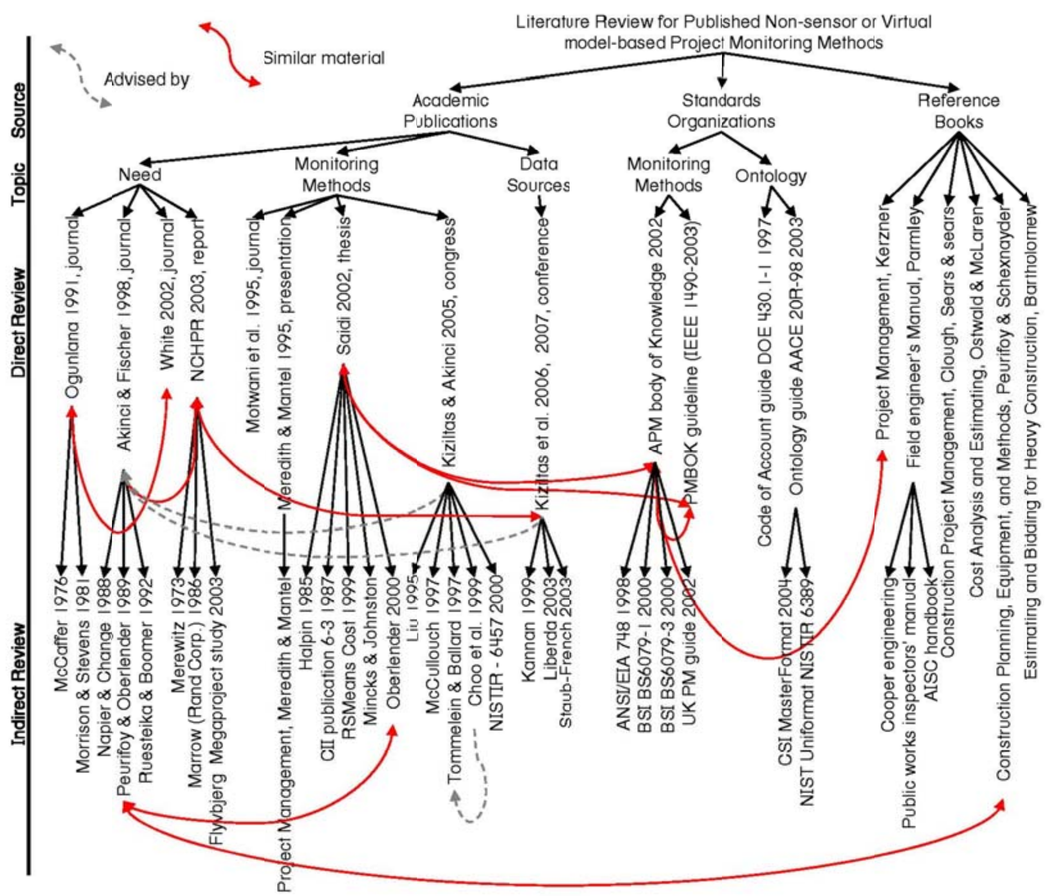

Figure 17 Summary illustration of literature review. The direct review sample n=29 and indirect review sample n=34 represents 63 publications spanning the last 40 years.

My literature review methodology introduces a limitation: because my search is based on publications; while quicker, I do not capture single document dissertations or theses. Throughout the literature review I add explanations based on my ethnographic experiences to clarify meaning or in some cases to fill-in gaps in the literature with my commentary. My intention is only to provide enough content to clarify the point, not to address the topic. Later in the ethnographic observations section I will go in to more detail on each of the points I raise in the literature review as well as other points that are missed entirely by the literature. Following this methodology, I will now present the reference literature followed by the academic literature.

5.1.2 Reference Literature

5.1.2.1 Introduction

In this section, I introduce the concepts *quantity* and *account*. I split these and cover each as a separate topic. Each has a verb, *'to quantify'* and *'to code'* respectively, Table 12. Because this thesis has already introduced the purpose of quantities (see Quantities Purpose p27), in this review I skip the theoretical *quantity* and go straight to the quantification topic with the section 'to quantify' (p94). After I review the quantification literature, I then review both the *'account'* and *'to code'* literature together in the next section titled "Chart of Account and 'to code' " (p114). The *account* and the act of *coding* the *account* to a *quantity* requires not just quality quantification but also quality coding. The consistent use or *coding* (there is not an established word for '*use*') of each account is important. How to achieve consistency is not explained in any of the texts. The quantity and the account as well as an effort expended on the quantification and coding are core to detailed project planning.

Table 12 The *quantity* and *account* are inseparable in use. The simplest form of account is the unit of measure. In practice, the account provides numerous *features* of context. Every quantity must have an account and every account must have a quantity.

Quantity	***Quantification*** **Performance & Quality**	Account	***'to code'*** **Performance & Quality**
noun	*verb*	*noun*	*verb*
Bill of Material[85]		Chart of Account	
Material_1		Account_1_uom	
Material_2		Account_2_uom	
Material_3		Account_3_uom	

To set the platform for the quality of quantities, let us return to the beginnings. In 1458, the Italian Benedetto Cotrugli introduced the concept of double entry accounting. The double entry provides the opportunity to catch an error: as a check, the sum of each duplicate series of entries must match. For the context of Benedetto's timeframe in the 1450s: the Inca are building Machu Picchu, Mr. Gutenberg has just introduced the printing press, and the construction had begun on elaborate religious buildings that certainly required a high degree of quantities. Vitruvi wrote the earliest text on construction 1,400 years earlier. In Book X, Vitruvi gives the accuracy he expects of a construction baseline forecast as +/- 25%. For example, if a project is baseline forecast to cost $1M, take 10 months, and require 100,000 CY of earthwork – then Vitruvi would expect an actual cost between $0.75M and $1.25M, 7.5 to 12.5 months, and between 75,000 and 125,000 CY of earthwork. Even today +/- 25% is within the range of

[85] Bill of Material is an example of quantities, these could also be permanent, temporary, removed, and modified materials, see Figure 30 p5—192.

baseline forecast accuracy. Vitruvi's expectation for baseline cost forecasting is evidence there was construction specific accounting and project forecasting practices at least as far back as Vitruvi's time.

The simplest form of double entry accounting is the *T-account* (Ostwald & McLaren, Ch 4.1, 2004). At its core, quantities are about accounting. In accounting, the quantity is the dollar amount, but the quantity concept just as easily expands to include quantities of all types regardless of the unit of measure, and the account description provides the features of the quantity. From Vitruvi and Cotrugli's times to the start of my own career in construction: a span of 2,000 years, the methods of project planning and monitoring have changed very little – if at all. If I walked into their workshop or they into mine, we would instantly recognize each other's plan sheets, schedules, quantity takeoff sheets, and cost estimates[86].

A core tie-in between the case problem I use in this thesis, my ethnographic experience, and this literature review, is an estimating text by Stewart Bartholomew (2000): This text connects back to the Problem Case: Design-Build Rail Corridor Project (p77). That later forms the setting for my

[86] The innovations in computerized project planning have changed a lot and Vitruvi would not immediately recognize a BIM model.

Ethnographic Field Observations (p196). The large drainage canal used by Bartholomew as a case project (Ch 4, 2000) is essentially the Transportation Rail Access Corridor project (ReTRAC). The methods in the text relate easily with the observed project and ties together the other reference texts that are less clearly related. This text and the others like it that come from a field context, tie-in the pragmatic field practices into this review.

A second tie-in, this time academic in nature, is the industrial engineering text. Industrial engineering is the closest field to construction engineering, therefore many terms and concepts are similar. The formal field of construction engineering and management (CEM) was started 60 years ago with John Fondahl and Clarkson Oglesby founding a CEM program at Stanford University in 1955 (News Release, 2008). Throughout the growth of the CEM field, researchers have been borrowing from industrial engineering (Levitt, 2007). The industrial engineering text provides a precise presentation of concepts and terms still used by field engineers (Ostwald & McLaren, Ch 4.10, 2004). The meanings of some concepts have drifted, changed terms, no longer have specific terms, or have taken on an entirely different meaning. For examples: The accounting term *standard cost* is defined as what the dollar amount should be, known in construction as the *estimate*. For project monitoring, field engineers measure *variance,* or the deviation from the average. As an extension, industrial engineers use *quantity variance* to measure the change in units that were required to produce the product. Field engineers do not use the term *quantity variance*. Logically, the *quantity variance* concept appears in construction with differing terms such as re-work, scrap, over-excavation, and waste. Later, I do find the term *quantity variance* during the Stallard interview (p175) where he describes the concept of quantity yield in contractually billable and unbillable quantities - he is the only source throughout the review that used this term. The texts that - while construction specific - use the industrial engineering field as a departure platform, tie-in a more academic style.

With these literature tie-ins to pragmatics and theory this literature review should pull a complete understanding of quantities as it is published. If there are gaps in this literature then it is gaps in documented practice and gaps in theoretical understanding. I expect the pragmatic gaps bridged through theory and vice-versa the theoretical gaps filled with pragmatics.

5.1.2.2 'to quantify'

Under the action 'to quantify': First, I will present the three performance factors that form a quality quantity measurement. Second, I will present latency and then the delivery methods for quantification. The third, fourth, and fifth sections will discuss sources of quantities, who measures the quantities, and communication paths from field to planner; use Figure 18 as a reading guide.

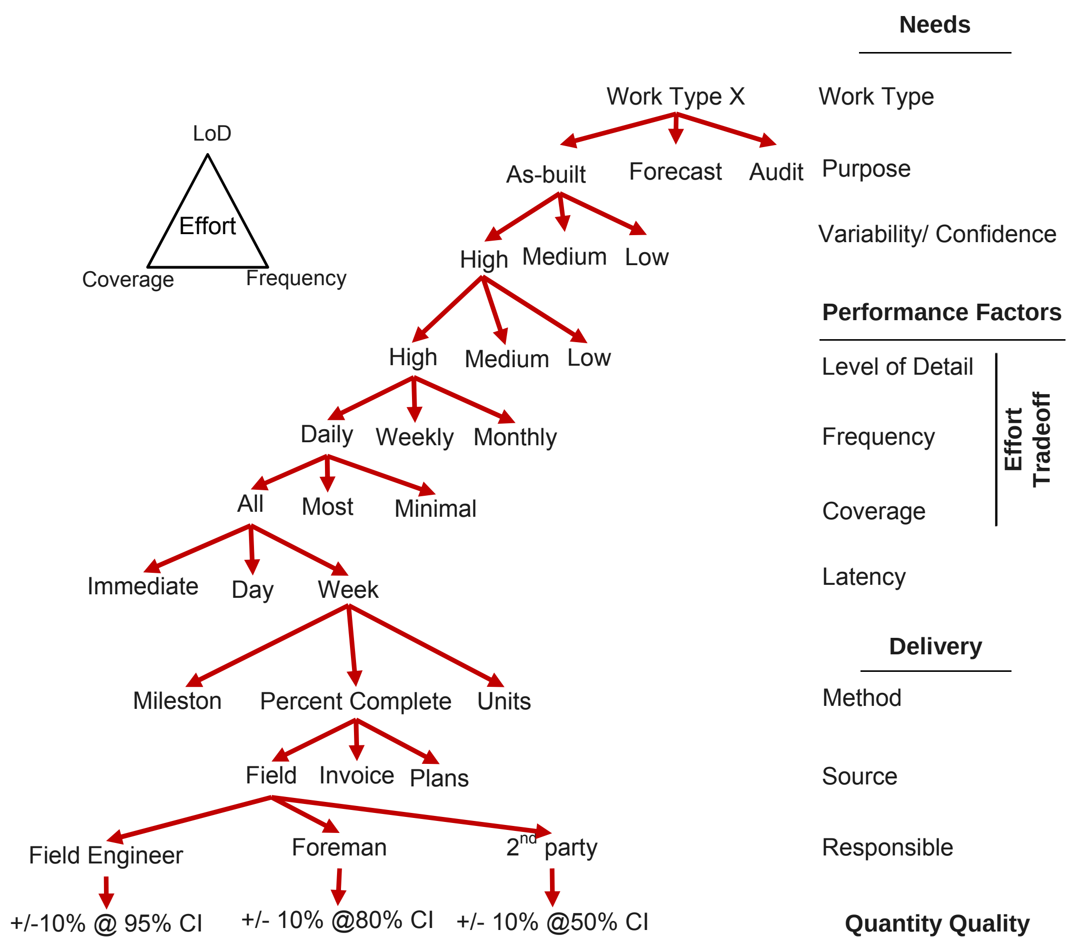

Figure 18 The "Quantity Measurement Performance" tuple Needs-Factors-Delivery=Quality. There is a tradeoff between the performance factors - the same quality of quantities can be achieved with different balancings. The weighting for each factor towards the overall quality of the resulting quantification is not known. The order of the features varies based on the specific feature set.

5.1.2.2.1 Performance factors

The performance factors are the aspects of the quantification process that are adjustable to achieve the quality necessary for the purpose of the quantity. The factors are frequency, level of detail, completeness', and latency. Because both CPM (2000) and PMBOK (2008) address the effort specifically and the other texts at least address the effort implicitly, the concerns with the payoff for effort exerted do not appear to be an idle concern. None of the texts explicitly state it, but there is a tradeoff between level of detail, frequency, and completeness that results in the same quality of quantities. The limiting factor in quality is the effort exerted towards gaining the quality – at some point the return on the investment turns negative and achieving a higher quality cannot be justified.

5.1.2.2.1.1 Limiting Constraints: Return on Investment

A core limitation of project monitoring is the quality of the measured quantities (CPM, 2000). Quality of quantities is defined by the accuracy and precision. The PMBOK (2008) does not give a target. The CPM text provides a numerical value: the authors advise that measurements must be made conscientiously and with accuracy within +/-10% (CPM, 2000). The APM text mentions a practical level – so there is also an impractical level of quantification (2002). The optimal balance between needs for quality and the effort is a tradeoff between Level of Detail, Completeness, and Frequency, see Equation 1. For example, a quantities plan with a high level of detail, sporadic account coverage, and high measurement frequency could provide quantities with an equivalent quality as a quantities plan with low level of detail, coverage of all accounts, and low measurement frequency. The field engineers must consider the balance between the costs of resources exerted in monitoring and the benefit the monitoring provides – the classic "return on investment" (ROI) (CPM, 2000).

Equation 1 The quantity quality factors are level of detail, completeness, and frequency. These factors have a relation but the significances are unknown. This equation shows the relationship with *A,B, and C* representing the significance of each factor.

$$\text{Quantity Quality} = A(\text{level-of-detail}) + B(\text{completeness}) + C(\text{frequency})$$

5.1.2.2.1.2 Frequency

In the simplest sense, the frequency of quantities measurements is at regular intervals and reported on a *cutoff date* (CPM, CH9, 2000) – addressed further as part of the latency discussion. After that, there are considerations to improve the quality or reduce the effort required. A consideration is correlating the intervals between time and cost reporting so to leverage the measurements for both purposes (CPM, 2000). Pragmatically, Clough, Sears, and Sears saw the progress reporting frequency based on the perceived time control rather than accuracy (CPM, 2000). Stevens relays the quantities interval as a weekly event (Stevens, Titus, & Sanford, 2002).

For the most part, the details of the reporting period interval are for the reader to discover empirically through trial and error. Reporting frequency is a frustrating omission from the texts. Existing theory does not allow a formulaic response, therefore requiring an artistic judgment from experience and intuition.

In Clough, Sears, and Sears they introduce the concept of a *cutoff date* (CPM, Ch9, 2000): they do not define the concept. From my ethnography, I can explain that the frequency usually represents the time for a reporting period. Though measurements can, and may need to be made more frequently. The cutoff date is the end of the reporting period and the beginning of the next. In the Level of Detail section, towards the end of the discussion I will tie-in the level of detail with the reporting period and that to the frequency of measurements.

5.1.2.2.1.3 Level of detail

The APM (2002) advises to "collect costs at or below the work package level: at a level to identify sources of variance." What specifically the work package level defines is not clear – I assume this is some sort of subcontracting chunk of work. The APM (2002) goes further and uses the return on investment as the limitation – they advise using a monitoring method that allows making the measurement at the lowest practical level of the feature breakdown structure.

The PMBOK provides the integration level of detail and called this the *Organizational Procedure Links* (PMBOK Guide, Ch7, 2008). This is the level for integration with subcontractors as well as the accounting system. Presumably, the measurement should be at this level or lower. Unfortunately the PMBOK does not precisely explain what level their estimating, budgeting, and control accounts are. I consider all three of these forecasting: Estimating is the pre-project forecast and includes all the bidding games, making it somewhat unreliable. The budget is the baseline forecast that removes the estimate games and is useable. The control is the forecast completed regularly during the project to find variance from plan and to replan around these both beneficial and detrimental but still unforeseen issues. Traditionally, each is at both increasing detail and an increasingly shorter reporting interval.

The duration of the lookahead forecast more-or-less correlates with the level of detail. For example, most baseline plans are at a system level of detail and the weekly plan is at the crew-level resource. Kerzner suggested durations for determining the application of methods (2009); I found no discussion on how he derived these or his source. Presumably, the duration is Kerzner's indirect nod to level of detail. This nod to level of detail is also a tie-in with the frequency, since each lookahead is a repeating cycle. For example, the five-week lookahead is reforecast and replanned every five weeks. Preceding the lookahead, the quantities must be reported.

Each estimating method correlates with the historical library level-of-detail and defines the minimum level of detail (p255); see Table 13 and Figure 19. To forecast at that level, the measurements must be made at a comparable level. If not, then the output level-of-detail must be achievable through post-processing. For example, if I use percentage of time complete, that does not leave much room for inferring a greater level of detail. Maybe I can distribute the percentage complete across all the components in the project and assume they are all equally complete. As the counter example: If I carefully measure the tons of material hauled to the construction site and I know the density of the material. With tons and density I can calculate the volume – it will not be exact but I have confidence it will be close. With that confidence, I can use the calculated volume for my quantity measurement. With confidence in the conversion from tons to volume, I would probably reuse the volume to infer the progress on related tasks.

Table 13 The estimating method levels of detail are comparable to the monitoring method levels of detail.

			Est & Bid for Heavy Const.[87]	Cost Analysis & Estimating for Engineering & Management		Project Management Body of Knowledge	
		Estimate Purpose	Estimate Types				
Level-of-Detail (confidence)	Owner	Conceptual		<u>Universal Methods</u> -opinion -conference -comparison -unit		<u>Analogous</u> compare previous projects	<u>Expert Judgment</u> mix of methods & levels of detail
	Owner	Alternatives_O	<u>Unit price</u>	<u>Project Methods</u> -power CER -other CER -factor	<u>Adv. Approach</u> -expected value -range (PERT) -percentile -Monte Carlo	<u>Parametric</u> statistical relationship	
		Bid					
	Contractor	Alternatives_C	<u>Labor-hour</u> crew & equipment work-item analysis	<u>Operation Methods</u> -cost & time relationship (CER/TER) -performance time algorithm	<u>Product Method</u> learning CER method		
	Contractor	Change				<u>Bottom-up</u> greatest level of detail	
	Contractor	Breach of contract					
				<u>Accounting</u> If cost is known then not estimating, it is then an accounting procedure			

The highest level of detail in estimating and monitoring is the project type. For example, excavations have an average duration *t* to build. Therefore, at duration *t* the contractor assumes the excavation is finished, progresses the schedule to finished, presents the owner a payment request, and mobilizes their resources for the next project. The lowest level of detail in estimating and monitoring is the bottom-up method. Using the same example of an excavation, the contractor monitors by both a truckload count and a survey - for example laser

[87] Estimating and Bidding for Heavy Construction (Bartholomew, Ch 1,2000) .

scanner - of the excavation. The schedule is progressed in relation to the quantity percentage of completion compared to the expected total quantity. When the quantity installed equals the quantity expected, then the contractor assumes the excavation is finished, progresses the schedule to finished, presents the owner a payment request, and again mobilizes their resources for the next project (Bartholomew, 2000).

The consensus is to make the quantification at an overly detailed level and then aggregate to the level needed for that planning cycle.

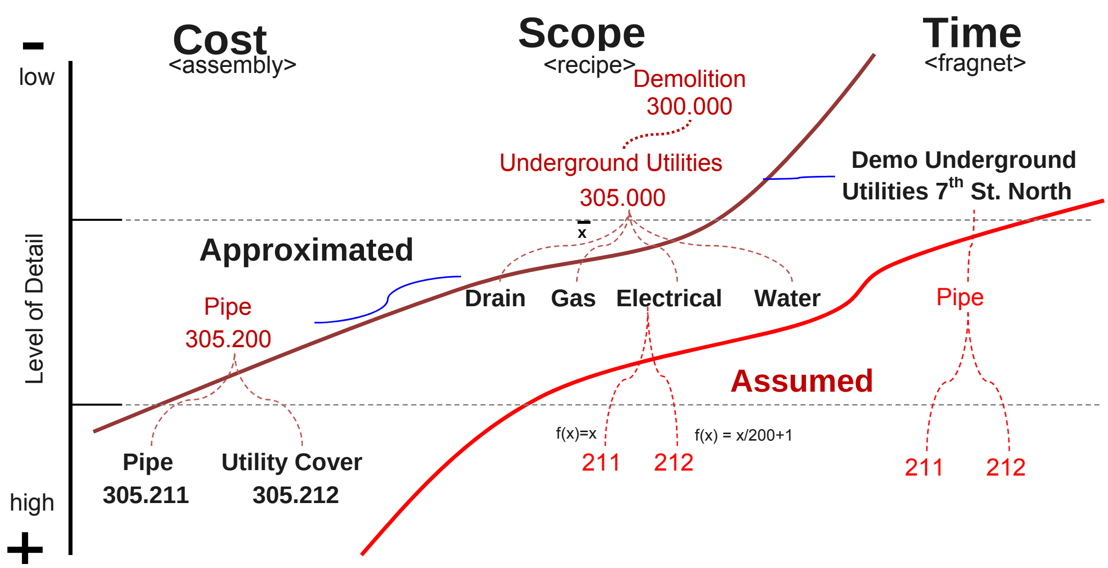

Figure 19 Measure progress at the lowest practical level (APM, 2002); at the minimum collect cost below the work package level. The dashed lines are implied structure that is usually not explicitly represented in the integrated scope-schedule-cost model. The field engineers often relate these in a formulaic way using different terms for the formulas depending on the planning silo. Adapted from Staub & Fischer, 1999, figure 4 as well as Aalami, Levitt, & Fischer, 1998; Fischer, Aalami, & Akbas, 1998. The nomenclature is from a large western united states heavy civil contractor.

5.1.2.2.1.4 Completeness

None of the reference publications address the completeness of quantities. The question is if the quantity for every account must be measured. Unfortunately, the reference texts are silent on this performance aspect. Later, in the methods section, I find an implicit argument for measuring only 20% of the project activities aspect of the 80/20 legend (see page 106).

5.1.2.2.1.5 Latency

The CPM mentions time lag in reporting project production (CPM, chapter 10.6, 2000). The text does not discuss the time lag in detail, only the mention of a tradeoff between level-of-detail and latency in reporting.

Based on ethnographic experience I will explain more fully later (see

Figure 52): The concept of a *cutoff date* is given by CPM (Ch9, 2000), though they do not define the concept. A cutoff date is the reporting date for the slice of time represented for a progress update. At the cutoff date the progress to date should be correct as well as the progress for the reporting period. The cutoff date is important to define the end of the reporting period so that progress from the next period is not included. In the latency of the measurement, the cutoff date is an important consideration since the measurements may be made sometime after the cutoff and backtracked to the assumed progress at the cutoff.

The longer it takes to obtain the quantity then the less contribution these quantities will have on the current reforecasting cycle. In the worst case the latency is such that some bundles of methods and sources are precluded from use on short cycle planning. I have a question about if latency should be considered a performance factor or if it is a delivery method – it is on the border between the two.

5.1.2.2.2 Delivery

In this section I will review the delivery options. As a bundle the four features given here have a performance measure based on the performance factors. For example, a bundle of method, source, responsible entitiy, and communication method with provide a distinct performance as measured by the four performance factors. The delivery features are: methods of collecting quantities, the sources of quantities, who is responsible to enact the measurements, and how the quantities are communicated from the field back to the planner. It looks like any of the methods can be used with the performance controlled by adjusting these factors to gain the optimal balance between what is available, what is convenient, and what is practical.

5.1.2.2.2.1 Methods

Monitoring and estimating share aspects in deriving a numerical value. The universal methods given by Ostwald (2004) and the PMBOK (2008):

- *personal opinion* approaches such as *guesstimating* or *expert opinion* – these methods are a combination of all methods, p249 and page 254
- *conference* approach – non-qualitative and only given by Ostwald
- *similar product* comparison approach an *analogous* approach
- *units* approach, qualitative using the *bottom-up* approach
- *parametric approach* - only given by the PMBOK, Table 75

Similar methods are used to estimate quantities – the quantification methods parallel the estimating approaches used for bidding projects. In this way some quantity estimating methods simply follow the same approach as a bid quantity estimate. Essentially an estimate approach is an estimate approach, regardless of the purpose. Which method to use in what situation is an open question. The CPM (2000) simply raises the awareness this is a question to consider, see Figure 20. Each project is a new design and has site specific constraints. Based on design and constraints the labor-equipment-material requirement will change. Each will have a differing production, cost, and specifics for quality. These resources and performance features (or combination) most likely controls which method to use. I do not know the significance or relationship of these features other than pragmatically if cost, time, or quality (in that order) is not controlling then convenience is.

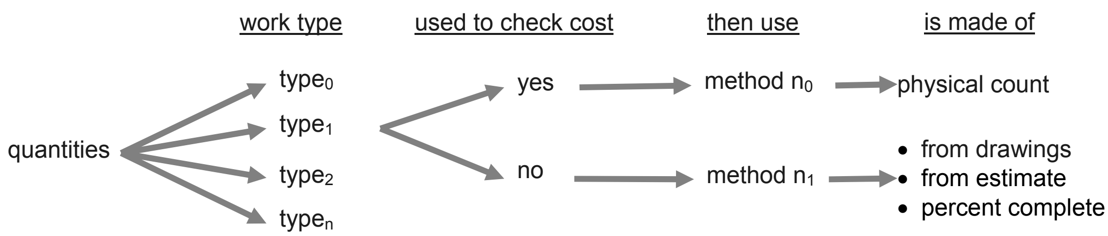

Figure 20 “How a contractor expresses activity completion,” (p236) is dependent on the activity type and if the completion measurements are used to check cost (Construction Project Management, 2000). Are the methods singular or plural, for example method n_1 in this example is actually a bundle of applicable methods that field engineers could use individually or in combination.

For schedule status updates, similar metrics are given by APM (Ch6.4.1 p32, 2002) as the PMBOK actual start / finish dates. Again, like the PMI PMBOK, the instructions do not include how to estimate the time remaining to complete; the *APM Body of Knowledge* gives additional references, Table 80 (APM, 2002). At the PMBOK level of detail, the processes to update the schedule are both implicit and explicit (PMBOK Guide, 2008). To update the schedule, three metrics are measured; these are start date (if progress > 0), progress, and finish date (1/0) (PMBOK Guide, 2008). Like the PMBOK, Stevens does not provide an elaboration of what progress is, for example, either unit-less percentage or unit quantities (Stevens, Titus, & Sanford, 2002).

In the following sub-sections I provide the known methods for measuring progress, use Table 14 as a reading guide.

Table 14 Synthesis of quantification methods published in reference texts.

	Reference								
Methods	Parmley	Bartholomew	Ostwald	CPM	Peurifoy	Stevens	PMBOK	Kerzner	APM
start / finish date							X	X	
percent complete:							X		X
-percent of time				X					
-percent of material				X					
-percent of cost								X	
-percent of component (visual)									
milestones							X	X	X
units complete:									
-count units (inputs)				X					
-field measure (outputs)				X					
fixed-formula							X		
plans:									
-scale from plans				X					
-use bid quantity				X					
opinion | guess			X						
Conference			X						
equivalent units								X	X
level of effort								X	X
network distribution				X				X	
apportioned effort[88]								X	X

5.1.2.2.2.1.1 a-priori

None of the texts explicitly give the a-priori method though it appears implicit in several of the methods. The method a-priori is the use of the project plans as a basis of measured quantities to assume reality proceeded as expected. The percentage of time and the network diagram methods of quantification rely on an a-priori approach. The formulaic approaches that use a relationship with another account, such as apportioned effort method likely are a-priori.

The core of the PMI PMBOK Earned Value Management approach (EVM) is based on the *Project Scope Management*; this is the process of monitoring project status based on a pre-defined project plan of “how requirement activities will be planned, tracked, and reported” (PMBOK Guide, Ch 5.5, 2008). This is the *a-priori* approach to project management. To have an affective a-priori approach then the project progress must adhere to a plan. Any deviation from the plan requires accelerating or decelerating to match the planned progress. The cost control is dependent on the schedule for start and finish dates (PMBOK Guide, 2008).

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[88] The apportioned effort method appears similar to the recipe formula assemblies concept.

5.1.2.2.2.1.2 Analogous

Analogous estimating is done through a comparison with the total quantity found (in traditional estimating this is the cost) in a previous activity (PMBOK Guide, 2008). For example, the last reprofile of a rail transportation corridor cost $70M per mile. If the next corridor reprofile is five miles, then it should cost $350M. In the same way – though the PMBOK does not suggest this – the quantities can be approximated based on an earlier project or phase of the current project. For example, the last rail corridor reprofile required 150,000 cubic yards (CY) of fill material – that is 50,000 CY per mile. For a five-mile reprofile, it should need 250,000 CY of fill material. Notice the inherent inaccuracy, a three-mile reprofile has nearly a mile of approach grade on each side – there is only a true mile of full trench cross-section. A five-mile corridor will have three-miles of full cross-section. The approach grades require half the material of the full section. In reality, the one-mile approaches each needed 35,000 CY and the one-mile full-section needed 75,000 CY. Using a more advanced analogous equation, I assume (length-1 * cross section volume) so length-1 * 75,000CY: the estimate for the five mile example should be 4*75,000 = 300,000 CY. My initial estimate based on a straight line relation is short 50,000 CY out of 300,000 CY (15%). For an owners conceptual or alternatives estimate +/-15% is within reason. A +/-15% error is close enough given the large number of additional factors that will affect the actual volume. For a lookahead forecast 10% is the difference between 10 days and somewhere between 9 and 11 days – close to the best time estimates today. On the ReTRAC project the field engineers were not able to gain a consensus for the baseline estimate nor the as-built measurement of the backfill volume within 15%.

5.1.2.2.2.1.3 Conference

A method given by Professor Ostwald (2004) in the non-construction Cost Analysis and Estimating for Engineering and Management is the conference method. This method is described as nonqualitative: no other description is provided. From the descriptive term, I assume the conference approach is what Stevens used at the Rocky Flats project where they held a meeting to defend the quantities: they are defending before a conference. This approach is probably an amalgamation of expert judgements in a review of quantities derived using all the methods of quantification.

5.1.2.2.2.1.4 Actual units

The actual units approach to quantities is comparable to the bottom-up estimating method: the quantity (PMBOK envisions a cost estimate) is estimated using the greatest level of detail available (PMBOK Guide, 2008). All the texts gave this approach implicitly, but none actually defined it. Actual units is the approach that is not based on estimating the quantity, it involves making every attempt to measure the actual quantity with the greatest accuracy available. Usually this involves field measurements by a field engineer using either the available measurement tools or specially purchased equipment. For example, a truck scale may be purchased by the project to weigh each haul load rather than count truck loads and assume a load capacity.

5.1.2.2.2.1.5 Expert Judgement

Expert judgment is a mix of all the methods given here and applied in a varying mix based on an artist's understanding of quantities. There is no theoretical basis for this approach that allows a formulaic approach. This method cannot be taught through a textbook and requires learning-by-doing and learning through informal apprenticeship.

None of the texts provided exert judgement to achieve a scaling of quantification quality with the time interval of progress forecasting. At the weekly level, quick quantities are necessary to allow for weekly updates to the forecast. At the monthly or quarterly level a reconciliation is needed for a longer forecast, and so a more accurate tally of the quantities is needed. Last at the completion of a task, the as-built quantity is obtained at the highest quality practical and this becomes the historical record used for forecasting on future activities.

5.1.2.2.2.1.6 Equivalent Units

The equivalent units method converts partially completed units into an equivalent number of completed units: only Kerzner (2009) provides this method. The APM gives an approach they call equivalent units that they describe as dividing *units to date* by *total units* (APM, 2002): this seems like a percentage of completion based on units. For clarity, I am duplicating the APM equivalent units approach in the percent complete section as a percent by material quantity. For example, the Kerzner approach for measuring the quantity complete on six generating units that are each a third complete is to sum the ratio of completion for all six units (6 * 1/3 = 2): the measurement or completed units is two units. The APM method would report (6 * 1/3) / 6 for 33% complete – if the unit of measure for reporting is in units completed rather than percent – then the 33% is multiplied by 6 for 2 units. The end answer is the same but the process is different.

5.1.2.2.2.1.7 Percent Complete

The PMBOK Guide (2008), APM (2002), Kerzner (2009), and the CPM (2000) mention the percent complete approach. The CPM authors instruct that for *activities in progress*, report the degree of completion (CPM, Ch9, 2000). Generically, some texts do not define what exactly the percentage of completion is – presumably this is a guesstimate based on intuition or a visual 'look.'

Following all the permutations of percentage complete with applied resources, results in the following three methods:

- Percent complete by expected material quantity
- Percent complete by expected time quantity (also sub-method of level of effort)
- Percent complete by expected cost quantity

The APM provides a sub-method they call equivalent units that is a percentage completion of expected material quantities.

Kerzner (p656, 2009) and the APM guide (2002) provide a sub-method calculated as percentage of budget (cost quantity): intended for activities longer than 3 months (Kerzner, 2009). The APM guide instructs that the percentage of cost should only be used if no other measurement is available. They give a good description of the process: add the actual cost to an estimate of outstanding commitments and report the sum, Table 15 (APM, 2002). I have not observed the time-cost method - it may exist only in theory: a plausible use of the time-cost metric (sum of cost report) is as a measure of project progress on a monthly basis.

Table 15 If no measurement is available – the last option that is always available is the percentage of estimated cost. If a quantity is needed in a unit of measure other than percentage then report the product of the cost percentage and the expected quantities.

$$\frac{\text{Actual Cost}}{\text{Actual Cost + Estimated Remaining Cost}} = \text{Percent Complete}$$

Kerzner advises, without explanation, that when using the percent complete by cost, calculate the percent cost quantity (dollars/currency) complete in 10% intervals (2009). A variation of the percent complete by cost quantity that looks like a hybrid with the milestone method is the 50/50 rule. Under the 50/50 rule, *book* 50% of budget at the start date and 50% at the completion date. This method eliminates continuously determining percent complete (Kerzner, 2009).

In the Project Management 10th edition Kerzner provides the percent complete by time sub-method, this is based on the task duration and this is the method observed used most often (2009). This method is a comparison of the ratio of time expended to the total time expected based on a resource loaded schedule (Kerzner, 2009). A limitation for estimating percentage of completion (PC) based on time is the assumed straight-line linear relation between time and work completed. The linear assumption may not be true (CPM, 2000). The percentage of expected time based on a schedule is how the EVM method monitors the project status (PMBOK Guide, Ch6, 2008). Therefore, the schedule is the core driver of the EVM method.

The CPM authors Clough, Sears, and Sears give two equations to assist with calculating degree of completion, see Equation 2 (CPM, Ch9, 2000). The method to measure the inputs to these equations - percentage of completion and work units put in place - is described as dependent on the type of activity and if the measurements are also used to check field costs and is not discussed further, Figure 20. I do not think these equations are necessary. The difference between a guessed percent complete and the calculated percent of total units based on measured completed units to date, does not justify two distinct equations. In the 'Vitruvi' style, it is to the reader to understand that the author has shown them to be aware, but the author cannot explain it: fair enough, that is a start.

Equation 2 Calculate days to completion - there is no discussion of how the inputs are measured. The quantity takeoff (QTO) usually comes from a dimensional model (*Construction Project Management).* The author appears to assume a fixed completion date.

Formula		Inputs	Input source
days to completion = d(1 - PC/100)	*d*	= contract duration in working days	Contract
by generic: PC = P	P	= estimated percentage of completion	Method (tbd)
by work: PC = W/T	W	= measured work units in place	Field measurement
	T	= total work expected	QTO or estimated

5.1.2.2.2.1.8 Network Distribution

Both the CPM (2000) and Kerzner (2009) texts have a network distribution type method. It is not well explained but seems to rely on the network logic to infer that tasks are completed. For example, if the crews have finished placing concrete, then the formwork must be completed. That is a straightforward example. This network approach assumes that if there is a finish to start relation between the concrete and the asphalt on the next street over, then assume the asphalt is completed. The method places a large amount of trust in adherence to the schedule network logic (CPM, 2000).

5.1.2.2.2.1.9 Apportioned Effort

Apportioned effort is used when there is no product to measure but is easily associated with an activity. For example, quality inspection has no product but is reliant on the activity being inspected. This method was only given by the APM (2002). Because the quantity is measured in proportion to another measured effort: this seems similar to the *recipe formula* method.

5.1.2.2.2.1.10 Level of Effort

Level of effort is used when there is no product to measure, such as project oversight. Instead the quantity is based on passage of another resource. In the case of overhead cost then measured in applied resources[89] consumed over a given time period (Kerzner, 2009; APM, 2002) such as labor hours or cash. Often the resource is simply the passage of time: essentially, this method pragmatically applies a percentage of completion based on time.

5.1.2.2.2.1.11 Formula

The PMBOK introduces the concept of recipe-formula (fixed formula) equations, these are a parametric relationship, but the PMBOK does not provide examples or guidelines for developing the formulas (PMBOK Guide, Ch7, 2008). The accounting text allows for formulas in the case of missing or corrupted measurements, they acknowledge that sometimes the quantity must be calculated from known quantities (Auditing, p247, 1912). Though in this they imply that recipe formulas should not be a primary method.

A theoretical approach to the use of formulas is found in the Kerzner text (2009). This is the only source for the 80/20[90] cost formula: used for long duration activity packages. Under the 80/20 rule, the first 10% of the task is progressed 40%, the middle 80% is progressed as 20%, and the last 10% is progressed as the last 40%. Under this formula a task that would otherwise be 90% complete is measured as 60% complete. Each 1% of the remaining 10% contributes 4% towards completion.

An alternative understanding of the 80/20 rule is a broader justification for a wide use of recipe formulas. As I understand this rule: 20% of the activity will consume 80% of the resources. Therefore, focus resources to monitor quantities on those items and relegate the other 80% to recipe formulas and with low level of detail monitoring based on less reliable but easier to obtain sources that are less frequent. The 20% focus is on the control accounts – while the 80% are simply accounting. Possibly the 80% do not even need a cost account and could just be lumped into a single ‘project’ account. Later I will discuss ‘driving activities.’ These activities are the critical path type or can be time estimated with confidence. For example, heavy equipment and haul trucks have formulas to estimate cycle time without relying on historical data for period quantity and period applied resource ratios (production rate = quantity/hours). Another is restrictions on site access that create a maximum resource barrier.

The Bartholomew text provides examples for takeoff calculations: each essentially is an example of a recipe-formula for different scenarios and field engineers can use the same approach to estimate their as-built quantities as they do their forecast quantities (2000). For

[89] Labor, Equipment, Material, Haul, Subcontractor, Finance Capital (L/E/M/H/S/$).

[90] Most likely a reference of Pareto’s Principle or 80/20 rule, that 20% of something is responsible for 80% of the results, the first 10% and last 10% of the work consume 80% of the project managers time, last accessed 5/19/2015 http://management.about.com/cs/generalmanagement/a/Pareto081202.htm

example, Peurifoy and Schexnayder give a method to estimate earthwork volume: The volume is the product of the average of the cross section end areas and the length between each end area. For practical purposes, the volume must be modified for the material state. The material state varies based on the material condition, particularly for earthwork. The volume removed from the excavation is calculated in-situ as bank cubic yards (BCY). Once removed the material is now in loose cubic yards (LCY): which I noticed is not included in the Peurifoy text. If the material is fill, it will be compacted to become compacted cubic yards (CCY). The volume of the soil for the same weight is different in each state due to the changed density (Peurifoy & Schexnayder, 2002). The unit of measure for the respective accounts for each operation should require differing states of units. The Bartholomew (2000) text provides the examples for how to convert between these states. The use of the end area for a takeoff quantity is no different than its use to derive in-place quantities.

5.1.2.2.2.1.12 Milestones

The milestone is based on a 0/1 (start / finish) measurement, it is one of the more common methods in the texts, Kerzner (2009), APM (2002), PMBOK (2008), and CPM (2000). With the milestone method no progress is reported, then at completion the quantity is advanced to 100%. This method is intended for activities less than one month (Kerzner, 2009). Though there is no mention about which schedule this applies such as the five-week, three-month, annual, or baseline: this is true for all the methods presented in the literature review. A modification of the milestone is dividing a task into subtasks, each with a milestone. The sub-milestones provide control points: it is intended for activities greater than one month and less than three months (Kerzner, 2009). The PMI PMBOK modifies this further with a weighted milestone method (Ch7, 2008). A series of milestones are weighted to a cumulative 100% but each represents a more exact representation of the contribution to the total. Another slight variation is given by CPM, they report those activities finished and those activities in-progress: this is the milestone method since reporting start is simply a start milestone in the schedule but no progress is given until completion – in this case the only difference is the wording (CPM, Ch9, 2000).

5.1.2.2.2.1.13 Scale

The text implies the field engineer uses the project plans and specification as the source of the take-off (Bartholomew, 2000), though the specific source of the takeoff is not given. The other texts that provide the method of scaling from the plans are explicit about the source – it is from the plans (Peurifoy and Schexnayder, Ch2, 2002; CPM, 2000).

Bartholomew provides a dedicated chapter out of 13 chapters; this indicates the importance he places on the Quantity Takeoff (Ch4, 2000): he gives this in the context of cost estimating but I assume he would have used the same approach for quantities. The CPM adds a caution for using quantities scaled from the contract drawings: scaling does not capture the variation between actual quantities and planned quantities (Ch 10, 2000).

A similar but slight variation of scaling from the plans is to just use the bid quantities (CPM, 2000). The core difference is that bid quantities are not necessarily scaled from the plans because there are games in the bid process that results in out-of-round bid quantities.

5.1.2.2.2.2 Sources

The reference texts mostly ignore the sources of quantities beyond a few mentions – some in passing – about who collects the quantities (CPM, 2000; Kerzner, 2009). The CPM (2000) gives a second party such as a subcontractor or supplier as a source of quantities. The source could be a factor in the quality of the quantities. For example, a direct first person measurement made by a field engineer may be more reliable than one provided by a subcontractor on their progress billing. The previous methods presumably are universal to all sources, though pragmatically they show preference for parings of method-source. At this time only experience can provide the answer to what these pairs are.

Table 16 Expanding the table derived from Construction Project Management (CPM, 2000) with the Project Management Guidelines (Kerzner, 2009).

				Features					
Method[91]	Source	Measure	Contributor	Latency	Completion	Level of detail	Work types	Accuracy[92]	Purpose
physical count		units in place	CPM, p184, ch9.7						
"	drawings	scale & color-in	CPM, p184, ch9.7						
"	sitewalk	direct measurement	CPM, p210, ch10.11						
percent complete	time		CPM, p 183, ch9.6						
"	qty of work-in-place		CPM, p 183, ch9.6						
"	budget	dollars expensed	PM10th						>3mo
"	f(activity)	determine from network logic	CPM, p210, ch10.11						
0/100 milestone		finished t/f	PM10th						<1mo
weighted milestone		subtask finished t/f	PM10th						<3mo
equivalent units	endogenous formula	exogenous measure	PM10th						
cost formula	budget	percent complete	PM10th						>6mo
level of effort	schedule	duration	PM10th						
apportioned effort	endogenous formula	exogenous measure	PM10th						

The use of reference material as a source to make assumptions about a specific project are commonly used. Conceptually, the activities' components, operations, and resources can be project independent or specific. None of the authors discuss this distinction. Peurifoy and Schexnayder do not distinguish between project independent specification and project specific plan detail libraries. Bartholomew (2000) relays that the estimators assemble these libraries prior to the bid. I assume Bartholomew intended that these were already in an estimating office. Again, the distinction between estimating for bid and estimating for progress is light. An example of specific and independent measured quantities: haul trucks carry a volume of material. Without a scale the weight can be assumed based on either a project independent

[91] A question I cannot answer: What work types are associated with each method? I do not think there is a correlation. Later from ethnographic experience this will be added.

[92] A question I cannot answer: What accuracy is suitable for checking cost? The easy answer is, as good as you can get. In my experience, anything more than 30% from actual, if noticed, will be a topic of discussion amongst the field engineers.

density table or by measuring a sample of trucks to determine the density of the specific material on that project.

If the Parmley field guide (Parmley, 2002) had a section explaining project monitoring it would be useful to both field crews and field engineers. The guide already has material density tables and geometric formulas as well as standard plans – combining these with a clear connection with quantities is a key addition. For example, the project engineer needs to make a quantity takeoff to order material for delivery, the mixed use of project independent specification data from the guide and project specific quantities measured from the project can provide a reasonable estimate of quantities. Further, another contribution is the use of conversion factors for post-processing of measurements, and project independent details and specifications to generate a takeoff quantity of the expected work-in-place. For example, on page 14-2 there is a project independent roadway cross section and on page 16-20 the pipeline bedding and backfill conditions. These project independent details are common to many projects. Based on minimal field measurements, for example lineal feet, a takeoff of the standard reference cross section multiplied by distance provides an estimated quantity. Then using the density table I have the material in three units of measure, ton, loose cubic yards, and compacted cubic yards: the purchase unit, the haul truck production unit, and the emplacement production unit respectively.

5.1.2.2.2.3 Responsible

The APM and PMBOK guides as well as the CPM text use the field engineer as the role they assign the task of quantities (APM, 2002; PMBOK, Ch6, 2008; CPM, 2000). Because Stevens mentions the foreman making errors in cost coding and talks of assisting them with their weekly quantities defense meeting, I assume the foremen are the primary measurer of the quantities and the quantity features – this person is commonly referred to as the cost coder (Stevens, Titus, & Sanford, 2002). The CPM text advises not to give the quantification task to a field supervisor: field supervisors have an incentive to level production by hiding low production to correct later. They also have a counter incentive to hide higher production to use as a buffer for future low production: called *sand bagging* (CPM, 2000).

The CPM authors use the term *conscientiously* to describe how quantities must be measured (2000). They define *conscientiously* as understanding the importance of factual and correct determinations of project progress. The text further uses the term *"person responsible"* rather than *"person making"* the progress measurements. This could just be a figure of speech. But, they imply that a manager is responsible for the quantities not the person actually making the measurement. If this is true then the Stevens (2002) "defense meeting" could be the handoff of the quantities from those making the measurement to the person responsible for the quantities and the ensuing verification for conscientious measurement. Stevens does not elaborate on why the foremen are defending their quantities. Since the CPM authors go on to advise against having field supervisors make the measurements, I assume the authors intended to apply the responsibility to the engineers actually making the measurements rather than those supporting the process (CPM, 2000).

I think the base conditions for being conscientious is the reason why field engineers are given the task of quantities. Stevens reinforces this when he suggests educating the project staff about project planning so they understand the importance of quantities accuracy. Either because of education or predisposition, field engineers are already prepared to be conscientious about the quantities.

5.1.2.2.2.4 Communication

The PMBOK gives an example for how to communicate project status from the project to the planner. The PMBOK method uses notations on the project schedule to indicate the three metrics for each activity – these are start date, percent complete (PC > 0% and < 100%), and finish date (PC = 100%) (PMBOK Guide, 2008). Stevens gives us a communication approach based on a verbal retelling of the quantities in an in-person meeting format (Stevens, Titus, & Sanford, 2002). The further sharing of quantities is given as being through numerous reporting formats – but the PMBOK does not go into details on these formats or the intended users (PMBOK Guide, Ch7, 2008).

5.1.2.2.3 Summary

The authors Clough, Sears, and Sears (CPM, 2000) advise that planning should be within 10% - the question is, why should the planning accuracy be +/- 10%? Vitruvi, the 1st century B.C. engineer, claims estimates should be +/- 25%. What are the constraints that limit accuracy – today and in Vitruvi's time? Is 10% based on accepted accounting rules? Is it pragmatic, in that author's experience, anything better than 10% or 25% required too much effort? Is it impossible? If the field engineers achieve better than 10% then are there constraints elsewhere that retain 10% as the limitation? To achieve in overall planning, then is this accuracy necessary for all monitoring types such as process control, material delivery, as-built progress billings, forecasting? Quantities must be critical – if the quantity accuracy is greater than 10% then is it possible to plan within 10%. Is it even necessary to know the quantities? Just in the act of collecting quantities, are they good enough? What bad things will happen if the quantities are not within 10%? If the field engineers need x quantity of material – is it acceptable to nearly always have 0.1x sent to a landfill? Pragmatically, the relation is not a straight line. Material is usually purchased in batches for each section of the project – any excess material can be used on a subsequent phase, it is only the last batch that will have waste – so the waste is 0.1x divided by phases. Of course, special order items or anything that must be purchased for the entire project at once will have larger waste ratios. Is it not good to achieve the best accuracy just so the field engineers know this is not the source of the limitation? This seems is the consensus of the reference publications – over measure in greater detail than needed.

Production is the ratio of the labor or equipment quantity measured in hours and the production quantity, usually material. If the quantity is wrong - regardless if it is labor, equipment, or material - then without averaging across a larger dataset the production will be wrong. Duration is the product of production and quantity takeoff. If the production is wrong then the duration will be wrong by the same degree plus the error in the quantity takeoff[93]. The most critical application of the duration calculation is the forecast on lookahead schedules. They are based on the product of the immediately preceding production rates and the quantity to completion. If the quantities completed or the hours completed are wrong, then the forecast has no chance of being reasonably close. When the forecast is wrong something must give, and usually that means the safety, the environment, or the community suffers.

For quality of the quantities, there is no consensus. The APM guide advises to use a monitoring method that allows the field engineer to “make [the] measurement at [the] lowest practicable level of the feature breakdown structure,” Figure 71 (APM 2002). The PMI PMBOK simply advises awareness about the level of accuracy (PMBOK Guide, 2008). As I described in the latency section, the CPM mentions time lag in reporting project production (ch10.6, 2000). The text does not discuss the time lag in detail, only the mention of a tradeoff between level-of-detail and latency in reporting. I assume in the tradeoff that the text held resources in monitoring constant.

The effort needed to achieve a reliable quantity rests on a triad balance of frequency, completeness, and level of detail. The reference texts do not clearly pull this relationship together, let alone explain it, though there is enough to trust this relationship exists. A quantity obtained with the same effort must tradeoff these three features. A reduction in level of detail allows for an increase in completeness and frequency. A reduction in frequency allows for an increase in detail. Like most everything relating to quantities, while the categories and relationships are given, it is to the reader to discover the details empirically through trial and error.

[93] The alternative is a time and motion analysis to build a hypothetical production and use a close context of measured production as a reality check (Stallard Interview, page 5—158)

There is a relationship between level of detail and latency in quantities –the time it takes to obtain the measurements (CPM, 2000). The delivery of a quantity from the field to the planning database requires methods of obtaining the measurements, a source of that measurement, someone responsible, and communication of the measurement. There are some methods that are universally used and others that are found with one or two authors. For example, personal opinion is popular as well as measuring the actual units as best as can be done. The source and communication of quantities is almost universally ignored. The few sources that address sources mention it in passing as a reference to where the quantity was obtained. Similarly, the communication is given as an implicit sub-topic, the only mention instructs the reader to write percentage of completion in the margin of paper schedule printouts. The responsible person is addressed only slightly more directly, though by more authors. The consensus is that field engineers or equivalent must be responsible for quantities. Never make the field crews and their supervisors responsible for quantities.

The consensus from the reference texts: The field engineers, field measure quantities, at the highest level of detail, at a weekly frequency, presumably for all accounts, and hands these to the planner on a piece of paper. If there are some quantities that are not ready in time for the forecast, then the field engineer use expert opinion to fill the gaps. The danger to look for is *a-priori* methods where the person measuring the quantities simply reports the expected quantity. There are numerous complexities and methods – but the core of quantities is just this – from my ethnography, the reference material is consistent with my experiences. I do not think this should be the single method of quantities and the advanced methods and sources should be explored, particularly in light of advances in electronic model-based planning.

That is the conclusion to the quantification performance factors and methods of quantification. These controlling mechanisms adjust the quality of quantities. In the next section, I will present the other half of quantities, which is the features of the quantity: the chart of account and its accompanying coding process.

5.1.2.3 Chart of Account and 'to code'

In the previous section, I reviewed the reference texts explanation for quantities through a look at performance factors and the delivery methods. In this section I will look at the other half of quantities, that is the features of the quantity. Without features, a quantity is just an abstract number. For example, if I say "I have two." You will think, "two of what?" That is features. In this section, I will present: the purpose of features, the breakdown structures used to represent features, the nomenclature to convey the features, the natural language text descriptions, the conditional statements that define feature boundaries, and last the process to change or add a new features. Each feature set '*account*' requires a quantity.

5.1.2.3.1 Purpose

In this thesis's introduction chapters, I do not introduce the context feature set or the account nomenclature, so I will provide the purpose here. The coder (*person*), codes (*verb*) the feature set (*noun*). The feature set uses a nomenclature that represents the features of a breakdown structure. The breakdown structure represents the features of a quantity. The core purpose of using a nomenclature for features organized in a breakdown structure is to define the meaning and allow reuse of that quantity – commonly called *job cost accounts* or similar (AACE 20R-98, 2003).

One purpose is integration with different planning systems. The start to integration is categorizing the plan takeoff and specifications (APM, 2002). The PMBOK provides a specific integration level of detail they call the *Organizational Procedure Links* (PMBOK Guide, Ch7, 2008). Where exactly this level of detail resides is not provided. The reason it is not provided is because both I, the PMBOK, and everyone else does not fully understand the relationships and so have no theory. Where there is no theory then pragmatics from experience and the art of the trade must fill this gap. Understanding the integration level of detail, or details, is an art. The same is true for the rest of the gaps in the quantities topics. While AACE 20R-98 (2003) and the DOE 430.1-1 (1997) are compelling sources for the use of the chart of accounts to integrate the scope, time, and cost components of the project, like the PMBOK (2008), exactly how to achieve this is for the reader to figure out. Through integration and mapping, the cost and schedule forecasting is simplified (AACE 20R-98, 2003).

The features sets represent the context of an account (AACE 20R-98, 2003). Stevens provides the purpose of feature set as the integration from the planning system to the field or "reality," the AACE 20R-98 (2003) has the same (Stevens, Titus, & Sanford, 2002). Stevens provides a method to do this. He explains that to control errors in mapping field context features to planning context features, identify each activity on the schedule with a nomenclature code placed on the schedule (Stevens, Titus, & Sanford, 2002). In an earlier attempt to create an integrated planning system, Stevens cross-references the multiple project nomenclatures but found this made the planning labor intensive (Stevens, Titus, & Sanford, 2002).

Ostwald and McLaren (2004) do not discuss the details of how industrial engineers derive the bill of material (a breakdown structure specific to material) beyond features for completeness and level-of-detail. The project planning theory presented by the authors integrates the *costed bill of materials* with the labor and material cost estimates but does not include the time, overhead, or equipment components.

The DOE guidelines include four parts to the chart of accounts; these are the feature breakdown structure, a nomenclature, a description, and a conditional statement (DOE 430.1-1, 1997). The main contribution of the DOE guidelines in this respect is the addition of conditional statements (DOE 430.1-1, 1997).

The chart of account is known by numerous names, most contain key descriptive words: A resource term such as *component, material, resource, asset, cost, charge, value, work, activity.* Then something to identify as a list such as *chart, elements, account.* Last a reference to a hierarchy with synonyms such as *classification, breakdown, categories, structure, matrices.* A few specify it is an encoded nomenclature with the word *coding.*

5.1.2.3.2 Breakdown Structures

At the minimum, the breakdown structure includes the units of measurement (PMBOK Guide, Ch7, 2008) – anything after that are additional features of context. The DOE 430.1 specifically addresses the feature breakdown structure and the cost code nomenclature that represents these features. They provide a chapter (Ch5) for the concepts and a chapter (Ch16) for the examples. A core understanding needed to continue: What is a breakdown structure? A breakdown structure is a tree made of categories and subcategories organized by commons features. Each subgroup bundles these features into increasingly more defined bundles – each reduction in features is by a level of detail. At the last level of breakdown are the leaves and these are usually unique sets of features. For example, construction produces components, there are some common types, say walls, slabs, and tunnels. Components require actions to construct, common types are forming, placing, and moving. Actions require resources; the most common are labor, material, and equipment. This breakdown example is the OARPlan standard (Darwiche et al, 1988). Each path through the breakdown structure of features from the root group to the leaf can be represented by an encoded nomenclature of the features. The key take-away is the correlation between the features, the breakdown structure, and the Chart of Accounts (COA) (Ch5): this - while obvious - is implicit in other literature. The COA embodies the WBS as a representation of the identified instances of reality. When a new instance or feature set of reality is discovered then a new account to represent that reality is added through adherence to the WBS guidelines (DOE 430.1-1, 1997).

The AACE 20R-98 (2003) reviewed numerous proprietary formats used at specific companies, several breakdown structures, and proposed a new breakdown structure as a synthesis of existing breakdown structures, see Figure 21.

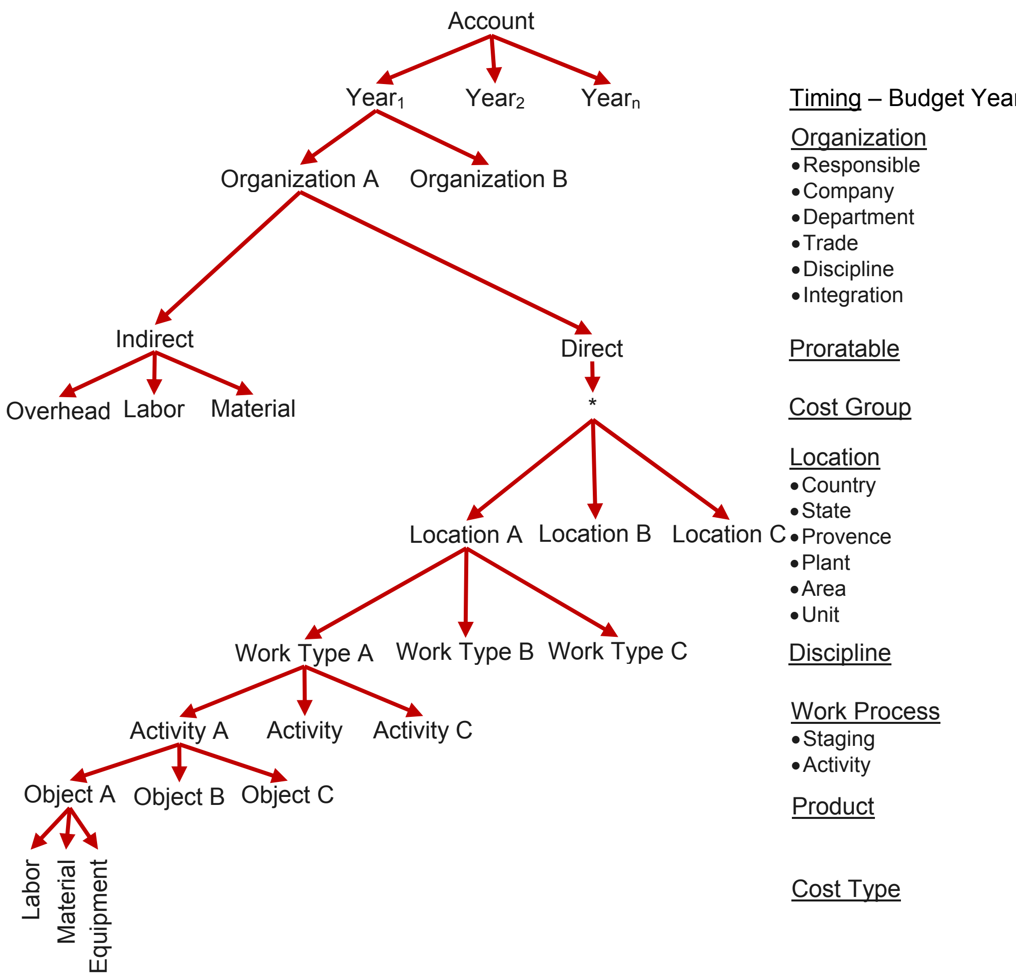

Figure 21 The AACE 20R-98 (2003) example breakdown structure. Notice the double breakdown structure at the Proratable and Cost Group Level – the indirect accounts are sometimes divided into indirect labor, indirect material, indirect equipment, and overhead, while the direct accounts do not have this cost grouping. The result is an inferred level that I represented with the wild *.

Two mainstream North American breakdown structures relevant to the construction industry are the MasterFormat and the Uniformat, see Table 17 for a comparison with the AACE 20R. The synthesized AACE 20R-98 (2003) format is in Appendix A: AACE Recommended Work Breakdown Structure (p369).

Table 17 The language of construction. Each of these examples is for the same activity, a curb and gutter. The resource breakdown is often considered the cost distribution. The breakdown structure when used as a nomenclature is commonly known as the 'cost code.' Note the reuse of MasterFormat (32.16.13.13 Curb & Gutter) in several of these breakdown structures.

Responsible Person		Projects Manager			Project Manager			Superintendent					Foreman									Clerical			
		Context breakdown						Location breakdown		Organization breakdown	Product breakdown								Work breakdown				Resource breakdown			
Standard	Code	Time mm.dd.yyyy (now)	Supply Chain	Facility Type	Company &/or Division	Project features[6]	Sub features	Location (here)	Sub-location	Organization	Discipline | System	Feature	Action	Resource | Material	Sub-resource | material	Function	Component | Feature	Sub-Component	Operation	Method	Action-space | Work-zone	Sequence constraint	Distribution (L/E/M/H)	Unique Identification	Unit of Measure	Description
e-cognos AROW[5]	text description												xx	xx			xx				xx					*OAR + workzone*
OmniClass Product	23-15 10 11 21 24												15	11	11	21	24									pavement roadway curb & gutter traffic safety barriers and protection
OmniClass Work	22-**32 16 13 13**										32		16	13			1	3								exterior improvements concrete + *MasterFormat*+as single object
Revit Keynote	**32 16** 00.B1										32		16	00			B1									6" curb & gutter
CIFE format[8]	text description					X		xx	xx		xx		xx				xx		xx							*CIFE CEE241 course material*
FOAR[4]	text description											xx	xx				xx						xx			*features + OAR*
AACE 20R-98, 2003	alpha-numeric	x				xx		xx	xx	x	xx		xx										x			
RGW Construction Heavy Const. Div.[9]	300188 285101	x			300	188					2		8	5			1		01				0000			curb & gutter grading
Bechtel Generic work-space[7]	text description												xx				xx				xx		xx			
NIST Uniformat	G2013										G		20				1	3								site roadway curb & gutter
Civil CICS	alpha-numeric			xx				xx									xx		xx				xx			
CARS[3]	text description												xx				xx					xx	xx			*OAR + sequence*
RSMeans	**32-16-13.13**.0430										32		16	13			1	3	04	30						*MasterFormat*+Means, wood forms, 6"x6"curb, 24"gutter
Clough, Sears & Sears	alpha-numeric					xxx	xx	xx			xx		x	xx			xx						x			
CESMM	8.28										8						28		c							road & pavement kerb excavation
OARplan[1]	text description												xx				xx				xx		xx			*object-action-resource (OAR)*
CSI MasterFormat[2]	**32 16 13.13**										32		16	13			1	3								cast-in-place conc. curb & gutter

The MasterFormat is notable in that it does not emphasize representing process projects such as equipment, piping, and process control. The Construction Specification Institute (CSI) organization intended the *MasterFormat 2004*[94] for project specifications and does not provide support for project planning nor control purposes[95]. However, I have heard of one large

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[94] Construction Specification Institute (CSI), *MasterFormat 2004,* www.csinet.org
[95] I emailed CSI and asked for someone in operations – this was their response.

international contractor that uses the MasterFormat as a convenient ready-made breakdown structure to organize quantities. For reasons like this, software developers such as Autodesk Revit and Reed RSMeans expanded the MasterFormat to include additional levels of detail beyond the specification level – then included MasterFormat in their products as the default breakdown structure of feature set nomenclature. There are two problems with using MasterFormat for coding activity context features. First, it is internally inconsistent; vendors trying to reuse the format for their product have not always been competent in the expansion of the accounts to the activity level, see Table 18. Second, possibly a root cause of the first problem, the MasterFormat is a specification format intended to define the quality of material and workmanship. Because of this, when it comes to feature breakdown structure there are unusable accounts in MasterFormat. For example, miscellaneous metals is an account for prefabrication but has no activity counterpart – nobody is tasked with installing miscellaneous metals as a distinct activity[96].

Table 18 The RSMeans breakdown structure and the derived Chart of Accounts (COA) by feature level of detail compared with a CIFE compiled format. The RSMeans format is based on the master format – the standard for teaching breakdown structures. The internal inconsistency is not my mistake, that is how RSMeans has it[97]. The MasterFormat was not intended as a cost breakdown structure. It was created and is maintained as a specification breakdown structure[98].

Feature Breakdown Structure												Chart of Accounts	Text Description
Company and Division	Bid Number for Year	Product Type	Location	Sub-Location	Building Units / Discipline	Master Schedule Activities	Resource	Objects	Operations	Operation method	Workzone		
					31							31.	Earthwork
						05						31.05.	Common Work Results for Earthwork
							13					31.05.13.	Soils for Earthwork
								10	00	10		31.05.13.10.00.10	Borrow
									00	20		31.05.13.10.00.20	Spread 200HP Dozer No Compaction 2MI RT Haul
									02	00		31.05.13.10.02.00	Common Borrow

Clough, Sears, and Sears (CPM, Ch10, 2000) has several discussions on cost code nomenclature to represent features, usage of cost code, measurement of activity quantities (CPM, Ch9, 2000), and special accounting problems. The authors provide an 18-digit nomenclature to represent their eight features (CPM, p203, Ch10.4), see Table 19. The CPM

[96] Thank you to Nelly Garcia-Lopez for pointing this out so clearly.
[97] I called and asked – the engineer told me she thought I was way overthinking these codes – she claimed they do not have this 'breakdown structure.'
[98] I called and asked the Construction Specification Institute (CSI) – this was their answer.

(2000) breakdown structure is similar to the OAR and AROW[99] breakdown structures developed by the CIFE research group at Stanford University (Darwiche et al., 1989; Ito et al., 1989; Mourgues, 2008). From encoding the breakdown structure features using a nomenclature, the authors derive an account, the example they give is 2000.08.05.03.1.57.20.3. A series of these accounts representing the activities a contractor engages is called the chart of account.

The Clough, Sears, & Sears breakdown (CPM, Ch10.4, p203): The first level, 2000.08, is the year followed by a sequential count of the bid for the year. They suggest that additional features such as the product and contract type should be included as another level in the 'project' code nomenclature. The next level, 05, is a single location breakdown, in the CPM example a location is defined by a major system's boundaries. Next is a seven-digit nomenclature, 03.1.57.20, based on the CSI 16 division MasterFormat[100]. These seven digits represent four levels of features; these are discipline, system, material, and then systems or component feature. The last digit, 3, is a distribution code, representing labor, equipment, material, subcontractor, or the sum of these four (CPM, 2000), in this case 3 represents material.

Table 19 Example chart of account breakdown structure (CPM Ch10.4, 2000). Clough, Sears, and Sears do not specifically give the text description as part of the chart of accounts, though it seems necessary.

Chart of Account											
	Breakdown Structure										
	Year	Project# of year	Contract type	Product type	Area code	Work division	Work type	Systems and materials	Project account number	Distribution code	
Level of Detail	WL0	WL1	WL2	WL3	WL4	WL5	WL6	WL7	WL8	WL9	Text Description
Account	2000	08	x	x	05	03	15	7	20	3	Stuff to Do

The CPM (2000) also gives project-billing cashflow as a resource but do not include it as a distribution. The project income has a breakdown structure to represent the different types of

[99] Note that AROW is a natural language structure –compared to OAR which is a concept structure. AROW provides the verb forst followed by nouns, OAR places the noun followed by verb then noun. For English, AROW is a closer fit to the spoken language.

[100] Note that this format relies on the CSI MasterFormat 16 division classification; the CSI MasterFormat was modified in 2005 to include 50 divisions.

income. In my ethnographic experiences, I have seen a range of types such as change orders, direct sales, back charges, extra-work, and various other contractual modification types.

The National Institute of Standards and Technology (NIST) publication *UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis* NISTIR 6389 (1999) - developed through the ASTM's Building Economics Subcommittee E06.81[101] - an assemblies-based breakdown structure. Commonly known as UNIFORMAT, this breakdown structure has a systems orientation that facilitates conceptual estimating. Due to its abstraction to the assemblies level of detail the UNIFORMAT is more prevalent in the design stages of a project than the construction stages. The assemblies used for estimating are often based on UNIFORMAT components, while the subassembly components are based on MasterFormat (NIST UNIFORMAT II, 1999). The UNIFORMAT loosely correlates with the higher levels of the example CPM feature set and elaborates the higher levels between location and discipline with a systems – which the CPM places at a lower level near the distribution level.

The breakdown structure Bartholomew gives is a possible basis to gain a more detailed context by combining the CPM, the NIST, and the AACE 20R breakdown structures. Bartholomew's breakdown structure fits as a suffix after the operation and before the resource details. Bartholomew does not go into breakdown structures and the related nomenclatures – that seems strange since he discusses forming cost libraries from historical costs, so he had some concept of categories. From the text, I can only assume he used text descriptions to identify the categories (Bartholomew, 2000).

The quantities to measure are labor, direct expense, material, and subcontractor (APM, 2002). The APM parallels the CPM distribution, with the omission of equipment and a 'sum of all,' and the inclusion of a direct expense feature. The APM does not explain what a direct expense is and how this differs from the CPM distributions. The Bartholomew (2000) text provides explanations for the breakdown structure to use for quantity takeoff from the project plans and is intended for use in cost estimating, see Figure 22. The author's explanation for that purpose also provides the logical reasoning and consideration behind a project breakdown structure. *The Quantity Takeoff* provides the five quantity types as either the *prime* contractor contractually obligated to the owner or a *sub* contractor hired by the prime, these are: subcontractor activity quantities (sub), permanent material (prime), expendable material (prime), payable (contractual) quantities (sub and prime), activity quantities by operation

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[101] ASTM Building Economics Subcommittee E06.81, www.astm.org/COMMIT/COMMITTEE/E06.htm

(prime) (Bartholomew, Ch4, 2000). Within these categories, the quantities must be identified by state change, such as, permanent items, removed items, temporary items, and altered items (e.g., soil treatment) (Bartholomew, Ch4, 2000). Within these categories the quantity relevant to each distribution must be identified. For example, the volume of spoil hauled to the site might not be equal to the volume needed – some may have been stockpiled from a previous operation. In a similar way, the purchase quantities for the applied resources may vary from the construction quantities.

Figure 22 Bartholomew's cost estimating breakdown structure; this breakdown structure is a suitable for suffix details in a chart of accounts. The bold categories are unique to Bartholomew's breakdown. Some pragmatic breakdown structures I have seen used by civil contractors places the subcontractor as an applied resource – though as Bartholomew points out this prevents maintaining a parallel plan for use to audit the subcontractor.

At the distribution level of detail there is a special conceptual problem that has no clear solution: though it is well documented. The problem: items are represented as *indirect* (activity independent) and *direct* (activity specific) items. I found six independent discussions of this issue, indicating the importance and perseverance. I discuss this problem here and further in subsequent sections of this thesis. The following sources raise the issue of indirect and direct items: the second *Special Cost Accounting Problem* example (CPM 4th, Ch10.23, 2000), my ethnography section on *Types of Quantities* (p217), also discussed by Stallard (p176), here in Bartholomew's Heavy Civil Estimating book,), by Ron Dukeshier (p168), and finally given an explanation by Paul Teicholz (p172). This topic is easy to dismiss. Bartholomew (2000) provides details on this distinction as a materials example but does not use the terms independent and specific. The classic direct versus indirect problem case: accounting for bulk material the field crew uses on multiple direct activities. The solution in CPM (2000), obtain and hold the material (or equipment[102] – more in the next section) quantities in an indirect *clearing account*. As operations consume the material (or equipment), credit the clearing account and debit the activities[103] that are consuming the material.

From my ethnographic experience: on the ReTRAC project the managers used three practices to address the applied resources indirect problem. These solutions created numerous problems with documenting the allocation of resources. First, they decided to dismiss associating indirect material with direct accounts. Second, they raised the equipment to the methods level of detail from the applied resource level: where labor, equipment, and haul resided. The purpose was simple – to see the equipment cost on the weekly cost and quantity report. To see the equipment otherwise required printing the report at a lower level of detail, but this caused an explosion in detail, most of it unwanted. The field engineers only wanted to see the equipment broken out, not the rest of the distributed costs. Raising the equipment level made equipment a direct account, but they did not provide a raised equipment method for every operation. Third, manually coding actual equipment cost directly to the activity meant there was no record of the equipment hours used on each activity. This resulted in consumed equipment resources that had no 'home,' resulting in a bizarre allocation of equipment cost resources to a haphazard assortment of accounts and no record of the equipment use in many other accounts. Some of this was a result of mistrust between the equipment and construction divisions – and a desire to limit the discretion available to the equipment manager. By manually

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[102] The text applies this same problem to equipment, which also was a problem I saw on the ReTRAC project. This issue was resolved with an existing equipment accounting system. The system was not utilized up to that point, despite memo requests from corporate accounting. Rather than code the equipment cost directly to the work account, the previous process, I 'rented' the equipment to ourselves at a set rate. The accounting software (JD Edwards AS400) contained an equipment module that allowed the equipment manager (me at that point) to give equipment an asset number and set rental rates and then pay the equipment asset number similar to how you would pay a labor employee number.

[103] This solution was not available on the ReTRAC project due to the lack of material distribution accounts associated with direct work activities. Rather, similar to the old way given in the Stallard interview, a spreadsheet was constructed by the field engineers with a list of associated activity codes. By the time the spreadsheet was constructed the distribution of these accounts was no longer known, though if it had been, each account would have been assigned a percentage distribution. Obviously, the solution provided in the text should have been employed. Or, as Stallard points out, the effort exerted is not worth the return in his opinion.

coding actual cost to the consuming activity – there was minimal room for the equipment department to accrue 'profit' from the equipment. I address the details of the pragmatic representing of material and equipment input and output in subsequent sections *Quantification Effort* (p 298), *Estimating and Bidding for Heavy Construction* (p 388), and as a special condition in the Stallard interview (p 88).

Bartholomew (2000) does not specifically address the representation issue, note that Bartholomew does not categorize the equipment and material as an indirect (Ch 11, 2000). Bartholomew relates carrying applied resources as an indirect or direct (Ch 3, p 42, 2000) with several features of indirects; I assume these instructions apply to the budget. There are problems with this split. First, individual estimators inconsistently group items as an indirect or direct. Second, the estimators estimate the indirect items after the direct items are finished. A solution is distributing indirect equipment resources across the direct activities (Ch 5, 2000): Cover the equipment costs by distributing the equipment usage using a distribution method such as percentage, level of effort, or cost ratio[104]. As an alternative, the 'real' solution is to define equipment as a cost center and cover the equipment usage with the apportioned effort method as the product of a predefined rental rate and a measurable unit, for example equipment operating hours or quantity of material worked (Bartholomew, 2000). This method leaves open the ability for the equipment department to set a higher hourly rate to charge the activity and accrue 'profit.'

This approach and others described in subsequent sections are an important but opaque consideration in representing features. The real effect was limited use of project quantities for forecasting and monitoring, as well as a general lack of trust in any of the quantities – both the measurement and the context features. There are likely more nuanced issues than just these.

Creating a breakdown structure to represent the features of quantities is an unsolved problem in not just construction: this is an open problem for computing. There are numerous breakdown structures for breaking down the features into a hierarchy of features ending with groups of unique feature sets, none seems to have proven itself any more worthy than another. Many are 'folkologies' and evolved with the growth of an organization and their specific circumstances. These are well fitting breakdown structures that are adapted to a specific niche. Attempting to create one from scratch and expecting performance without an adaptation period of years, is an exercise in futility and denial of the complexities involved. In this section, I have presented example breakdown structures and only a few special conditions to consider.

[104] Bartholomew does not specifically give these methods by these terms, they are implied as intuitive methods available to the field engineer.

5.1.2.3.3 Nomenclature Code (to code)

In the preceding sections, I found breakdown structures used as a nomenclature to represent features, and in the case of *Construction Project Management* (CPM, 2000), I found a specific example of a breakdown structure. In this section, I take a deeper look at the feature set and the act (*verb*) of assigning these features, as opposed to the breakdown structure (*noun*) of these features. I found additional feature cost coding (*verb*) literature through a web search for key terms such as *cost code*, *work breakdown structure*, and *cost coding*. In subsequent chapters I will present an empirical example of cost coding to illustrate underlying issues with misrepresentation of project resources.

How to apply the codes is not in the CPM text (2000). There is simply a mandate for the consistent use (there is not an established word for ‘use’) of each code. How to achieve consistency is not explained (CPM, 2000). Who codes is not clear, the CPM (2000) applies this task to the field engineer. Incorrect coding is termed a *miscode*. Auditing for and correcting miscodes is a necessary task. Steven describes the problem he had with miscodes of what he described as the coded association with activities. He felt that most of the miscodes were due to three issues, the foreman’s learning curve, changes in the chart of accounts during the project (reversing the learning progress), and managements' learning curve (Stevens, Titus, & Sanford, 2002). The CPM (2000) authors almost advise encoding the account by concatenating the sub-code as feature tokens rather than memorizing a long list of codes – but stop short of that, nor do they explain how that would be done though they appear to give an example.

Through a University of North Carolina (2005) guideline, I found several methods for auditing assigned codes. The UNC guide addresses how to check for out of balance accounting and where to look for the cause. They provide two types of errors, the *double code* error (presumably the same item is coded with the same features and entered twice creating a duplicate entry), and the *different cost code* error, also known as a miscode; meaning the features assigned to the item were incorrectly measured. An online search for these keywords did not return additional sources – the following UNC instructions are all there is. For the *double coded* condition, check if the *expenditure* column does not balance: adjustments are made on a *Journal-Entry* document. To check for miscodes, if the *encumbrance* column does not balance then look for a mismatch between the code on the *Transaction Redistribution*[105] (used to document a recode) document and the original *transaction*: make adjustments on an

[105] Redistribution Instructions http://www.asu.edu/fs/forms/Redistribution_Request_Instructions.pdf

encumbrance[106] document. These three checks are the only code audit instructions I could find.

Procedural changes reduced the occurrences of miscodes. The Rocky Flats engineers (Stevens, Titus, & Sanford, 2002) recommend four procedural changes: First, assign a universal chart of accounts to the activity schedule and the POWERTool[107]. POWERTool is a U.S. government Department of Energy estimating tool. Second, "Move efforts to improve the degree of coding accuracy from the *sets* (unknown level, probably operations) level of detail to a *media* (for example pipes) level of detail." In a subsequent section of this thesis Stallard gives similar advice on rolling up the codes a more abstracted level of detail and focus on ensuring that while the subcodes might be inaccurately coded, when rolled to a higher code, that code is accurate. Third, explain to the supervisors responsible for coding the importance of the relation between good coding and good forecasting – CPM has similar advice (2002) as well as later in this thesis Professor Meredith will agree (page150). Fourth, the [field engineer or project engineer] helps the foremen with their weekly quantities and to review the features they cost coded (Stevens, Titus, & Sanford, 2002). The University of North Carolina (2005) coding guide has advice to reduce miscodes: do not code the original *open order* - instead code from the invoices. The *open* order is a status indicating that an *order* has been placed but no part of the order has been executed[108]. The invoice is the actual order delivered. Those five suggestions are all I found for adjusting the quantity of the coding process.

The single clear explanation for pragmatic coding is from a University of North Carolina (2005) accounting knowledgebase[109], it has instructions for two methods of coding items: single and multiple. Both methods are based on using a computerized interface – there is an implicit assumption that a paper-based document has had the features written in the margins as a cost code. The first method is to code one item at a time by selecting the code from a chart of accounts hybrid of a category button and hierarchical dropdown list.

> *"To assign cost codes, one item at a time, simply click on an item in the topmost section of the items tab. Then, in the bottom left part of the window, click on cost code group title in the "Cost Code" column. Then select a "Cost Code" from the drop-down list in the bottom center of the Items tab. Repeat the above steps to cost-code all your items, one by one." (University of North Carolina, 2005)*

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[106] Encumbrance: the purchase order or invoice https://en.wikipedia.org/wiki/Encumbrance
[107] U.S. government department of Energy estimating tool (POWERTool).
[108] *Open order* definition, online Fidelity glossary.
[109] University of North Carolina its.unc.edu/ccm/groups/public/@its/@eapps/documents/content/ccm1_002940.pdf

The second method, autofill, assigns one code to multiple items (University of North Carolina, 2005). The autofill instructions are similar to the single coding approach with additional steps for making multiple selections and an autofill command (University of North Carolina, 2005).

The core advice for good coding is from Stevens and the difficult Rocky Flats project: Educate the staff on the correlation between improved project control and the coding[110] accuracy; unfortunately, Stevens does not give the benefits of improved project control (Stevens, Titus, & Sanford, 2002).

5.1.2.3.4 Text Description

Not all the texts that define the chart of account explicitly define a descriptive text field – for example, Clough, Sears, and Sears, only imply there is a text field. The DOE 430.1 (1997) is explicit that the description and conditional statement guide the coder to the code. The PMBOK provides for process text descriptions for estimating, budgeting, and control accounts (Ch7, 2008). I would consider all three of those process accounts as subprocesses of *forecasting*. Presumably, they mean every account in the chart of account should have a text description. At that, none of the texts provide anything about what the text should say: the *natural language* encoding of the alpha-numeric encoding. While a research publication and not reference, the topic fits here - Mourgues (2008) at CIFE defined a natural language breakdown structure called AROW[111]. The breakdown structure is *Action, Resource, Object, Workzone*. As a natural language the leading verb flows to the components making for a meaningful text sequence. For example, *Build Formwork Abutment Northbound*.

5.1.2.3.5 Conditional statement

As I stated in the introduction, the main contribution of the DOE guideline 430.1 is the conditional statement, see Table 20. It is my sole source for the conditional statement as a component of the chart of account. Through this literature review and the investigations provided in the rest of this thesis, other than DOE 430.1 I have not seen conditional statements attached to a chart of accounts.

[110] The term used is “charging.”

[111] Note that AROW is a natural language structure –compared to OAR which is a concept structure. AROW provides the verb forst followed by nouns, OAR places the noun followed by verb then noun. For English, AROW is a closer fit to the spoken language.

Table 20 Department of Energy standard DOE 430.1-1, 1997 adds a fourth part to the chart of accounts, this is the conditional statement.

Feature Breakdown Structure	Nomenclature	Description	Conditional Statement
Action-Resource-Object-Workzone	032-16-13-23	Build Form Curb and Gutter Zone 23	Includes labor to build wood forms for curb – excludes supporting equipment.

The ambiguity in the DOE example conditional statements leaves room for interpretation and therefore the potential for a miscode. For example, the following is an example conditional statement from the DOE 430.1-1 (1997):

> *"This includes labor and material costs that are not addressed by other subaccounts under the 501 account, such as the labor and material required for installation of bridge and gantry cranes, monorails, conveyors, and pipe handling trolley assemblies, including related electrical feed rails, crane rails, internal wiring, erection, and rigging."*
>
> *"Also included are the labor and material required for installation of miscellaneous building equipment attached to and part of the building, such as elevators, dumbwaiters, lunchroom equipment, and metal lockers, etc."*
>
> *"This cost code excludes process equipment and equipment includable in building systems, such as monorails, bridge cranes, gantry cranes, pipe handling trolley assemblies, shop equipment, and installation of temporary construction overhead cranes."*

In the sample conditional statement, the distinction between the code used for labor and material and the code used for process equipment is confusing. Both novice coders and veteran coders do not necessarily instinctively perceive it. Gaining the feel for and respect for both tacit and formal rules that distinguish between accounts in a specific chart of accounts takes time. As an experienced coder on a large project I initially had no idea what this example account includes or excludes. I would not be able to constantly code to this account. Further, I would reapply the quantities associated with this account inconsistently. In this breakdown structure, there are two equipment types, the construction equipment, and the product equipment.

> *"This includes…, such as the labor and material required for installation of bridge and gantry cranes, monorails, conveyors, and pipe handling trolley assemblies…"*
>
> *"This cost code excludes …, such as monorails, bridge cranes, gantry cranes, pipe handling trolley assemblies, shop equipment…"*

To clarify the terminology I referenced the AACE 20R-98 (2003). The AACE 20R defines material to include equipment, therefore blurring the distinction even further. Is "process equipment" different from equipment as defined in AACE 20R? After closer reading, I think this account is for labor and the associated material to install process equipment, there are other accounts for the process equipment itself and the haul cost. To me the equipment terminology is initially confusing since equipment refers to the construction process itself. What account holds the equipment used to install the process equipment? Is this where the AACE 20R definition for material comes into play? The material in this case is the account for the installation equipment. For example, a crane is equipment used for the process, while material is the product itself, for example, equipment such as a permanently installed sump pump (DOE 430.1-1, 1997). This account is for the labor and material needed to install a permanently installed pump, but the pump itself will be covered by a separate material account. To me, this is illogical, there should be a distribution code for labor and material and have a sub account for permanent and expendable material used to install the pump.

Using a more formal approach to statements, something like the Gellish *natural language* standard, Table 21, would probably help with a formal representation of relationships (DOE 430.1-1, 1997).

Table 21 A *Gellish* representation of observed assemblies. Gellish is a development of ISO 10303-221 and ISO 15926. A subset of the Gellish dictionary (STEPlib) was used to create ISO 15926-4 (Gellish, 2005).

Left hand object name	Relation type name	Right hand object name
Account 501	is classified as a	labor
Account 501	is classified as a	material
Account 501	is related to	part of buildings
Account 501	is related to	permanent
Account 501	is related to	process equipment
Account 501	is related to	miscellaneous equipment
Account 501	is related to	equipment *unit* systems
Account 501	is related to	erection and rigging
Account 501	Is not classified as a	process equipment

5.1.2.3.6 Change Process

The chart of accounts must allow a process for adding or removing codes as needed (Stevens, Titus, & Sanford, 2002). Providing a process to field modify the chart of account is consistent with theoretical findings made by Suchman (1987)[112]. Suchman essentially says any system must allow for customization by the user to accommodate the phenomenological realities they encounter. Later, in this thesis I will introduce Suchman and her arguments for customization by the end users and adaptation to the end user.

[112] See Forest Peterson General Qualification Exam Proposal.

5.1.2.3.7 Summary to Chart of Account and Coding

In this section I have reviewed the reference literature for five attributed of quantities as it relates to representing the features of a quantity measurement. The five attributes I found are the breakdown structure, nomenclature, text description, conditional statement, and the change process for the previous four. Before these attributes, I present the reference texts purpose for representing the features of a quantity measurement.

The concept of a quantities' features represented with a breakdown structure of features and placed into an alpha-numeric nomenclature is not new to construction. The features are simply the meaning surrounding a quantity. When this practice began is not presented in the text. The purpose of the feature nomenclature is to map a quantity to and from the field reality and between software applications. With a distinct feature and nomenclature – the sharing of a distinct feature is possible. The breakdown structure has levels of detail – features are represented at these varying levels allowing for abstracted concepts that are less specific. In the breakdown structure the base case is *unit of measure*, this is the simplest feature and presents what measuring unit is used to measure the quantity. For example, feet or yards for a distance. The advice in the reference texts is to use one nomenclature for the field quantities and planning systems. Using more than one nomenclature on a project does not work. The specific breakdown structure used is up to the project, there are as many different breakdown structures as there are companies. Some companies – most software developers - have tried to use a universal breakdown structure or include this as a default breakdown structure in their software product. The problem is that the most widely known breakdown structures are not intended for construction project planning and when expanded for this purpose numerous errors are introduced, resulting in a breakdown structure that is internally inconsistent. The study of these breakdown structures is incomplete and unsolved.

The reference texts universally ignored the application of the nomenclature to a quantity – commonly called *cost coding*. The act of coding is a verb – it is the assignment of a code to a quantity in contrast to assigning a quantity to a code. I found audit checks for mistaken codes or *miscode*. The reference text provided five pieces of prevailing advice: look for inconsistencies in the quantities due to coding, code at a lower level of detail than the quantities will be reused at, apply a single nomenclature for a project, explain the importance of good coding to those coding, and code the *invoice* not the *open order*.

In addition to representing the features with a breakdown structure, then applying this to quantities through a nomenclature, there are also text descriptions and conditional statements that assist with matching a code to a quantity. The text descriptions reiterate the nomenclature in a natural language. The conditional statement provides a series of conditions that define what the code applies to and what it does not apply. The reference texts were vague on how to formulate a good text description. One source provided examples of conditional statements: the other sources ignored the topic. An interesting development is the use of a formal concept representation format – the Gellish language provides this function.

The last aspect of feature representation is adding a new feature, removing a feature, or changing a feature. One source found that this function is necessary but does not go into much detail.

The reference literature provided a framework for organizing aspects of quantities then filled-in the features.

5.1.2.4 Summary and Cross-case Analysis of Reference Texts

In the previous sections, I have reviewed reference texts for methods of collecting quantities, developing a chart of account, and applying those accounts to the quantities. The core takeaway I have is just how shallow the literature is on this topic. There is no formulaic approach to know that for a specific account given these project features and for these uses then measure the quantities at this frequency and at this level of detail. Further, given the project features then for all the accounts measure across the project at this completeness of account coverage using this frequency and this level of detail for each account. Nor do the texts provide the methods nor the appropriate sources of measurement for a given account with the above condition. These features are given, but the significance of each feature and the bundled performance is not known.

That said there is a good foundation of knowledge. The features look clear, it is only the significance of these features in relation to each other that is unclear. The relationships at the high level are clear – the tradeoff between level of detail, frequency, and completeness is intuitive –it is the significance that is missing. The knowledge I have here was validated by most of those authors through their pragmatic experience, that is reliable. The details that allow a formulaic approach was unnecessary for these authors, in their era it would be impractible to do anything more than present the factor and allow the reader to then use their experience and intuition to apply that knowledge.

With regard to the chart of account and the application of those accounts to the quantities, the pragmatic knowledge in the texts is less clear. The breakdown structures appear to be based on legacy – someone else did it so I will do it too. I found no logic behind why the breakdown structure features are present. My focus is not so much on the breakdown structures since I believe this field is so early that it requires a dedicated investigation on its own. I see the application of the account, for whatever breakdown structure of features is used, as the core topic. On this, the reference literature is silent. It is an open theory on how to apply the accounts to the quantities. Are some breakdown structures inherently easier to code?

5.1.2.4.1 Limitations

My review of reference texts is not without gaps. In the introduction I disclosed the unpublished theses and dissertations I missed and that the review used a saturation test rather than complete coverage of the literature. In addition, I have not found a few topics that should have been there: The topic of post processing measured quantities into assumed quantities is missing. I found nothing from RICS – Royal Institution of Chartered Surveyors – this is surprising since it is what they do. All I can conclude is the RICS group does not have much engagement with other standards organizations and so I did not find them referenced or as a source. I did not review the medical field. There is an established practice of encoding medical knowledge and *coding* this to invoices and procedures. There are medical organizations dedicated solely to this – I did not review their literature.

5.1.2.4.2 Conclusion

The course textbooks and reference material defines the existing accepted project monitoring knowledge. Reference material is the boilerplate as accepted practice for contract and legal reference. This is the material academic programs regularly teach to undergraduate and graduate students.

In the next section, I will look at the same topics of quantification and assigning feature representation as I have in the previous section and in this section. In the next section the sources are published research papers as opposed to reference texts. Research publications are considered validated for truth but are not accepted practice. Most make the argument that the practice they have shown is an improvement on existing practice. In this, the sources I review either provide a better quantification method or in making that argument explained the current practices.

5.1.3 Research Publications

In this section, I will review the published works by academic researchers. I present their work clustered around those that did field experiments, those that did case studies, a counter argument for even collecting quantities, and last, quantities culture. For the most part I rely on the works by five academics: Dr. Saidi during his time at the University of Austin at Texas working with Professor Haas, Professor Kiziltas during her time at Carnegie Mellon advised by Professor Akinci, the survey work by Professor Motwani from Grand State University, and Professor Meredith at Wake Forest University. From their finding I have assembled the known body of theoretical knowledge concerning quantities collection and accounting for the feature of those quantities.

5.1.3.1 Field Observation

Two researchers have based their contribution to quantities on field experiments and observations. Their research stands out in the clear understanding of the significance and relevance of factors involved in the quality of field quantities.

5.1.3.1.1 Field Observation of Quantity Bias

In this section, I review the work of Dr. Saidi. The intention is not to solely focus on his work, though that is the result. The work of Saidi is the sole source I have found for field experiments in quantities monitoring. His work is reliable because he collected his observations as an embedded researcher on a civil works project.

The literature review in Dr. Saidi's thesis (2002, University of Texas at Austin, chapter 3) presents quantity-tracking methods. While the National Cooperative Highway Research Program (NCHRP, 2003) project cost estimating report concludes the importance of the schedule to the estimate, Saidi provides the details of practices that he observed provided an improved degree of accuracy and repeatability in scheduling. To begin, Saidi makes several definitions:

- First, the definition of *quantity tracking* by Professor Halpin[113] a recognized authority in construction process research (Saidi, 2002, Halpin, 1985).

> *"a means of acquiring information about installed quantities at the jobsite, which can then be matched with resource expenditures"*[114]

[113] Professor Halpin Purdue University engineering.purdue.edu/CEM/People/Personal/Halpin
[114] Financial and Cost Concepts for Construction Management (1985).

- Then Saidi extends the definition,

> *"quantities tracking is the continuous monitoring of installed quantities that [the field engineer] then compared with the estimated quantities based on the schedule, therefore providing project progress."*

Dr. Saidi relies on CII publication 6-3, *Model Planning and Controlling System for EPC* (Engineering, Procurement, and Construction) *of Industrial Projects* (1987), as a point of departure for the following six methods of measuring project progress (CII ch6-3, 1987): these mirror the APM (2002) and Kerzner (2009), reference Figure 17 page 89:

- Units Complete: for activities involving repeated production easily measured that consumes equal resources, for example linear feet[115] (LF) of wire pull or pipe installed and cubic yard (CY) of concrete placed
- Incremental Milestones: for sequential activities with clearly defined milestones, for example pipes inspected, pipes supported, pipes aligned, pipes welded, pipes tested, and pipes finished
- Start / Finish: for activities without interim milestones or are difficult to quantify in terms of time and cost, for example cleaning, testing, and aligning
- Supervisor Opinion: for minor activities where detailed analysis is not necessary, for example painting and construction support facilities
- Cost Ratio: for long-term activities that span the life of a project and are allocated bulk cost/time, for example project management and quality assurance
- Weighted units or Equivalent units for long-term activities that include multiple subtasks with different units of measurement, for example structural steel erection (includes bolting, shimming, connecting, and aligning)

[115] *Lineal Feet* has an implied width component while linear feet is a measure of length http://www.usingenglish.com/forum/threads/81174-Lineal-vs-Linear

Table 22 Adding to the previous tables compiled from the Construction Project Management and Project management 10th edition texts, Saidi's thesis adds the opinion method of measurement.

				Features					
Method[116]	Source	Measure	Contributor	Latency	Completion	Level of detail	Work types	Accuracy[117]	Purpose
physical count		units in place	CPM, p184, ch9.7						
"	drawings	scale & color-in	CPM, p184, ch9.7						
"	sitewalk	direct measurement	CPM, p210, ch10.11						
percent complete	time		CPM, p 183, ch9.6						
"	qty of work-in-place		CPM, p 183, ch9.6						
"	budget	dollars expensed	PM10th						>3mo
"	f(activity)	determine from network logic	CPM, p210, ch10.11						
0/100 milestone		finished t/f	PM10th						<1mo
weighted milestone		subtask finished t/f	PM10th						<3mo
equivalent units	endogenous formula	exogenous measure	PM10th						
cost formula	budget	percent complete	PM10th						>6mo
level of effort	schedule	duration	PM10th						
apportioned effort	endogenous formula	exogenous measure	PM10th						
opinion	supervisor	guesstimate	Saidi, 2002						

[116] A question I cannot answer: What work types are associated with each method? I do not think there is a correlation. Later from ethnographic experience this will be added.

[117] A question I cannot answer: What accuracy is suitable for checking cost? The easy answer is, as good as you can get. In my experience, anything more than 30% from actual, if noticed, will be a topic of discussion amongst the field engineers.

Dr. Saidi's thesis is the academic source for descriptions of quantities tracking attributes and uses. He reviews five sources and adds two additional conditions found from observation, these sources are:

- RSMeans Mechanical Cost Data book (1999)
- William Mincks (Boise State University) and Hal Johnston (California Polytechnic State University at San Luis Obispo) who have together published several books on construction management
- On the frequency of measurements, Professor Oberlender (Oklahoma State University)
- On measurement errors, the previously mentioned Professor Halpin (Purdue University), and
- the University of Texas at Austin Construction Industry Institute (CII)

The nine topics covered by Dr. Saidi and reviewed are: measurement methods, unit of measure, frequency, resource intensity, recording, measurement, data entry, bias in reporting and reports: quantities report, productivity report, and cost report. These topics form the core elements of the feedback loop utilized to update the schedule and forecast cost to completion – also used as the preliminary format of the

Ethnographic Field Observations section on 196.

Similar to the six methods cited from CII 1987 publication 6-3 are those given in the Project Management Institute's (PMI) Guide to the Project Management Body of Knowledge (PMBOK Guide 4th Edition, 2008), see p401. Saidi provides the unit of measure through examples he derived from the RSMeans Cost Data book. Note that while the cost database is maintained using a given unit of measure - often what is used in the estimate - these are not necessarily the same unit of measures used in the product model, process model, cost budget or used to make field measurements. Professor Oberlender (McGraw-Hill, 2000) contributes the metric frequency of measurements. Oberlender finds that contractors often report quantities on a weekly basis, but does not provide other reporting periods, or define the type of quantities. Saidi references Professor Halpin for both the resource intensity and the risk of errors in recording of measurements. First, Halpin correlates the resources needed to collect field measurements with the method of collection. The need to calculate resource quantity demand indicates that methods have an inherent variation in resource intensiveness and/or the resource intensity depends on the conditions. The questions not answered are what methods, what resources, and by what degree. Second, Halpin addresses the physical recording of the measurements and the handwriting method as a function of the prevalence of errors[118].

The previous five topics led to the goal of obtaining a measurement. Again, Saidi relies on Halpin to provide eight points of features and related quantities that are included with a measurement, though Halpin does not provide the reasoning for their inclusion; these points are (Table 23):

- Features as a cost code
- Contract item numbers: code
- Descriptions
- Units of measurement
- Quantities from the previous reporting period
- Quantities from the current period
- Quantity adjustments
- Quantities to date

Once the field engineer measures or collects the quantities, she then produces three reports, Table 24: the progress report, the quantities report, and the cost report. Saidi relies on Mincks and Johnston for the quantities and cost reports and CII documents and Oberlender to

[118] Halpin found the disadvantage of the handwriting method as an increase in the prevalence of errors: I saw at RGW this is also a method to decrease mistakes.

illustrate that there are multiple indicators of project progress. These provide basic attributes represented as the cost report columns, these are activities description, feature set as a cost code, work completed during the previous period, the current period, to-date total, and remaining to completion, Table 23. The cost report includes the labor hours reported on time cards and the measured quantities so to produce productivity and unit cost. The field engineers review and update the cost report to evaluate activities progress and forecast cost to completion.

Table 23 This table is from Saidi (2002; Minks & Johnson; Halpin, 1985) with four columns added, these are unit of measure, takeoff, percentage of completion, and cost to date. I converted the units of measure for three activities from reported units to the units used in the RSMeans historical library. These are reinforcing from pounds to tons, spray cure from square feet to as CSF (hundred square feet), and backfill footing - depends on if loads or compacted in-place is measured, historical is in LCY.

		completed						
feature description	feature nomenclature	previous period	this period	to-date	remaining	labor hr. to-date	MH/ unit	unit cost
excavate footings	031231	128	0	128	0	23	0.180	12.43
place footing reinforcing	032113	2,916	0	9,720	0	74	0.010	0.77
F/P/S footing forms	031113	346	86	432	0	35	0.080	3.66
place footing concrete	033113	36	18	54	18	22	0.400	13.10
spray cure on footings	033923	162	162	324	324	1	0.002	0.10
structural backfill footing	031232	13	13	26	102	4	0.150	9.98

Table 24. These Earned Value Management (EVM) progress report indices (Saidi, 2002) are how field engineers using the EVM method quantify project progress. These formulas rely on measured quantities that as presented in EVM texts are a guesstimate rather than a measurement.

Indicator	**Description**	**Formula**
PC	Percent Complete[119]	Sum or *earned* work-hours of tasks included / Sum of *budgeted* work-hours or tasks included
PI	Productivity Index	Sum or *earned* work-hours of tasks included / Sum of *actual* work-hours or tasks included
SPI	Schedule Performance Index	Sum or *earned* work-hours to date / Sum of *scheduled* work-hours to date
SV	Schedule Variance	*Earned* work-hours less *budgeted* work-hours
CPI	Cost Performance Index	*Earned* work-hours to date / *Actual* work-hours to date
CV	Cost Variance	*Earned* work-hours less *actual* work-hours

Based on Saidi's observations he finds two previously unpublished issues. The first is the inefficiencies of *double data entry*. This is the case of the field engineers repeatedly entering

[119] The percent of the project (or specific work package) that has been completed.

the same quantities into various project control tools, Figure 23. For example, quantity tracker *A* records on paper the week's measurements from an activity, then enters the quantities into a spreadsheet, prints, and submits the paper printout to quantities tracker *B*. The quantities are then re-entered to a spreadsheet by *B*. Who then calculates the post-processing and assembly equations for quantities, and then prints the week's quantities and gives them to *C*. The field engineer *C* or possibly by a fourth field engineer *D,* then keys the compiled list to an enterprise cost system. This redundancy is consistent with my ethnographic experience. Obviously, the redundancy is not necessary and opens the possibility of errors.

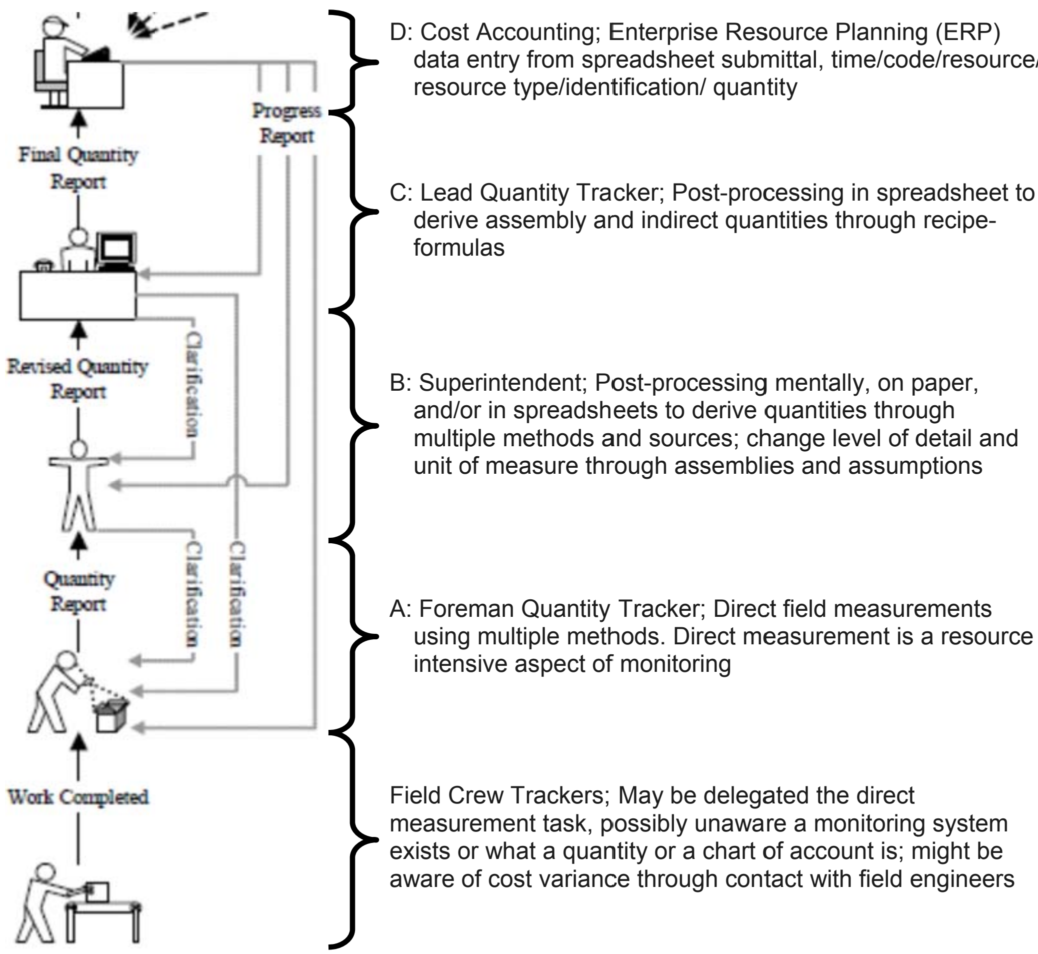

Figure 23 Project progress quantities flow for quantity tracking (graphic from Saidi, 2002). Note the multiple coding steps and context features request and revision loops. The resources are distribution features such as for L/E/M/H/S. The resource type could be the trade or discipline type, and management level.

The second issue is a practice of over - and under-reporting of quantities - called *sandbagging*[120] [121]; the purpose is to artificially over-report or under-report productivity (or cost). The benefit to the field crew is that they can level across several reporting periods a variance in production. Sandbagging prevents triggering a variance warning and therefore prevents additional oversight resources placed on that activity. The leveling of quantities reported provides a false positive to the monitoring process.

I think the practice of sandbagging implies that field hands are not realizing a benefit from project monitoring, or at least not from the reports. The benefit of field crews seems one of the purposes of project monitoring. If field crews are not the beneficiary then there is an inconsistency between theory and practice. This raises questions about project monitoring: What the purposes? Who are the beneficiaries? What their motivations?

With the inefficiency of double or more data entry and sandbagging bias in reporting established by Saidi through field experiments, I next look at the case study work (also collected as an embedded researcher on a civil project) done by Kiziltas.

[120] Sandbagging is addressed on page 61 in the textbook.
[121] The Stallard interview on page 35 notes that foreman reports are “notoriously suspect”, possibly in reference to sandbagging.

5.1.3.1.2 Field Observation and Case Study Quantity Performance

The topics I present here are monitoring and sources. At Carnegie Mellon University under the mentoring of Professor Akinci, Professor Kiziltas's doctoral research investigated methods of obtaining field measurements through sensor-based methods: Kiziltas explored through a case study how a field engineer collected quantities on a 38-month civil works highway construction project (Kiziltas & Akinci, 2005) and then published observations of quantities collection completeness.

5.1.3.1.2.1 Resource Literature

A literature review provided Kiziltas the monitoring methods she would expect to observe in practice. Kiziltas reviewed six sources of literature for resource intensity, accuracy, and sources:

- Dr. McCullouch at Purdue University[122]
- National Institute of Science and Technology (NIST) 2000 publication Non-Intrusive scanning Technology for Construction Status Determination (NISTIR 6457)
- Professor Liu of the University of Illinois at Urbana-Champaign[123]
- Professor Tommelein at U.C. Berkeley[124]
- Professor Tommelein's research assistant Dr. Hyun Jeong Choo[125], and
- Professor Huat[126] at the National University of Singapore.

Through literature, Kiziltas found that the expected accuracy of the quantities collected by the superintendent is dependent on the judgment and writing skills of the person actually collecting the quantities (Liu et al., 1995). She found that field supervisors dedicate 30%-50% of their time is to measuring, recording, and analyzing field quantities (McCullouch, 1997). Kiziltas did not publish the type of supervisor and quantities. The overhead resources expended to monitor and record project progress is 2% of sitework resources (NISTIR 6457, 2000) – I assume labor only. If the resources are labor and only the superintendent measures quantities then knowing that 50% of the superintendent's time represents 2% of sitework labor then it is logical to conclude the total supervisor labor is equivalent with 4% to 6% of sitework labor.

As a reality check, in my experience, 4% to 6% - while low - is within the realm of reality. Using the ReTRAC project as a case study I know that the project contract was $170M and of the contract $22M (12%) was hourly labor; indicating a minimum 0.3% (12% * 2%) of project cost was dedicated to monitoring. Therefore, the cost of monitoring the 4-year project was at a minimum $500K. This seems low but for strictly the monitoring aspects it is in the ballpark.

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122 See mccullouchconsulting.com, rebar.ecn.purdue.edu/multimedia/new/
123 See cee.illinois.edu/liang_liu
124 See www.ce.berkeley.edu/~tommelein
125 See www.strategicprojectsolutions.com
126 See www.eng.nus.edu.sg/civil/people/cvedavid/david

5.1.3.1.2.2 Monitoring Literature

Project monitoring is though a regularly updated schedule for weekly updates. The inputs of a formal three-level schedule update process are project, look-ahead, and commitment (Tommelein & Ballard, 1997), Table 25. A database allows feedback of the updated measured progress quantities for daily labor, daily equipment, and daily material resource demand to the weekly look-ahead schedule (Choo et al., 1999). Ideally, the database should include the resources and the associated knowledge in the lookahead schedule forecast[127] (Chua et al., 1999). Kiziltas observes that the methods outlined in the three publications contain the underlying assumptions that the quantities are to some degree: accurate, timely, complete, and collectable.

Table 25 Synthesized Lean project monitoring attributes.

3-level schedule				Resource measured progress quantities			
	Project	Lookahead forecast	Progress commitment	Daily labor	Daily equipment	Daily material	Associated information
Weekly update							

From the literature review, Kiziltas identifies that the source of progress measurements and the quality of that source is a feature to project monitoring. Kiziltas makes two initial observations of inefficiency in the case study company's feedback recording and archive system. First, Kiziltas perceives that latency in feedback is due to the field engineer physically transferring the measurements paper record from the field to the office. Second, paper and digital data are stored with ad-hoc methods, presumably creating a delay in retrieval.

5.1.3.1.2.3 Application of Literature

Examining the case study material with the source metric from her observational role of the project scheduler, Kiziltas makes several observations. First, schedulers rely on multiple sources, each specializing-in and fulfilling a different requirement. I assume the reporting workflow follows a path similar to what Saidi presented (2002), Figure 23. Second, these sources exhibited patterns for the degree of latency, completion, and accuracy, Table 26. Intuitively, due to the multitude of inherent interests in paychecks the labor hour metric had the highest completion rate and was accurate and consistent by an order of magnitude of three. Third, Kiziltas found that field crews measured and reported 90% of discrete countable items. If the quantities required a physical measurement or calculation then the field crews reported these at a low level of detail so to become countable or the field crew did not measured them.

[127] Note that these three publications are in the context of lean construction methods.

For a reality check of quantities accuracy, Kiziltas reviewed one month (CI 18% @ 95% CL)[128] of project 500 quantities submitted by the company's inspectors and foremen (timecards). A comparison between the inspector and foremen reported quantities, found that 90% were equivalent. The 10% that did not match had less than a 10% variance. A comparison of the reported quantities with the original estimate found that 99% were comparable but less than 1% (10% * 2%) varied up to 40%.

Table 26 Observations provided by a review of one week's (37% CI @ 95% CL) timecards on a 38-month civil works highway construction project (Kiziltas & Akinci, 2005).

method	source	measure	latency	completion	accuracy	purpose
	timecard	location	1 day	30%		payroll & monitoring
	timecard	work description	1 day	30%		payroll & monitoring
	timecard	labor job code	1 day	10%		payroll & monitoring
direct measurement	timecard	labor start & finish time	1 day	>94%	high	payroll & monitoring
	timecard	equipment job code	1 day	80%		payroll & monitoring
	timecard	equipment type	1 day	30%		payroll & monitoring
	timecard	material type	1 day	30%		payroll & monitoring
	timecard	material quantity	1 day	30%		payroll & monitoring
	timecard	external data	1 day	10%		payroll & monitoring
	timecard	feature, e.g., weather & unusual occurrence	1 day	30%		payroll & monitoring
visual count	timecard	work-in-place quantity	1 day	high	90%	monitoring, unit cost, and production
with post-processing	timecard	work-in-place quantity	1 day	low		
without post-processing	timecard	work-in-place quantity	1 day	low		
	document exchange	e.g., RFI, plans, spec.	day			planning
	meetings		1 wk. - 1mo			
	verbal exchange	Quantities, context features, and associated information				
on request	time logs		day			
	delivery slips		day			
	invoice					

[128] Confidence interval calculated and added by this author.

With these small samples, Kiziltas was not able to find a variance between the sources of reported quantities or between the reported quantities and the planned quantities. The variance between the original estimate and the reported quantities may be the result of a practice to unbalanced bids[129] [130] rather than an error or mistake. I cannot rule out as an explanation for these observations the influence of informal agreements between the reporters of quantities to compare values prior to reporting, nor can I verify the uniqueness of each source – the inspectors may have been relying on the foreman timecards – and engaging in *a priori* reporting of quantities.

5.1.3.1.2.4 Monitoring Quantity Sources

In her doctoral research, Kiziltas investigated sources of project monitoring quantities[131], Table 27 (Kiziltas et al., 2006; Kiziltas et al., 2007). Finding quantity sources and calculating endogenous quantities for updating the schedule or other project documents is a constant occupation of the field engineers. Without the field engineer physically observing what is occurring on the various project locations, through the gleaning of quantities from sources, she can form a partial representation. The level of detail of the quantities collected varies by the use. The quantities collection is also by locations, for planning purposes the locations are for workzones for each shift. Recording of the quantities collection includes the project phase number (features set nomenclature). Kiziltas found that often the record is missing when and where the field crews recorded the measurements.

[129] Front-loading is a well-known and established practice. In front-loading the estimator places a greater weighting to several items early in the project, this is a hedge against project cancelation and to reduce reliance on financing the cash-flow for subsequent activities.

[130] In my ethnographic experience, this may indicate out of round bid items that are intended to gain an extra profit due to some mistake in the plans.

[131] Note that this publication starts with sensor-based research, that portion is not included in this study.

Table 27 Kiziltas found eight sources of quantities. Derived from Kiziltas & Akinci (2005) and Kiziltas et al., (2006; 2007). The input metrics to the project planning and sources of quantities. I assume *verbal exchange*, is an informal process of requesting measurements and contextual features. Notice the reliance on timecards for quantities and project progress.

Project Information for:	Purpose	Timecard	Invoice	Meetings	Document	Verbal	Enterprise system	Geotechnical Report	On-board Sensors (OBI)	Specification database	Schedule	Public database	Sensors
Monitoring	Activity description	X											
	Labor hours	X					X						
	Equipment hours	X	X				X						
	Material quantities	X	X				X						X
	Production (daily progress)	X				X	X						
	Site conditions	X				X		X					
	Equipment factors									X			
	Material type											X	
	Haul distance & cut depth								X				
	External, e.g., weather	X				X						X	
Forecasting	Labor availability			X		X							
	Material availability		X	X									
	Equipment availability		X	X									
	Workspace requirements			X		X					X		
	5-week operations			X									
	Predecessor activity status			X		X							
	3-week schedule			X									
	Stakeholder constraints			X									
	Design information				X								
	Milestone status			X									
	Contingency risk mitigation			X	X								
	Change orders & extra work			X	X								
	External, e.g., weather					X							

Kiziltas cites three authors (Kiziltas et al., 2006) for what contextual features estimators need collected on the project site; these are: at the project-level (Liberda, University of Calgary), and at the activity level (Kannan, University of Southern Denmark; Staub-French, University of British Columbia).

Table 28 Findings of what activity features to measure for quantities reuse. Kiziltas categorizes the features into four factors; external factors are uncontrollable. Derived from Kiziltas et al., 2006.

Uncontrollable

	Ogunlana 1991	Akinci 1998	White 2002	NCHRP 2003
inflation/deflation				X
scope change			X	X
subcontractor[133]		X		

Controllable

	Ogunlana 1991	Akinci 1998	White 2002	NCHRP 2003	Kiziltas 2006
management | leadership | support			X	X	
engineering survey (admin) | site conditions[132]		X		X	X
organization structure (admin)				X	
contracting practices (admin)				X	
professional skills (admin)	X		X	X	
time dependent risk | weather		X		X	
communication		X	X		
project (plan) estimate accuracy		X			
project scope		X			
exogenous factors (i.e., outside)[134] | client[135]		X		X	
schedule resources | monitoring | feedback	X	X	X	X	
construction method[136]					X
design factors[137]					X
monitoring quantities context	X				

From a civil works case study Kiziltas and Akinci[138] (2005) define two attributes and dependent variables of performance, these are latency in feedback - method used to transfer the measurements record from the field to the office - and recorded measurement storage medium - guidelines or ad-hoc method. Kiziltas observed that schedulers rely on multiple sources for progress updates, each source specializing in an aspect of the schedulers quantities needs[139]. Kiziltas defined four metrics to measure quantities by, these are: quantities requirement, latency, completeness, and accuracy. Kiziltas found that if the field engineer synthesized the sources, then they compile a record of the project events, Figure 24.

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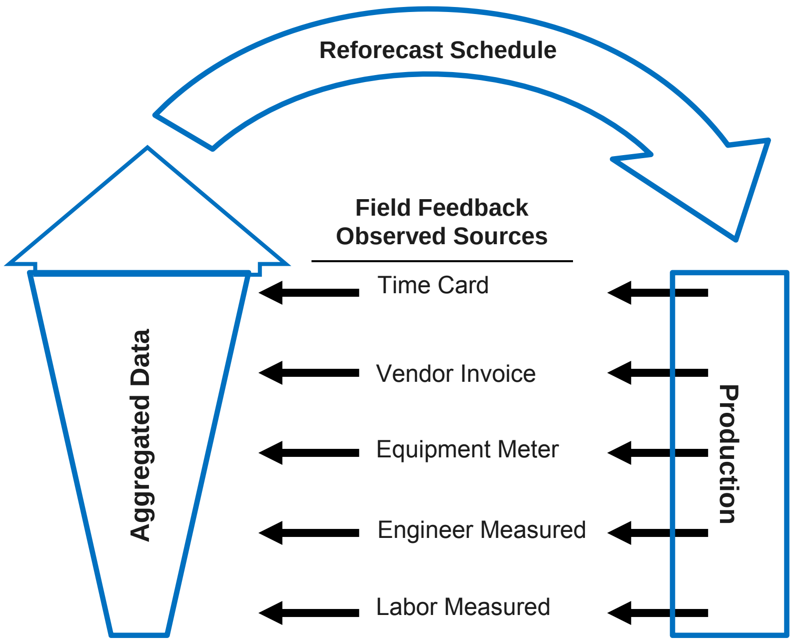
[132] Haul road, length, width, and grade; moisture content of soil; site access constraints ;site space availability.
[133] Backcharge and extra work orders.
[134] Location of project; time of year; weather.
[135] Change order.
[136] Crew composition, crew size; material characteristics, e.g., concrete strength, soil type ([FP]“relative clumsiness of elements, e.g., #4 bar versus #12 bar.”); method of forming, bracing used, and formwork size; quantity of equipment; stockpile dirt versus off-haul; type and capacity of equipment.
[137] Staub-French’s doctoral thesis provides design related factors.
[138] “The Need for Prompt Schedule Update by Utilizing Reality Capture Technologies: A Case Study.”
[139] A discussion of exactly what sources were used, why used, by who and how often each source was used in a specific case is suggested on page 232.

Figure 24 Sources of project progress. On the ReTRAC the labor crews, engineers, and vendors reported estimated quantities rather than actual measured quantities. The equipment meters and payroll timecards are the reliable sources. Graphic revised from Kiziltas and Akinci (2005).



My observed sources exhibited 10% completeness of feature set, 10% to 30% completeness of production quantities (quantity, location, inspector, material type, equipment hours, weather, activity description), and as should be expected a completeness of 94% to 98% for payroll. From these degrees of quantities quality, it is apparent that the quantities provided by field crews on the case study project are incomplete. The sources Kiziltas observed used on the civil project for conditions and the latency of each are as follows: time card (1 day), exchanged documents with other parties (day) (for example: RFI, drawings, specifications), meetings (1 week to 1 month), verbal quantities exchange (NA), time logs (on request) and delivery tickets (day). The partial quantities can be finished through other sources, but appear to have a delay of one week to one month. The project records lagged the project progress by one month and were composed of assumptions and opinions.

5.1.3.2 Merits and Culture of Monitoring

Two authors looked at the practice of quantities from the standpoint of why quantities are or are not utilized rather than look at the underlying merits.

5.1.3.2.1 Counter Argument: Survey of Quantity Tracking Methods

Professor Motwani of Grand Valley State University published a survey in 1995 - sample size is 44 contractors - of measurement methods used by Midwest contractors to monitor project progress. Professor Motwani does not define the activity type, contract type, nor the scope of projects. The sample size of 44 is a problem – this survey is not large enough to provide valid results but it is the best available on the topic. Accepting the results is difficult not just because of sample size but also due to the results, I find it hard to believe that 70% of contractors do not collect quantities. That is inconsistent with my experience, though I have never been to the Midwest and seen their construction practices. Motwani subdivided the survey responses into three categories: measurement method, reason no measurements are collected, and source of production rates used in project planning, Table 29. Motwani split the production rates sources between commercially published tables and the estimators *gut feeling*, 70% and 20% respectively. Motwani found that the vast majority of contractors simply found no benefit from collecting quantities and instead either guessed a production rate or cost or used a commercially published book of production. There might be more at work in Midwestern construction bidding practices than the upfront picture, possibly Motwani has found evidence of widespread *bid collusion* and *big rigging*.

Table 29 Survey responses from 44 Midwest contractors (Motwani, 1995); 30 contractors (70%) collected field measurements and 14 (30%) did not; likely for reasons of time, cost, and difficulty as the same issue, that is, resource intensity.

Those contractors that do (70%) collect field measurements used the following methods

Method	Drawback
1. units complete	resource intensive
2. percent complete	subjective
3. incremental milestones	N/A
4. start / finish measurement	N/A

Those contractors that do not (30%) collect field measurements cited four reasons

Reason	% non-collectors	% of total	My inferred reason
1. no two jobs are the same	35%	10%	implies no re-use of quantities
2. too time consuming	35%	20%[140]	indicates a negative return on investment (ROI) is perceived by the contractors, potentially due to professional knowledge
3. too costly	22%		
4. too difficult	8%		

[140] Sum of time consuming, costly, and difficult; these three have the same meaning.

5.1.3.2.2 Monitoring Culture

A 1995 presentation by Professor Meredith (Meredith & Mantel, 1995) of the Wake Forest University and adapted from *Project Management: A Managerial Approach* (Meredith & Mantel), in the 6th edition 2006, provides an outline of the culture surrounding quantities collection. Meredith emphasized that the project monitoring process big picture is that “the planning-monitoring-controlling cycle [is] a closed loop cycle based on the same structure as the parent system.”

The form or method of measurements can be:

- frequency counts
- raw numbers
- subjective numeric ratings
- indicators
- verbal measures

Meredith stresses in his presentation not the methods and uses of measurements but the culture surrounding measurement practices. A serious issue with measurements he gives (echoed by Saidi on page 133, Stallard on page 88, and *Construction Project Management* (2000) on page 388) is the bias of those reporting the measurements and the need to audit them to confirm honesty in reporting, Meredith suggests:

> *“the project manager must make sure that the bearer of bad news is not punished; nor the admitter-to-error executed” and “the hider-of-mistakes may be shot with impunity - and then sent to corporate Siberia”*

Once collected the field engineer compiles the measurements into reported quantities and then publishes these in reports for review and feedback. Reports are to be routine, referenced in the event of an exception, and utilized for special analysis. Meredith states “project reports should include an amount of detail appropriate to the target level of management,” similar with the survey results, Table 1 page 38. Through communication and formalization, these reports provide the following benefits:

- understanding goals
- progress awareness
- realistic planning
- relationship of tasks
- reliable early warning and response

As the last publication reviewed, the methods provided by Meredith (1995) – while having a differing vocabulary - appear in the previous literature. Therefore, the literature review appears to be saturated and complete for published monitoring methods.

5.1.3.3 Analysis of Research Publications

Based on a review of the published quantification literature I found four researchers that have addressed the topic, these are Dr. Saidi while at University of Texas at Austin (2002), Dr. Kiziltas while at Carnegie Mellon University (2005), Dr. Motwani at Grand Valley State University (1995), and Dr. Meredith at Wake Forest University (1995). Each added a contribution to the theory of quantities. The cumulative work of these researchers provides six of the twelve methods of quantification I have discovered through this literature review, Table 30. Of those methods, none was unique, I found all in the resource publications – this is expected since these researchers were focused on automating quantification and presented the existing methods based on their observations and literature reviews. One source that both Saidi and Kiziltas provide is the fixed formula approach to quantification, a method I have otherwise only found in the PMI Project Management Book of Knowledge.

Table 30 Synthesis of quantification methods published in reference and academic publications.

	Method	Saidi study	Kiziltas study	Motwani survey	Meredith
Methods	start / finish date			X	
	percent complete:			X	X
	-percent of time				
	-percent of material				
	-percent of cost				
	-percent of component (visual)				
	milestones	X		X	X
	units complete:	X	X	X	
	-count units (inputs)				X
	-field measure (outputs)				X
	fixed-formula	X	X		
	plans:				
	-scale from plans				
	-use bid quantity				
	opinion | guess				
	Conference				X
	equivalent units	X			
	level of effort				
	network distribution				
	apportioned effort[141]				

[141] The apportioned effort method appears similar to the recipe formula assemblies concept.

The field embedded researchers both found comparable results as far as their literature review. Their field observations is where they saw a difference – I suspect that Saidi was a cost engineer and Kiziltas was a scheduler – they seem to imply or state as much. From Saidi I found the path of quantities from the foreman's measurement of quantity to clerk keying quantity to the accounting system – and the redundancy in repeatedly compiling quantity reports from subreports. Returning to the previous section with reference texts, Saidi relates that the foreman collects the quantities and passes these to the superintendent. A core finding for Saidi in respect to quantities is the game of formen to *sandbag* and misreport the actual quantities so they appear to always be on-budget. This explains the reference publications consensus advice to not let field supervisors do quantities. Kiziltas identifies numerous sources of quantities and this comes to define her work.

Here is a major distinction between the two observers, indicative of their role – Saidi relates the representation of features of quantities as a cost code nomenclature and Kiziltas does not. For the most part schedulers do not use quantities because of the abstracted level of the schedule. Whereas the cost engineer lives in quantity features due to the very detailed context accounts. While Saidi provides a good overview of quantities and the bias involved, Kiziltas measures the performance of quantity collection depending on factors, the factors are accuracy, latency, completeness, and the reason for the quantity. The intention was clearly to correlate these features with various sources of quantities and the quality of the quantity. The underlying knowledge is too incomplete and Kiziltas ended up with defining features for quantity quality – which is consistent with the reference text knowledge in the previous section, and measures of baseline quantity performance. Some broad performance trends are human behavior based, if countable then counted, if not then abstracted to become countable, otherwise not quantified. Some features of quantities are habitually omitted such as location and time. Because of the inherent interest in being paid, the quality of quantities for labor hours was near perfect. An interesting finding was a very small number of bid items with large variances by orders of magnitude – here Kiziltas did not see fraud but likely if she dug deeper she would have found out-of-balance bidding similar to how Saidi found sand bagging when he pushed for the answer. The work by Kiziltas is important for the measured performance that she provides from real world observations of a civil works project – it is unique work and a core foundation of this thesis.

The work by Motwani and that by Meredith looks at the culture and opinion of quantities. Motwani's survey of Midwest contractors clearly shows that the contractors collecting field quantities is in the minority – they simply do not find a benefit from real production rates in their project bids and planning. His work predates the internet and while there was electronic computing at that time – possibly paper-based planning methods were still widespread. In that context real production factors simply would not matter since it is too tedious to plan at that level of detail. The culture work by Meredith supports the findings by Saidi of bias in reporting quantities. Meredith recommends auditing field quantities for bias and rewarding honesty in reporting over punishing poor performance. It is poor performance – endemic on projects at the cost accounting level and the purpose of hiding through misrepresenting quantities. Otherwise, like Saidi, Meredith shared methods of quantity measurements echoed in the resource texts.

With that analysis of the research publications it looks like the reference texts are theoretically grounded. Consistent with thir focus on making a technology related contribution - the researchers have not added anything substantial to the reference texts but the formal approach to validation and reliance on field observations provides confidence in the sum of this knowledge. Next, I will compare the reference literature with the research publications.

5.1.4 Cross Analysis of Reference and Research Literature

Through a review of both reference texts and research publications I looked at 300 publications, of these 29 were relevant to quantities. All but one was specific to construction quantities – the exception was an industrial engineering reference text. From the industrial engineering, it is clear there are methods of quantification that are not used in construction. Once aspect I failed to capture are the internal guidelines, this was due to the tacit nature of the knowledge. Without an ethnographic presence as a quantification engineer, I just cannot find a discussion of quantification practices used by practitioners. The division between the resource material and the research publications is the degree of acceptance. Reference texts are considered doctrine while the research publications are validated but still are exploratory. The research publications provided insight into the methods of quantities as observed by the researchers. The best insight is into the process, the sources, the degree of adoption, and the culture of quantification. The aspect that is clearest in the research publications that is absent in the reference texts is the role of fraud and misrepresentation in quantities. Through the literature review, mostly through the reference texts, I found seventeen methods of quantification (twelve without counting submethod variations) and through the research publications I found eighteen sources of quantities.

Table 31 Comparison of methods and sources as presented in the preceding literature reviews.

		Input Source																	
		sitewalk	time card (time log)	equipment meter (OBI-type)	sensor-based (embedded)	sensor-based (remote)	2^{nd} party invoice	delivery ticket	field crew	engineer	meeting	drawings	schedule	estimate sheet	endogenous formula	cost report | budget	productivity report	project (logistics) database	publicly available database
Method	a priori											*	X	X					
	start / finish date												X						
	percent complete	X	X	X	X		X	X	X	X	X	X	X			X			
	milestones	X	X				X	X	X	X			X						
	units complete	X			X							X							
	fixed-formula											X						*	*
	trust a 2^{nd} party						X	X			X								
	opinion | guess								X	X	X								
	equivalent units											X			X		*	*	*
	level of effort												X						
	cost formula															X	*	*	*
	apportioned effort														X		*	*	*

Table 32 Synthesis of quantification methods published in reference and academic publications.

Method	Parmley	Bartholome	Ostwald	CPM	Peurifoy	Stevens	PMBOK	Kerzner	APM	PM 6th	Saidi	Kiziltas	Motwani	Meredith
start / finish date							X	X					X	
percent complete:							X		X	X			X	X
-percent of time				X										
-percent of material				X										
-percent of cost								X						
-percent of component (visual)														
milestones							X	X	X		X		X	X
units complete:										X	X	X	X	
-count units (inputs)				X										X
-field measure (outputs)				X										X
fixed-formula							X				X	X		
plans:														
-scale from plans				X										
-use bid quantity				X										
opinion | guess			X							X				
Conference			X											X
equivalent units								X	X	X	X			
level of effort								X	X					
network distribution				X				X						
apportioned effort[142]								X	X					

Through the literature review I have found a solid domain of quantification knowledge but based on my ethnographic experience in quantification I can see that there are large gaps and some aspects are not represented with the significance I would expect. In the next chapter I will expand on the literature through three approaches, these are questionnaire survey, interview survey, and ethnographic observation.

[142] The apportioned effort method appears similar to the recipe formula assemblies concept.

5.2 Project Monitoring Tacit Knowledge: Surveys of Practitioners

5.2.1 Introduction

While I was a field engineer and earlier as a highway Laborer on large heavy construction projects there were no written guidelines, by tradition and custom, knowledge was passed from journeyman to apprentice. As a field engineer, there was one written guideline for a cashflow chart in a spreadsheet used for a *project monthly report* (PMR)[143]. Each month this chart was prepared and transmitted to a division office presumably for a projects progress review meeting. It is possible the report served no purpose other than to keep the project teams *head in the game*. Other than this report's instructions that nobody really understood (it was an s-curve style report) – as field engineers worked solely from knowledge passed from field engineer to field engineer.

The tradition of construction is a culture where field engineers build large projects with a flat drawing of what may be built, a performance specification, and a large body of guidelines in the form of textbooks and standards. These have gaps in knowledge and are often presented at an abstract level that leaves details as a field issue. The tradition of large projects monitoring is one that textbook and research literature does not present beyond a summary; field engineers cannot learn the large projects' body of knowledge through a review of existing published theory, they can only learn through practice.

Looking back to the case project in this thesis – why was there a rail project through Reno Nevada? Leland Stanford - the man behind the original Overland Project - at the core was a haul vendor. To improve his business and provide his customers a lower freight charge, he adopted incremental innovations in the transport of bulk commodities: starting with mule trains he transitioned to steam locomotive trains, in the process reducing the transportation cost. The disruptions in the status quo necessary to adopt this innovation were huge – mule trails were changed into rail lines.

I also wanted to adopt innovations – on a smaller scale. Similar to the kid illustrated in Adam Smith's[144] account of the invention of the automated steam engine, I was either an iconoclast or valued time. Adam Smith provides a story of a child employed to open and close the check-valve on an early Newcastle steam engine – the stationary precursor to the steam locomotives

[143] This chart over the course of the project evolved into an Earned Value Management type S-curve. The inputs are revenue, projected revenue, cost, cash flow, projected cash-flow, and time (project duration in days); the chart represented actual cashflow, forecasted cashflow and the maximum pay curve.

[144] Adam Smith (1776) *The Wealth of Nations,* Modern Library Edition, 1994. In Chapter 1 is a discussion on three causes of increased production and contains a story originally published by J. T. Desaguliers *Course of Experimental Philosophy* vol. II 1744 p.533.

Leland Stanford would later employ. The boy wanted to play ball with some other kids so devised a linkage between the reciprocating assembly and the check valve to automate his task, therefore freeing the child and as a side effect doubling the engines production.

As a field engineer during 2005 and 2006 on a large design-build transportation corridor project[145], I tried to innovate, test, and validate methods that improve accuracy and precision in collecting and post-processing production quantities, reduce monitoring resource requirements, and therefore allow for purposeful planning with the goal of improved working conditions for field hands. The project managers discouraged efforts to change the existing collection methods. Unable to pass-up the opportunity of the stable test-bed the project provided - allowing feedback in days or weeks after each change - I made an argument for testing new practices. As long as the changes did not result in a perceivable negative impact, the managers approved limited trials.

I implemented two incremental innovations on the ReTRAC. One was a collection method I tested with the help of an engineer at the waste management company. I give barcode cards to the Teamster haul truck drivers. The intention was to use electronic invoices for quantities monitoring. A second innovation was endogenous functions, for example $y = mx+b$. My project managers had doubts for the transferability of the methods I developed. In their expert opinion, while these methods will reduce labor resource demands and improve the degree of completeness, accuracy, and consistency, the methods will increase the learning process - through a reduced learning curve - and will therefore reduce robustness. Simply put, they would have trouble if I quit and my replacement had no idea what I was doing and could not use my system: a valid concern.

In the project and business managers' expert opinions, the only reliable method available to field engineers for collecting quantities is a method that relies on physically measuring the work-in-place and recording these on paper. Based on this compelling logic, while I realized short-term gains in reduced labor resources, the long-term labor cost will likely be increased through the increased labor skill necessary to support the new methods, therefore realizing no net gain in the long-term. The institutional process of recruiting new field engineers does not support the technology employed. The use of technology requires recruiting field engineers from rigorous construction education programs or the project must provide the specialized skills through additional education after hiring.

[145] Reno Transportation Rail Access Corridor (ReTRAC) Granite Construction Heavy Construction Division.

In the following sections, I present my findings gathered through a range of survey methods. The first section is a pre-survey survey. From the pre-survey I gathered an understanding of the problem and solutions, then developed a questionnaire using the pre-survey as a test. Second, after reworking the pre-survey questionnaire I distributed it in a broad survey of the project based industries both within construction and outside construction such as ship building.

The survey questionnaire contained gaps and I was not confident in the results without corroborating evidence. While the survey provides the methods of quantities and the performance – there were details I wanted to understand. The survey population is large (n=127) but the response rate is low, therefore raising the issue of self-selection. The survey self-selection should affect the survey's confidence interval by 5%[146] [147]; this widening did not affect my conclusions.

After the questionnaire survey, I conducted interview surveys of four industry professionals. They are all exceptionally talented people, with long carriers, and I was very lucky to have access to their time. First is a heavy construction project manager, second, a heavy construction projects manager, third a former heavy construction senior project controls engineer, and last a heavy construction cost engineer (similar to project control engineer).

The interesting connection, all four worked either directly together or indirectly across their careers. The project engineer worked for the projects engineer, and the projects engineer worked for the senior projects control engineer. This tuple worked at a large contractor and then the project engineer and projects engineer moved to a second large contractor where they both worked with the senior cost engineer. Further, three of the four are alumni of the Stanford University Construction Engineering and Management program. This is an interesting group due to the vertical cross-section and the comparable sources of quantities.

The sum of these surveys captures a context of project monitoring and categorization that is otherwise unavailable.

[146] Typically, a 20% response considered acceptable https://en.wikipedia.org/wiki/Response_rate
[147] Holbrook, Allyson, Jon Krosnick, and Alison Pfent. "The causes and consequences of response rates in surveys by the news media and government contractor survey research firms." Advances in telephone survey methodology (2007): 499-528.

5.2.2 Pre-survey and Survey

My ethnographic observations of the ReTRAC project provides depth and insight into the processes used to monitor a large civil project. While valuable, I do not know if my oberservations are representative of other large civil projects, the construction industry as a whole, or if this is typical of the project-type. A comparison of the construction industry and the project type process is not feasible due to my inability to find comparable surveys with a sufficient sample size. To determine what percentage of civil construction projects my ReTRAC observations represent, I surveyed the civil industry.

My survey had wide-ranging intentions of observing the adoption of sensor-based monitoring systems and software tools, the baseline manual methods, and the accuracy and consistency of the baseline methods. I distributed a questionnaire with multiple-choice responses by email during the autumn of 2008. The survey population covered a diverse domain of industry divisions sharing the need to monitor progress.

The industries surveyed are: building, industrial, heavy civil/infrastructure, mechanical/electrical/plumbing (MEP), recycle/waste management, mining, timber, agriculture, ship building, petroleum extraction, railroad, medical care, manufacturing, software, engineering, government, utilities, and facilities maintenance. Within the industry divisions the following subcategories were defined: academic/research, design, consultant, owner, construction manager (CM), general contractor (GC) and subcontractor/self-perform (sub). The logic for including construction sub-divisions as a feature is that CM firms have a fundamentally different need for quantities than self-performing contractors. Self-performing contractors use quantities for three main purposes: production monitoring, billing progress payments, and historical quantities for estimating/forecasting. In contrast, CM firms are interested in monitoring project time variance and verifying GC progress payment requests.

This section is the baseline monitoring methods portion of the survey as published at the 2009 ASCE International Workshop on Computing in Civil Engineering *Project Monitoring Methods Exploratory Case Analysis: Industry Responses* (Peterson & Fischer, 2009c).

5.2.2.1 Questionnaire Development

Based on a pre-survey roundtable discussion I gained insight into the current state of quantities, coupled with my ethnographic experience I grouped their responses into five categories. These categories formed the structure of the survey:[148]

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[148] The full range of the questionnaire is not covered in this paper.

- quantity-tracking tools
- methods of collection
- methods of recording
- ***current state of quantities collection***
- insight into improvement, innovation, and coding

In this chapter, to keep with the topics in the rest of this thesis, I focus on the second and fourth survey categories: *methods of collection* and *current state*. The tools, recording, and insight are tangential to the core methods and current state that I want to capture here. The survey measured the current performance and asked seven questions.

- What degree of accuracy is expected?
- What degree of consistency is expected?
- What level of detail (LoD) provides this degree of accuracy and precision?
- What level of applied resources provides this degree of accuracy and precision for the given LoD?
- How many individual items are measured?
- What is the magnitude of these measurements?
- How often are quantities estimated rather than measured?

5.2.2.2 Pre-survey Group and Survey Population

Prior to distribution as a survey, I distributed the questionnaire with open questions back to a pre-survey group of Stanford Construction Engineering and Management alumni. I asked the pre-survey contacts to forward the questionnaire to those within their organizations active in project monitoring. I then used those responses to further define the answer options in the survey as well as correct a few questions that were misunderstood.

With the questions modified based on feedback, I then expanded the focus-group population to include the mining and recycling industries. I based the decision to survey outside the construction industry on the intuition that other industries use monitoring methods adaptable to construction. With this larger group, I made a second round of refinement to the questionnaire.

5.2.2.3 Pre-survey Group Analysis

The pre-survey responses provided a couple unexpected responses. First, the building contractor unexpectedly preferred manual collection methods to automated methods. This preference for manual methods is for the learning experience project monitoring provides to new field engineers, Figure 25.

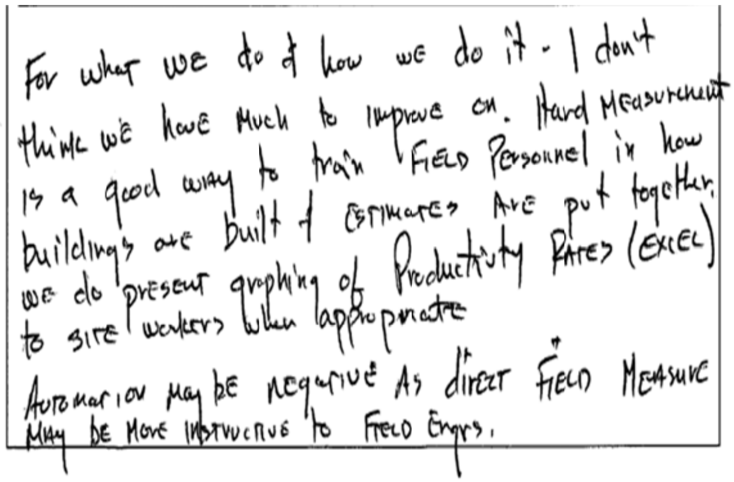

For what we do & how we do it - I don't
think we have much to improve on. Hard Measurement
is a good way to train field personnel in how
buildings are built & estimates are put together.
we do present graphing of Productivity Rates (Excel)
to site workers when appropriate
Automation may be negative as direct field measure
may be more instructive to field engrs.

Figure 25 A commercial builder felt that manual collection methods are preferable because it is a “way to train field [engineers] how buildings are built.”

Second, the commercial builder was not as concerned with project monitoring for project progress reporting as they were with reporting to government regulatory agencies. Sustainable building practices dictate that field engineers reuse the building material from construction operations. To abide by California Section 01151 requirements for government-funded projects or to obtain LEED points, builders must document the diversion or reuse of 50% to 75% of construction demolition material.

The environment and government compliance were not expected and provided illustrations of an unexpected values from project monitoring. I did not observe these values in the literature review or my on-site field observations, nor did I perceive this value during my lab analysis. On the ReTRAC I observed contaminated soils that were monitored with a distinct account but this was for billing purposes rather than planning or compliance purposes.

5.2.2.4 Survey Analysis

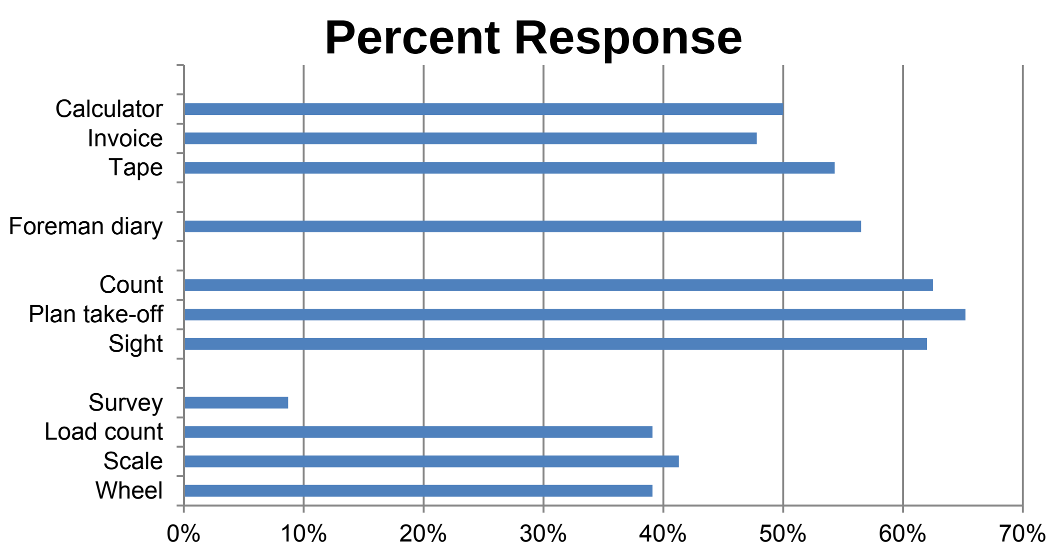
I revised the focus-group questionnaire with standard responses and distributed it as an online survey in late 2008 to an international population representing all the global regions – with a much stronger representation in North America. I sent the survey to my three target construction industry segments of heavy construction, construction management, and non-residential commercial construction.

Based on the survey, I found that these three construction industry segments have different concepts of quantities collection. There was a variance between the degree of quantity estimating that occurred in place of field measurements: Over 60% of the heavy civil manager responses thought that field engineers estimated 10% of the quantities in a reporting period.

While 70% of construction management responses thought that field engineers estimated 25% to 50% of the quantities. The construction management domain is comparable to the non-residential building construction managers, 40% thought field engineers estimated 25% to 50% of the quantities. For all three domains of heavy civil, construction management, and building, 20% to 30% of the managers did not know what percentage of reported quantities the field engineers estimated.

At the same time that across the industry field engineers estimate a quarter of reported quantities, 70% of construction industry managers think the accuracy of quantities is highly important. Obviously, the reported widespread practice of estimating quantities does not support the expectation for accurate quantities. A possible explanation for this practice is the 80/20 rule – from this I'd expect 80% of the quantities estimated and 20% measured. In that light, 20% estimated is one fourth what I'd expect, and so I have found through this survey a high degree of measurement and a low incidence of estimated quantities.

Table 33 These methods are representative of two-thirds to four-fifths (63% to 81%) of United States construction companies; sample n=127 confidence interval is 9 @ 95% CL at worst case of 50% response for population of 490,000 U.S. construction corporations (IRS, 2007) – plus add 5 to the CI to account for self-selection for a total CI of 14. The percentage is the ratio to total sample.



The last section in the questionnaire is the need for improvement. Due to the open-ended format of the questions, a quantitative analysis is not practical. There is qualitative data mining tools available but due to time constraints, I did not attempt this approach. My qualitative analysis provides highlights for areas needing improvement, the role of technology or improved methods, and miscodes, Table 34.

The survey responses supported the need for formalized methods as both an area needing improvement and as a role of improved methods. As for the role of technology, the managers thought the collection process is a good application for technology that researchers need to investigate.

The last question on miscodes provided two interesting anonymous responses from heavy civil engineers.

The first is,

> *"usually miscodes are made under management direction to move cost around."*

The second is,

> *"30% of the time, foreman are coding to incorrect cost codes."*

The remaining responses concerning coding described the codes as a linchpin of their planning and control system. This pre-survey identified monitoring theory (the goal of this study), implementation of sensor-based methods, and a process of coding measurements as processes that need improved.

Table 34 Focus-group responses (2007 CIFE questionnaire): Note that a segment of responses provides methods of monitoring as both an area needing improvement and a role of improved methods. The percentage is a ratio of the total responses.

Focus-group Response - What can be improved n = 27

Areas of project monitoring needing improvement?		The role of technology or improved methods you envision?		What is your view of miscodes and the importance?	
collecting	9%	methodologies	19%	low	4%
recording	9%	systems	15%	medium	0%
analyzing	9%	collections	41%	high	37%
methods	30%	markets	4%	exception	11%
automating	4%	roles	11%	directed miscode	4%
displaying results	4%	reports	4%	consistent	7%
communicating	4%			analyze	4%
find nonproduction	13%				
staffing resources	9%				
historic library	4%				
unknown	4%	na	7%	na	33%

The second question, vision for role of technology or improved methods prompted another wide domain of responses within the topic of automation. The last question, "your view of miscodes," presented responses indicating the importance of codes and the various applications – nearly half thought miscodes was a highly important topic. Specifically, one response captured an underlying issue, *"codes often seem to be used as holding places for data that will be inevitably shuffled to another location before finding a final home,"*

This quote is describing *cost shifting:* a fraudulent activity used to inflate billings or to hide financial issues*:* a serious problem (Haider, 2009). The issues of accuracy, repeatability, and truth in representing reported project measurements, are relevant to stakeholders with an interest in project progress such as financial institutions, owners, oversight agencies, regulatory agencies, contractors, and subcontractors. The issue of 'how things are' versus 'how people want them' is a topic in construction that could be a study by itself.

Table 35 Survey responses to questions for quantities characteristics[149]. The accuracy and consistency are what I observed typical on the ReTRAC project. The applied resources are generally field engineers but could include the superintendents, foremen, and office clerical support staff involved in quantities.

Context				Performance						
Industry	Industry role	Population	Manager[150]	Accuracy	Consistency	Level of detail	Applied resources	Items measured	Magnitude	Degree estimated
Building	GC[CM]	30	70%	90%	High	Med-High	4	100s	10s	25%
Building	Sub	8	Y	70-90%	Med-High	Med-High	1-3	1000s	100s	50%
Heavy Civil	CM	12	75%	80-90%	High	Med-High	4	100s	100s	25-50%
Heavy Civil	GC[sub]	26	92%	80-90%	Very High	Med-High	1-3	1000s	1000s	10-25%
Mining	GC	6	Y	90%	Very High	High	4-6	10s	100,000s	10%
Medical Care		2	50%	90%	Very High	High	1-3	1000s	1000s	0%
Manufacturing		3	Y	90%	High	High	4	100s	100,000s	10%
Petroleum	Owner	2	Y	90%	Very High	High	5	1000s	1000s	10%
Utilities	Owner	3	Y	90%	High	High	10's	1000s	1000s	0%
Facilities	Owner	3	67%	80%	High	Low	4	100s	1000s	25%
Specialty Trade	Sub	3	Y	80%	High	Med	4	10s	100s	10%

5.2.2.5 Qualitative Discussion

The core values of auditing ethics are independence, integrity, impartiality, professional competence, confidentiality, and professional behavior (Handbook of International Standards on Auditing and Quality Control). While the topic of this study is not auditing, the subject matter is relevant and the ethics of auditors applies. The quantities collected by field engineers are used to forecast future events and represent past events. Accountants at publicly traded

[149] Suggestion for future work, perform an ANOVA on this data.

[150] Presumably, the fewer responses from managers the more reliable the results because this survey is for operation knowledge not methods and significance of tactics in management of humans – 80% of the survey responses are from those who self identified as managers. I did not subdivide the dataset for the manager criteria because the sample size would be insignificant. For example the building industry GC[CM] would have the largest sample of ten. I did not look to see if there was a difference based on this division.

companies - also likely in private companies - rely on project quantities to prepare financial statements for each quarter. While field engineers are not independent, the values of the auditor are important. Corporate stockholders and the managers they employ entrust the field engineers to observe a flow of quantities that is synthesized into project information confidential to their employer.

5.2.2.6 Survey Conclusion

From the survey and the references to widespread bias in reporting - the auditing code of conduct is increasingly important as technology allows field engineers greater influence to sway project expenses and progress reporting. The professional conduct of field engineers not just as engineers but as independent professionals demands that they maintain impartiality and integrity and that they do not modify measurements or codes to facilitate desired results rather than the results the observations suggest.

The survey provided two responses that were unexpected.

First, I did not anticipate the use of quantities measurement as a learning task for new field engineers. The response came from the pre-survey during the open question format of the questionnaire development. If they also benefited from the quantities or if this was a pure red herring to get field engineers engaged – I do not know. This learning aspect would be lost if the quantification task was automated or made overly rigid as a formally structured process to derive the most efficient use of resources. The field engineers need room to make mistakes and derive their own quantification approach to learn. In my ethnographic experience maybe that was the purpose of my quantification responsibilities. On the one hand I saw some use of quantities, but in all honesty at the same time I saw no use for quantities other than for identification of process variance. I rarely saw quantities used to forecast in the formal sense – this proved too tedious in an evolving planning environment – the rule was a long series of weekly and quarterly short term guesstimates throughout the project. Some were better at guessing than others. It made me really uncomfortable to see these broad guesses thrown out and seeing those same guesses prove wildly wrong several months later. I am divided on the pragmatic purpose of quantities – though I am certain that in a more integrated and automated future the accurate and efficient collection of quantities will become essential.

The second use of quantities I did not expect was government reporting. During my ethnography I saw quantities specifically measured for contaminated soil excavation. This was not specific for government reporting but was for a higher cost allocation to that task for payment to the contractor. The contaminated soil cost more to excavate and dispose than regular soil, so the contractor was paid for this soil as a special contract provision. The temptation was clearly to misrepresent regular soil as having the contaminated soil features since the special contract provision paid double for contaminated soil as it did for regular soil – and then the regular soil could be disposed of onsite as fill material to avoid the disposal fee for contaminated soil. During the pre-survey survey one participant said the new provisions require reporting quantities for reused material. My ethnographic experience is with a lumpsum contract using monthly progress payments based on percentage of completion for a list of payable tasks that numbered in the tens. There are contracts that require submitting quantities for repayment – my understanding is this system is a huge game though while I trust my source this is hearsay and I have not seen it myself.

The questionnaire survey produced suggested areas for focus, these are formalized methods of quantification, technology for quantities, and the coding process. The very concept of the quantity varied between the commercial, residential, and heavy construction domains. Commercial and residential builders are more comfortable with estimating a field quantity (50% estimated) than heavy construction contractors (10% estimated). All three domains agree high accuracy of quantities is important. The discrepancy between commercial, residential, and heavy construction may be explained by their contract style. Commercial and residential builders often use a soft bid format – where renegotiations to cover unforeseen events and changes is common. In heavy construction, usually civil works, the plan is expected to adhere to a higher quality and the design more fixed, therefore the bids for the project are hard bids, meaning they are infrequently modified and so the contractor must adhere to a closer expectation to reality than commercial builders.

The differences across the three domains are in the contractor role, there are general contractors and construction managers that do not actually construct the project, they are administrators. The administrators of construction measure the project in 100s of quantified accounts while the actual builders measure in 1000s of quantified accounts. They both measured the magnitude of quantities in the 100s to 1000s. The specialty trades are an exception, they measured in 10s of quantified accounts. The reason for the difference between administrators and builders is the purpose of quantities. Administrators use the quantities to allocate credit and reward that credit with a prescribed payment for progress. The builders also want to be paid but at the same time they must forecast their future to ensure they are proceeding on the path that will be rewarding. For this reason the builders measure ten times the detail of the administrators.

There are methods that are clearly more commonly used and those less commonly used. The most common: Counting, this is consistent with Kiziltas's findings (2006). Plan takeoff, the most universal method and given by Vitruvi 2,000 years ago. Sight, this is the simple percentage of completion based on a visual idea of what the final product will be and a guesstimate of what percentage of that is viewed at that point in time. The less common methods are formal surveying with chains, load counts – probably unique to earthwork, scale - again probably earthwork specific, and the measuring wheel – likely also specific to earthwork, it is a device like a walking stick with a medium sized wheel the field engineer pushes that counts rotations of the wheel to generate distance. Methods that are found with a medium frequency are the invoice, tape measure, and formulas to calculate new quantities based on assumptions and know quantities.

For the suggestions for improved assigning features – these were provided with advice that mistakes in feature sets were, a) common – as found by Kiziltas (2006), and b) often directed – this bias is consistent to the findings by Saidi (2002). The consensus from the survey is that the codes are the linchpin of the planning and control system and the importance is under understood.

There are gaps in the survey responses and the confidence interval of 14 is broad enough that I can make only a few broad conclusions for the most clearly differentiated topics. For the most part heavy contractors measure much more of their field quantities than commercial builders. Self-performing builders need ten times the detail than do the administrators of the builders. There are methods of quantities that are universal to construction, these are counting individual items, measuring from the plans, and just looking and envisioning as a percentage of the expected final product. These are the main methods.

To close some of the large gaps remaining after overlaying the literature review with the survey, in the next section I will ask open ended questions in an open interview format with four heavy construction project engineers with long careers and a broad understanding of heavy construction.

5.2.3 Interviews for Tacit Knowledge

In the following four interviews I look for tacit knowledge that I suspect is missing or at least incomplete in the literature review and questionnaire survey. One of the relationships I'd like to better understand is the role of indirect and direct materials – formwork is an example, the lumber is purchased by the project but is consumed by numerous concrete operations. How is the material resource applied to those accounts. During the ReTRAC project the project engineer instructed the field engineers to report neat line quantities (plan quantity) instead of actual quantities – this never seemed right so I asked during the interview why neat line. In addition to specific questions, I am also looking for knowledge offered voluntarily by each of these practitioners.

5.2.3.1 Project Manager: Project Materials Distribution

> *The quantities are what matter, if the quantities are wrong – the one-thing field engineers can know – then nothing else can be correct.*
> Ron Dukeshier - ReTRAC Project Manager (2002 – 2007)

The ReTRAC project manager often acted as a construction engineering mentor to myself and the other field engineers. He provided an example of a quantity tracking system he had observed used at Atkinson Construction[151], another heavy civil company specializing in large civil projects that peaked in the 1980s, twenty years before the ReTRAC project. Atkinson was three times the size of the full Granite Construction Corporation and much larger than the Granite Construction division overseeing the ReTRAC. Ron explained that the format used at Atkinson[152] placed the permanent materials and temporary materials as a direct job quantity. This was important because at that point on the ReTRAC project the field engineers had no record of where most of the bulk material was used – for example, the underground utility precast components and dimensional lumber. We could not see if the material cost was following what we had expected – essentially material was just whatever it was. This may be OK, but we did not know this and not knowing why the field engineers did not need to know what the material cost was nor knowing what the actual material cost was in relation to expected cost made Ron uncomfortable. As a new field engineer, I asked Ron about the association of material to the direct activity and that I would like to know my material cost by activity – Ron confided that he too wanted to know. Ron then pulled an old Atkinson cost report out of his file cabinet and with the current Granite cost report compared the differences with his understanding of the purpose of each field and opinion on each from the field engineers perspective.

The permanent and temporary materials were handled differently at Atkinson and Granite. The Atkinson activity breakdown placed materials as an applied resource. At Granite the material was not an applied resource, it was placed in an entirely separate breakdown structure parallel to activities. Ron explained that the downside of the Atkinson format is it may have resulted in difficulty recording the quantities of temporary materials used as a part of multiple operations. The field crews reuse the same temporary materials for multiple operations and the same

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[151] See Atkinson Sonctruction, last accessed 10/26/2015 www.atkn.com

[152] Note that Professor Paul Teicholz (founding director of CIFE) worked for Guy F. Atkinson Co. from 1968-1988 as the information technology manager, www.nbm.org/biographies/dr-paul-teicholz.html (Darryl Goodson interview (2009) vice-president of heavy construction division, Granite Construction and former project engineer supervised by Teicholz at Atkinsons Construction).

material is repeatedly counted and reported as a quantity for each use, leaving no record of the quantity purchased originally. This suggests the solution of renting temporary material to operations or similar methods as suggested in the Teicholz interview: I will present this later in this chapter.

At Akinson, the materials and operations shared the same code and the field engineers separated materials with an applied resource code. For example, a direct account (distributed account) for earthwork backfill has sub accounts for labor, equipment, material, haul, and subcontractor. At a later date if only the labor and equipment unit cost for an activity was needed and the material cost will be derive based on current market rates, then the material applied resource code allows filtering the material subtype out. If the material market has not experienced a change in cost variance from labor and equipment cost, then it is simpler to use the unit cost for the sub accounts rather than derive material cost separately.

The capture of the labor, equipment, material, haul, and subcontractor under one account allows the cost and bill of material to be reviewed without first distributing undistributed material accounts. A complication is if the activity encompasses multiple materials, then which material do field engineers measure for the reported quantity.

Also, will coding cost for other material negate the use of the material unit cost metric for control or estimating purposes. In the case that the material account is capturing multiple material types, then associated prorated undistributed material accounts as a percentage is a solution. Therefore, it appears that regardless if the distributed account includes material there will still be the need for undistributed material accounts, though intuitively for 10% of the accounts rather the current 70%, therefore resulting in a simplified and complete representation of the project.

The discussion with Ron did not find specific formulaic answers to the material representation question through the discussion. Intuitively the solution is reliant on the specifics of each scenario and requires practical experience with a study of project monitoring theory.

Next, I will present my interview with Ron’s second level supervisor Darryl Goodson. Early in his career Darryl was a field engineer for Paul Teicholz: Dr. Teicholz later founded the Stanford University Center for Facility Engineering (CIFE). At one time Paul, Darryl, and Ron all worked for Atkinson Construction.

5.2.3.2 Project(s) Manager: Robustness, Boundary Objects, and Corners

> *Technology must be redundant with manual processes; the technology improves every five years and will happen regardless of investment in research.*
> Darryl Goodson – Granite Construction Heavy Construction Division Vice President

As a junior civil engineer, Darryl Goodson learned scheduling - with punch-card computers - on the staff of Paul Teicholz at Atkinson Construction. Paul Teicholz later founded the CIFE research group at Stanford University and developed his methods into virtual construction theory. Large project management methods and the associated issues have a long tradition in the heavy construction industry. While Paul Teicholz formally established these methods and to a degree field engineers universally practice them, the practitioners poorly documented their methods and they simply are learned-by-doing.

Throughout Darryl's career on large projects, these methods have provided the basis for monitoring large heavy-civil design-build projects: one of the riskiest and most challenging project types. From practical experience as a scheduler, Darryl has an understanding of the context of the issues that CIFE researchers develop theories to resolve. I appreciate that through informal discussions Darryl shared his knowledge.

One of the methods Darryl used that is not represented in the ReTRAC observations or literature review is for the edge scenarios of quantities that are beyond reconciliation. The issues Darryl described sounds similar to issues relating to marginal objects[153]. Boundary objects [marginal objects] are items that are difficult to categorize, they can be both and neither at the same time.

The approach Darryl used is to settle 'position taking' with the direct participation of the field engineers or the participation of someone at an appropriate level for each stakeholder organization. As a project engineer, Darryl provided the field engineers a regular Tuesday, Wednesday, and Thursday meeting sequence; he suggests the practice for heavy construction project engineers.

The meeting sequence: On Tuesday, Darryl provided a scheduling meeting in the afternoon for the managers, engineers, and trade supervisors. On Wednesday, he hosted a cost meeting for the field engineers to audit the previous weeks cost, quantities, and the accounts these are

[153] *Marginal Objects*: Winograd, Terry, and Fernando Flores. Understanding computers and cognition: A new foundation for design. Intellect Books, 1986.

associated; each month, quarter, and year he hosted a similar review for the preceding period. On Thursday, he provided a project schedule and quality meeting for the project stakeholders such as the general contractor and subcontractor field engineers.

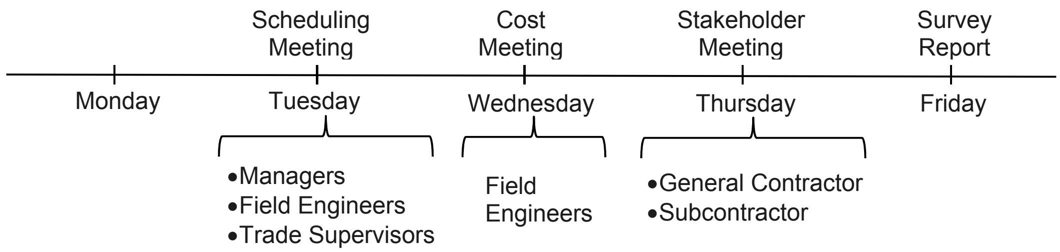

Figure 26 The Darryl Goodson weekly meeting sequence used to flush out boundary problems that the project planning and control process could not adapt to.

In Darryl's opinion, the project engineer must establish the meeting sequence and ensure the reconciliation process is functioning. There will be items that must be reconciled through agreement and cannot be resolved by field measurements – usually these are quantities that cannot fit an account definition or the definition does not exist. At the end of each week, Darryl provided a questionnaire survey, analysis, and report of the results to the project stakeholders. The survey provides buy-in from the participants and a noncommittal communication path. The meeting face-to-face discussions makes changes; the survey fine tunes the changes. At these meetings boundary issues are resolved such as, quantities issues that are nonconforming rather than a computational problem. The weekly meeting process is necessary to provide robustness through manual redundancy in a mechanical system.

During a follow-up discussion Darryl notes that the quantification process as used on the ReTRAC is the result of a shaping process based on tax code and civil law. I was not able to explore this further and he did not provide examples.

Next, I will present the interview of Darryl Goodson's former second level supervisor Dr. Paul Teicholz.

5.2.3.3 Philosopher of Construction: Indirects

Despite literature review, multiple surveys, and talking with the most senior heavy construction projects manager at Granite, the question about direct and indirect quantities raised by Ron Dukeshier was unanswered. I turned to the person Ron mentioned as the senior cost engineer at Atkinson Construction, this was Dr. Paul Teicholz. At Atkinson, his role was Information Technology Manager - though I think this title hides the scope and degree of Dr. Teicholz's contribution to projects engineering.

The ReTRAC field engineers found a specific issue in the monitoring system that they were not sure of the function; the ERP accounts contained direct and indirect cost and quantities. The directs were work-in-place and the indirects were time variable cost and materials that were associated with multiple direct accounts. Ron Dukeshier found the issue through a comparison between the Granite ReTRAC and Atkinson systems[154].

Granite placed material as indirects while Atkinson placed material as an applied resource cost type within the direct accounts; the Granite system had provisions for material types but the ReTRAC projects manager did not allow their use. The project staff had lost knowledge of charging the material accounts to direct accounts and what the variance values represented – I tried backing into these values and suspected a dual function based on actual and budget.

The question is where to draw the line between direct and indirects[155] [156] [157]. The mapping of quantities to the various accounts creates a problem for items such as formwork that field crews reused and consumed over the course of multiple activities. The next question is who bears the distributed cost and how is it distributed? The three solutions I have observed so far are:

- assign an asset number and rent (not observed or found used)
- carry as an indirect (method used at granite HCD ReTRAC)
- carry as a direct (method used at Atkinson per R. Dukeshier).

Through an exchange of emails looking for the lost knowledge, Paul Teicholz recognized the issue. He noted, "This can be a difficult problem if a cost system does not have the provision to handle inventory accounts for materials," and described the Atkinson system. To ensure

[154] Ron Dukeshier - once an Atkinson Project Manager - was constantly comparing the Granite HCD ReTRAC system with the Atkinson system.
[155] Batholomew - Chico State - covers this issue in "Estimating and Bidding for Heavy Construction."
[156] The BIM handbook is the source on these things, Ch 6.6 - 6.10 and Ch 7.6.
[157] The text Clough, Clough, & Sears has a discussion but is dated.

context and that I do not loose details of knowledge; I reproduced the Paul Teicholz email here without editing:

> *During the estimating stage, labor, owned and rented equipment, materials, sub-contracts were each treated as separate cost types. If Atkinson did the work, then the labor, equipment and materials were estimated and a production rate assigned to these resources on this operation of work (say forming a wall) was assigned by the estimator using his (we had no woman estimators) knowledge of anticipated job conditions and data from past projects that had similar work (our system provided online access to this information using a work classification system that was used within Atkinson). In any case, the result was a budget for each cost type, a budgeted production rate, say square feet (SF) per work hour, an estimated duration in total days of work and a budget work quantity (from the takeoff). All of this information (for each type of labor and equipment and material) was stored in the file for this operation of work. Of course, some work was performed by others and the budget would consist of just a unit price per unit of measure and a budget work quantity (based on the bid from the subcontractor)*[158]*.*
>
> *When material was procured for a project it was charged directly to a cost account if the material was used just for that account. If the material was ordered in bulk, it would be charged to an inventory account for that kind of material. Then, when it was used for the work, a given quantity of that material, say lumber of a certain type or rebar of a certain size, would be charged to the cost account using that material and credited to the inventory account. Thus, the direct cost accounts showed the cost of material as it was used and the inventory accounts for each type of material showed the cost of material that was on the job but not yet used. This system required that there be at least one person in charge of the warehouse to handle the accounting to direct cost accounts as the material was issued and charges to inventory accounts as it was received. Normally, Atkinson had large projects with significant warehouse facilities, so this was not a problem. On smaller jobs with just a small amount of inventory, it would be easier to charge directly to end use accounts and not setup inventory accounts.*
>
> *Our cost system forecast the final cost of a project at all stages in the life of a job. In the early stages the remaining costs were based on budget values of cost and quantities, but as the project progressed, we phased in actual costs and production rates for un-started work so that actual performance was reflected. At any time the project manager could override these forecast values with manual values, but we monitored these to show all instances where they varied from automatic forecasts (plus or minus) by more than a stated percent (which got smaller as the job neared completion).*
>
> *This is one reason why it is important to put material in the direct costs and not carry material in overhead. It is an important part of the cost forecast and needs to vary as quantities change for the direct accounts. Remember, one of the most important capabilities of a cost system is not to keep track of what has been*

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[158] Edited: During the estimating stage, labor, owned and rented equipment, materials, sub-contracts were treated as separate cost types. If Atkinson did the work, then the labor, equipment, and materials were estiated and a production rate assigned to these resources on this operation of work (say forming a wall) was assigned by the estimator using his (we had no woman estimators) knowledge of anticipated job conditions and data from past projects that had similar work (our system provided online access to this information using a work classification system that was used within Atkinson). In any case, the result was a budget for each cost type, a budgeted production rate, say SF per work hour, an estimated duration in total days of work and a budget work quantity (from the takeoff). Data of the type labor, equipment, and material were then stored in the file for this specific operation of work. Some work was performed by subcontractors and for these items the budget had a unit price and a work quantity from the subcontractor bid.

> *spent, but to forecast what will be spent and give management an opportunity to ward off bad surprises. The motto of our system was "no surprises."*
>
> *Hope this gives you an insight into what we did and why we did it that way. I might add that initial reactions to our forecasting system by the project managers was negative - they wanted the ability to "manage" the forecast. But within 2 years, they changed completely because senior management also started rewarding them based on a "no surprise" system. By doing this we had alignment of goals and the system that supported these goals.*

Paul Teicholz - years since he last used a large project accounting system (20 years) - explained direct and indirect material without hesitation. He covers the small details that even practitioners – a team of practitioners trying to figure out how it is done – could not decipher: I now have the indirect to direct account relationship. On the ReTRAC project, I talked with Ron and looked at Atkinson and Granite accounting formats. The field engineers compared and contrasted but could not understand why Granite's accounts did not accommodate the direct material and in that lost the indirect material features as well. This rendered the material accounts useless.

After talking with Dr. Teicholz, I think the Granite system was fine and they just needed to allow moving material from the indirect account to the direct accounts (in the next interview Stallard will explain that yes this is correct – they purposefully locked out the direct material). The way Dr. Teicholz explains this in his email and provides the context with related tasks such as forecasting makes it seem intuitive. Without doubt, I am impressed. If on the ReTRAC the field engineers had Dr. Teicholz's clarity, the field engineers could have requested this change to our accounting system and without doubt it would have been approved.

Next, I interview Bob Stallard, Darryl Goodson's senior cost engineer at Granite Construction Heavy Construction Division – more or less Paul Teicholz's counterpart at Granite. Bob established and maintained the practices I discussed in the interview with Ron Dukeshier.

5.2.3.4 Interview of Heavy Construction Senior Cost Engineer

5.2.3.4.1 Interview Background

As a mitigating measure against the possibility that literature review, field observation (in next chapter), online survey, and three interviews do not capture a sufficient scope of the tacit project monitoring knowledge, I interviewed a heavy construction senior cost engineer as a reality check. The interview was in an open format by phone on 5/14/2009. I had one guiding question, "why are some quantities reported as a neat line takeoff." Through my ethnographic field observation, I found an uncertain use of this quantity type and I could not find the answer in publications or through surveys.

I interviewed Bob Stallard; he is the senior cost engineer at Granite Construction Company Granite East[159]of the four interviews Stallard is the only that never worked at Atkinson Construction. Stallard's official title is Director of Project Controls. Stallard was an element of the oversight of the rail transportation corridor project and has a broader view of why he and the management team selected the methods used. Stallard's professional background is in heavy construction and he has a graduate degree from the Construction Engineering and Management (CEM) program at Stanford University[160]; he represents a strong integrity in honestly reporting quantities. Every six months he conducted an audit of project monitoring records for mistakes and errors. On the rail corridor project his knowledge and insight mentored the project teams understanding of cost engineering and likely was a factor in motivating this study. The interview unfolded into a discussion of nine topics, as follows:

- Heavy construction business demographic
- Work breakdown structure (WBS) concepts
- Work breakdown structure approach to cost records
- Monitoring consistency
- Monitoring level of detail
- Monitoring yield for unit cost contracts
- Monitoring material resource
- Projecting (forecast) quantities
- Cross check validation
- Project final report

5.2.3.4.2 Representing Project Features

In the following three sections, I will present Stallard's understanding of breakdown structures and representative nomenclature codes.

[159] Formerly Heavy Construction Division (HCD) www.graniteconstruction.com/
[160] See cem.stanford.edu/

5.2.3.4.2.1 Heavy construction characteristic

As a preliminary introduction to project monitoring Stallard noted that twelve fundamental operations and twenty-four materials characterize the heavy construction business demographic. The four core operations are moving, shaping, forming, and re-forming, each with three sub-operations[161]. The six core materials are earth, concrete, steel, wood, aggregates, and asphalt, each with four subtypes[162]. While the operations and materials are constant, the logistics, that is movement of resources, can be different from project to project. I assumed that the constrained domain of operations and variability of the observed effect is a characterization of heavy construction and is different from other construction industries such as residential, commercial building, and industrial projects that are characterized by specialty operations and products. Stallard's breakdown of operations and materials leads to a tree structure representation known as a breakdown structure and represented by a chart of accounts – this case one unique to Granite Construction East.

5.2.3.4.2.2 Project record breakdown structure

The breakdown structure chart of accounts provides a template breakdown structure for a project monitoring record that is transferable back to the estimating office. The bottom-up approach in the breakdown structure is to define items at the lowest possible level of detail and then compile into increasingly higher summary meta categories. This method is applicable if a cost forecast is available[163], revenue[164] and, to-date cost and revenue[165] for labor, equipment, material, and subcontractors. This method is detailed and Stallard emphasizes that the project engineer and field engineers must ask, "can I effectively manage this project [with this method]". The answer is likely no, the bottom up method is often in-practice defined by the principle of "because I can measure it, I do."

A top down breakdown structure is in Stallard's experience the best approach, Figure 27. First, the purpose of monitoring is dual, for the short-term, it is to facilitate loading management metrics to monitor project progress: examples of short-term purposes, to budget and to track-work, long-term examples, it is for the estimating database, for example, production, cost, and method. Stallard's approach to facilitate these dual goals is to provide a breakdown structure and then let the project team propagate the lower levels of the monitoring details while when rolled-up the breakdown structure provides the quantities needed for estimating purposes.

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[161] What are the sub-operations L/E/H?
[162] What are the sub-types?
[163] Implies estimate, i.e.., takeoff quantities and parametric (unit cost) or bottom up production estimate.
[164] Implies resource leveled and contingencies (weather) schedule, and table of values.
[165] Implies quantities if unit cost.

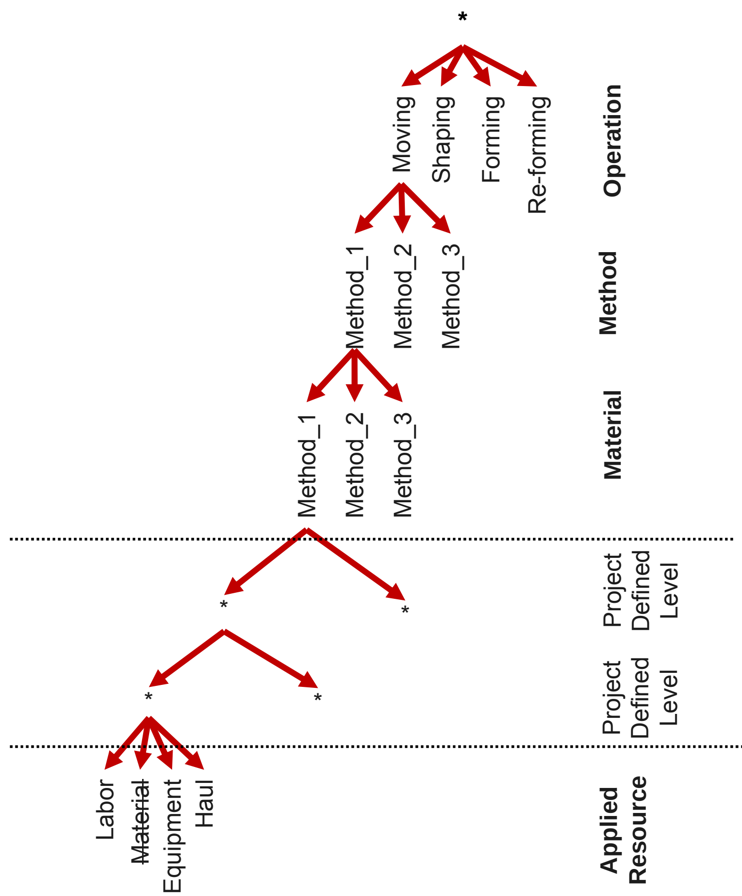

Figure 27 Stallard's approach to defining the breakdown structure is to start at the top and ask what is needed to detect project variance and to reforecast plan to completion with reasonable accuracy. Stallard provides his project teams with an upper level breakdown structure and lets the project teams define the lower levels as needed to reach the level of detail for sources of quantities. The last levels for applied resources are defined.

Providing a higher-level breakdown structure as a template and allowing the end user to propagate the lower levels is similar to the CSI MasterFormat 2004 standard and the adoption by vendors. The MasterFormat 2004 is complete to feature level four (resource level of detail) and subsequently has been expanded by end-users such as Revit to feature level five (component) and by RSMeans to feature level seven (method level of detail). This variation in the breakdown structure between Revit and RSMeans implies that estimating needs quantities at the resource level of detail and project monitoring needs component and operation level of detail.

An analogy provided by Bob Stallard is a room and the furniture, "the room is defined and the furniture is defined, where the project team puts the furniture is up to them," Table 36. From practical experience, Stallard has found that allowing the project staff to define the lower levels of the monitoring breakdown structure provides better results: dictating the breakdown structure to feature-level seven or eight results in lost context as a historical estimating library[166].

Table 36 The analogy provided by Bob Stallard of how the breakdown structure that facilitates the dual use of project records for short term monitoring and long term estimating. The *room* and *furniture* ,i.e., the activity and component are formalized while the *placement of the furniture,* i.e.., operations and methods of constructing the component monitored are for the project staff to define.

Code	Description	Analogy
50	Structural Concrete	Room
506	Substructure	Furniture
507	Superstructure	
510	Traffic Control	
520	MSE Wall	

5.2.3.4.2.3 Breakdown structure concepts

Providing a formal breakdown structure has several issues. First, Stallard has observed that if the project engineer defines too fine of a activity division then the reliability of the quantities collected by the field engineers is reduced. Second, the accuracy of quantities generated is a function of the accuracy of the foreman report, that is, measurement and coding, and the foreman report is notoriously suspect. At the simplest definition for pipeline projects, one activity could be defined as *lay pipe*. The *old way* at Granite Construction HCD was to define the breakdown structure of the activity sequence from the bottom-up, Figure 28. This method is for large projects because each operation is several days in duration, completed by a unique crew to that operation, and a buffer separates the preceding and succeeding operations, Table 37.

Table 37 The old way of project monitoring with each activity operation defined as a unique measurement metric. This method works on large projects such as installing a several hundred-mile pipeline. On a project of that scope, there is a crew specific to each operation with minimal interaction with preceding and succeeding crews.

Code Element	Description	UoM	Quantity
	Pipeline backfill		
	Dig		
	Fine-grade		
	Bedding		
	Fill to springline (hand method)		
	Fill to top (mechanical)		

[166] Unable to find examples of what context is lost.

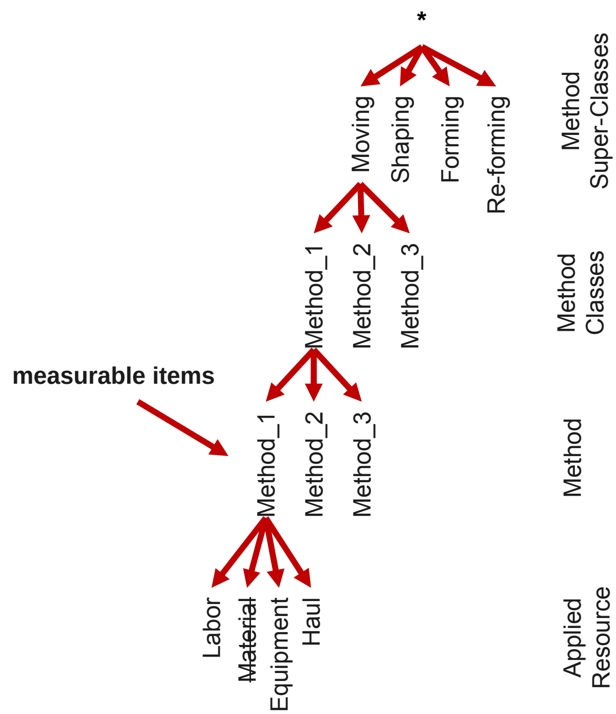

Figure 28 The old approach to breakdown structures – see what is measurable and then aggregate those items into a feature group, then aggregate those groups into super groups.

The *new way* at Granite Construction East is for smaller projects and has a top down breakdown structure. The project engineer represents an activity by one operation, for example, Stallard describes pipeline backfill as *dig/lay/backfill* and one universal crew completes this activity rather than a separate crew for each operation. Monitoring at the operation level is still possible with the quantities weighted using a ratio of 4/4/2[167] equivalent units. For example 1,000 lineal feet (LF) of measured excavation or pipe contributes 400 LF (1,000 x 40%) each as a reported quantity, while 1,000 LF of backfill contributes 200 LF (1,000 x 20%) as a reported quantity. The text *Project Management Using Earned Value* (Humphreys, p629) provides the same example of constructing pipelines as Stallard does for the application of equivalent units. The purpose of using equivalent units is too roll-up to a higher level of detail to align with the degree of accuracy in quantities provided by the projects measuring capacity[168]. On the rail corridor project, as a field engineer I intuitively used a similar method as equivalent units for the activities *Grade/Base/Finish* and *Form/Place/Strip* with an intuitive distribution of 2/6/2.

[167] Stallard interview notes have 4/2/2 – presumably a misquote.
[168] What is the breaking point metric (project size) and value (in $M) to decide between utilizing monitoring methods?

5.2.3.4.3 Project Monitoring

In the following four sections I present the categories Stallard defined in his interview, these are monitoring precision, level of detail, yield, and a case example.

5.2.3.4.3.1 Monitoring precision

Precision, also known as consistency, is the repeatability of a measurement, and the standard deviation measurement. The precision of monitoring is initially constrained by two assumptions. First, in repetitive activities Stallard found through experience that variability in measurements is still high. Second, for variability in task components Stallard has found them too high from day to day for task analysis.

Another example of an activity that presents difficulty discerning between some operations[169] is *set and strip forms.* This activity is in practice combined, strip is the start of set and set flows into place concrete. The solution is to use the same code so the difference between set & strip is nullified. The *set and strip forms* example may have a distribution of 80/20, implying the equivalent units should be 8/2.

The condition for precision is that measured quantities are inherently imprecise even if there is a sufficient degree of accuracy. Stallard's solution is to use a variance comparison. A precise inaccuracy (or apparent inaccuracy due to imprecision or inherent variability) provides the same variance as a consistently accurate measurement, if consistently inaccurate. Stallard bases the variance comparison method on the assumption that the inaccuracy in the core quantities is too prevalent to manage. The project engineer applies the Stallard rule-based solution with the following three rules:

- rule 1 maintain significant digits to one digit
- rule 2 maintain consistentcy in method of measurement and source
- rule 3 maintain consistentcy in analysis process

With these rules articulated the consistency in analysis allows for a variance comparison to measure project progress over time. The measurements must be at a regular period over period interval and depends on consistency in methodology and process.

[169] assumed at some measurement frequency x.

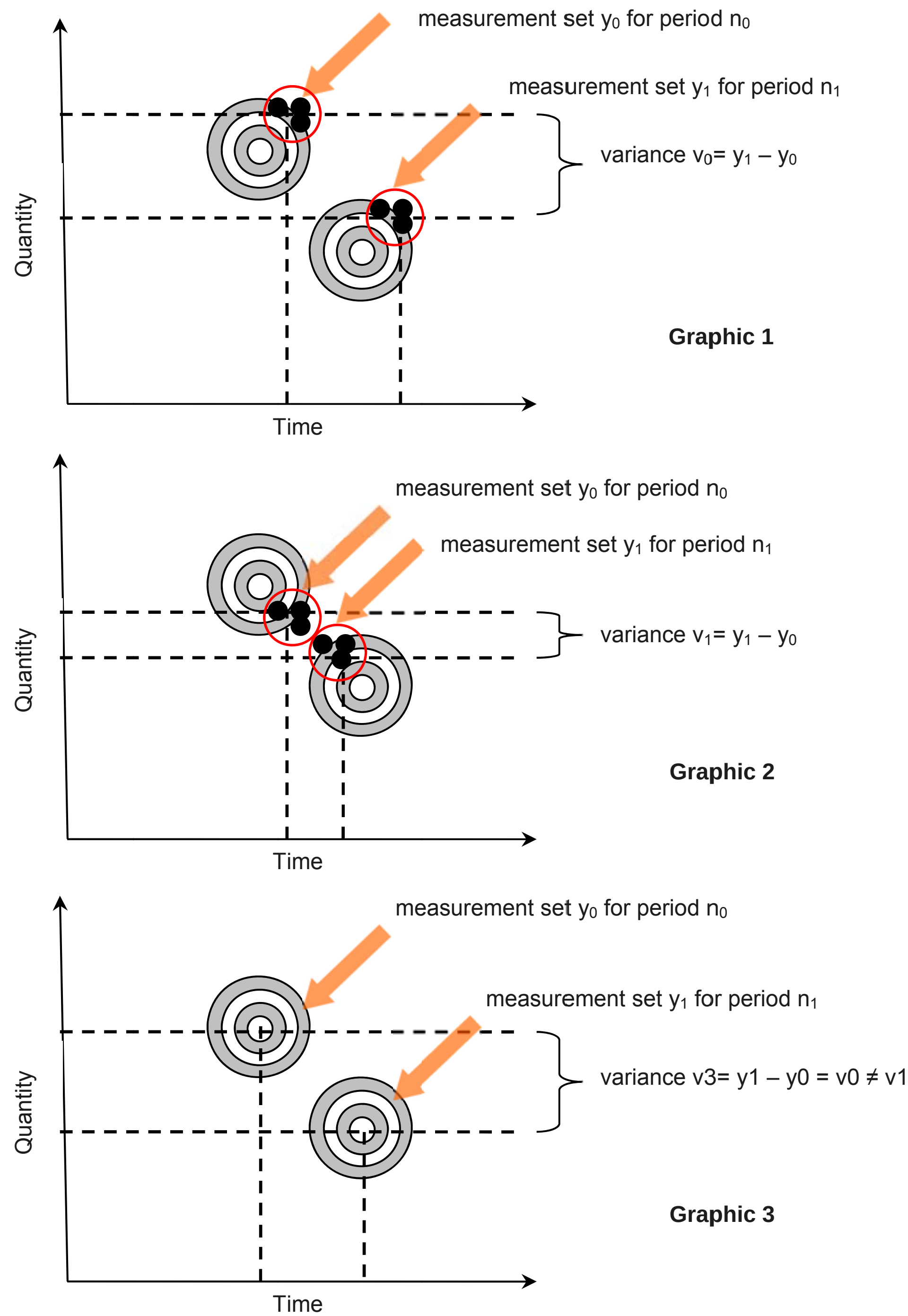

Figure 29 These illustrations present the graphical argument for variance as a management metric.

In Figure 29 the first graphic presents two measurement sets that are imprecise and inaccurate, represented with an average circle, and equally precisely measured (equal standard deviation). The second graphic presents two measurements sets that are imprecisely inaccurate and equally precisely measured. The last graphic presents the *form* or perfectly accurate and precise measurement sets, this is traditionally unattainable from empirical measurement. The variance for graphic 1 and 3 are equivalent, implying that the variable of accuracy in measurement can be discarded if the inaccuracies are precise. Therefore, the focus is on maintaining precision in inaccuracy. The repeatability (precision) of the measurements is an average of multiple measurements due to the inherent imprecision of monitoring.

5.2.3.4.3.2 Monitoring level of detail

The monitored level of detail must be appropriate with the projects measuring capabilities and is dependent on the features of the activity (tacit knowledge)[170]. The pipeline example presented earlier is an example of holding the reporting level of detail at the monitoring capability. For example, concrete cost and quantities are monitored using batch tickets: these are a printout of the mix design and volume. Field engineers use these tickets in addition to inspection to answer two key questions “did I get what I ordered” and “is it what I expected.” As features of the activity this defines the level of detail in monitoring, most likely, *place concrete,* with units of cubic yard (CY) with additional contextual information in the project final report of psi, slump, and air entrapment. In estimating, the estimator defines the level of detail by building a production-based estimate. For a reality check the estimate is composed with lower level of detail historical quantities as a reality check “touch stone” for sanity.

5.2.3.4.3.3 Monitoring yield

Yield is a concept I did not find during the literature review, project observations, or survey. This concept is specific to unit cost billing. Concrete placement results in waste. On a unit cost project, that is, billing is by units of work-in-place rather than percentage of completion, the metric of yield is used, this is the measurement of waste. The field engineer measures production as yield, see Equation 3. The yield equals actual versus neat line, the variance comparison is neat line to neat line + yield. The control metric is the yield control versus over excavation control. There is a base quantity; I assume this refers to the neat line take off.

[170] Would have been nice to provide a specific example of dependency.

Equation 3 Waste is difficult to predict and field engineers incorporate it into the actual production measurement. Reuse of historical quantities must account for the imbedded waste factor and the expected waste factor of the project plan. There may be a dual use of the term yield here and in *Projecting Quantities* on page 184.

Productivity equation	Variable	Description	Measurement
unit/HR	P =	Production	
$P = (Y + W) / R_h$	N =	*Neat line*	Expected measurement
	Y =	Yield	Measured actual (*neat line* + yield)
HR/unit	W =	Waste	Variance between planned and actual
$P = R_h / (Y + W)$	R_h=	Resource hours	Measurable Hours

5.2.3.4.3.4 Monitoring example

Monitoring material resources is characterized by field engineers *chasing* delivery tickets to a specific feature set. Due to bias in reporting, field engineers hide items in the wrong codes. For example, plywood and form lumber have a code in each operation. These are also a temporary material, i.e., an overhead cost, the practice is to estimate overhead cost for plywood and form lumber as a lump sum. Because field engineers track the material as a lump sum in an indirect account and as a direct cost in an operation, (I assumed due to the ERP system) the field engineers cannot track both locations and so they track at the operation level. The solution in the *old days* was too:

- Set up a spreadsheet identifying where the materials are used and include with project final report
- Distribute across accounts

This created an issue – the process becomes a shell game to follow ideal scenario and not the actual scenario. A *shell game* means that through bias in reporting the field engineers report the expected quantity rather than the actual quantity. There are two benefits to the field engineer. First, resource intensive field measurements are not necessary since field engineers can derive the quantity from a plan quantity takeoff. Second, there is no variance from the expected quantities therefore not triggering a variance warning. Through practice, Stallard has found that there is no benefit to track the form hardware material separately due to their frequent use for other purposes. For this reason, Stallard discarded the old way of maintaining a spreadsheet to map with operations and the field engineers now only monitor material as an indirect.

The top-down breakdown structure template while allowing the lower level details to be arranged by the project staff is limited in the ability to rearrange the higher level *cost groups,* such as, *Indirect Material* and *Direct Material,* to accounts if desired monitored at a lower level of detail by the project team. Therefore, the team must resort to the old way with spreadsheets to record accounts and distributions.

5.2.3.4.4 Projecting Quantities

Projecting quantities is a process of estimating the missing values. Field engineers should not use forecasted quantities as actual measured work-in-place. The quantities depend on conditions. Often field engineers project the quantities for reconciliation issues. For example, 100 BCY is the neat line excavation, the excavator actually moved 104 BCY, and this results in a 4% yield. Be aware of the inaccuracies introduced in measuring the bank cubic yard, as this is impossible empirically. The field engineers base the cost on the actual volume moved and base the billing on the neat line takeoff. An issue with neat line reporting is the manifestation of *a priori*, that is, prior knowledge of quantities, rather than actual observation of what occurred. Again, the process becomes a *shell game*: the drawing of end-points and a physical summary of the end-point.

The process of reporting the expected quantities rather than the actual is different from reporting 4/4/2 equivalent units quantities. The difference is truth in process, reporting equivalent units is purposeful, using the 4/4/2 ratio as a recipe formula to derive quantities and then reporting them as actual measurements is deceitful. It is not wrong to derive measurements as long as the field engineers represent them as derived measurements. They should round these measurements to significant digits. The issue arises when a field engineer presents a derived measurement as a physical field measurement. The difference is analogous to asking for a cast bronze and delivered a Rodin, it is OK if it is a quality reproduction, but not if presented it as an authentic Rodin.

5.2.3.4.5 Crosscheck Validation

As an auditor, do not look below the summary level (top down). The lower level quantities are not precise enough to allow analysis with confidence. Stallard uses crosschecks to look for hidden issues in the quantities. The billing status is a source of analysis quantities. Over and under billing indicates something is wrong. If the variance is outside a narrow range [experience defines what defines the narrow range] the nonconforming value will trigger a warning. Stallard uses mnemonics, such as labor ratio and equipment expended, of the project job cost to indicate issues in the quantities or problems with the project.

5.2.3.4.6 Project Final Report

The project final report manifests in the project teams memory, the report is in their head. The best method of accessing this information is discussing it with someone on the project. Collecting material and writing the project final report is difficult since the field engineers and project management focused on completing the project and not documenting how they did this. In many fields, this is an issue; in computer science, it is fun to write a neat program and decrease the time to delivery by skipping the documentation process. The problem is then if anyone – including the person that wrote the program – wants to reuse it, modify it, or fix a bug, there is no documentation to rely on; this renders even the best programs null. For this reason partnering with a research group and bringing research assistants onto the project at various stages as interns or field engineers allows leveraging their academic mentoring support and need for publications to also allow documenting the project for a project final report. The project engineer and project manager can then publish the final report as a technical report in the research publication database. The drawback to this - or benefit depending on the companies thoughts - is they are sharing knowledge across organizations since the publication database is accessed and added to by project engineers on numerous projects. With todays increased use of advanced electronic programming, custom programs for niche applications and technical procedures, the technical database should include not just the traditional working papers, technical reports, and funding proposals, but also an open-source code library.

5.2.3.4.7 Conclusion to Interview

The interview with Bob Stallard provided context, answered a persistent question, and offered new material. The issues Stallard has found illustrates the long-term observation necessary to identify trends in the quantities. Stallard has concluded that material such as form boards, are best represented by project engineers as an indirect account rather than as a direct account. This issue is recurrent throughout my literature review, my field observation, and my attempts at reasoning through the issue. The lingering question of why the project engineer wanted the quantities reported as a neat line takeoff rather than actual quantities was resolved as particular to unit cost contracts. The project engineer was in error instructing the field engineers to use a neat line takeoff for reported quantities on a lump sum contract. The concept of monitoring yield is a new topic that I did not found in literature or observed. This indicates that the topic of project monitoring is universal, though each contract type has peculiarities to them such as the neat line reported quantity.

To recap the storyline, years ago at Granite in Reno I was a field engineer on a $200M rail project. It made lots and lots of money - Bob Stallard thought I was playing games with him it made so much money. Something else happened at the end of the project: One day our business manager tells me there is a huge mistake and I must correct it - the equipment accounts had no money in them. These accounts cover maintenance and fuel - they are supposed to be empty except for a small amount. When I took over the equipment accounts they had huge amounts of money in them - in the millions. I slowly drew them down over a few months to what they should be by changing the unit rates (I figured out how to change the rates in the AS400 accounting system) then reset them to a self-sustaining unit rate - they should never accumulate or decline over several months. I told the business manager to do it himself and left for Stanford: he was not much with computers and couldn't reconfigure the AS400 - so he'd have to be less clandestine about asking someone else to move a few million around. Stallard explains in my ENGR thesis what they were doing - not directly but I can see it now: It is called a shell game. Granite Construction as a practice inflates the equipment rates (we own the equipment at Granite) and draws the project profits down. I am certain they do the same with the material. Then, they can tell the project teams and whoever else they promised profit sharing with (joint venture partners) that the project actually lost money. I was confused as to what the business manager was up to - I thought it was just about someones bonus, but now I see it was much bigger. Here it is done to avoid taxes[171] and here so they don't have to pay screenwriters[172].

5.2.3.5 Conclusion to Interviews for Tacit Knowledge

Following my ethnographic experience on the ReTRAC rail realignment project I had three topics relating to quantities. The first question was about cost coding – assigning the features of a quantity measurement – this has been answered as good as it could through literature review and then the current performance further verified through the questionnaire survey. The second and third questions are captured here in these four interviews – they are tacit in nature and I could not find these in the literature and the questionnaire did not capture the answer. These questions are about the neat line takeoff reported quantity and the direct and indirect material.

The neat like takeoff was easily answered – as it was used on the ReTRAC was a mistake. The project engineer used a quantification method used for unit cost contracts on a lump sum contract. The previous large project was a unit cost contract and the project engineer (then a field engineer) had been taught to report neat line quantities – this was correct. On the next project he instructed the field engineers to use neat line quantities as he had been taught, but this project was a lump sum where neat line quantities are not reported. In both cases the actual quantities are necessary for forecasting with unit production, the neat line is used for billing purposes only. As a shortcut the field engineers on the previous project were using the neat line quantities for both billing and entered these into the accounting system used for the production forecasting.

The interesting question turns out to be the indirect and direct material. The answer is to purchase bulk material for large projects – and account for the material purchase in the

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[171] Shell-game by Washington Monthly http://www.washingtonmonthly.com/features/2000/0007.dorgan.html

[172] Shell-game by New York Times http://www.nytimes.com/1996/03/04/business/shell-game-hollywood-net-profits-dreamworks-may-be-shaking-up-some-time-honored.html

warehouse indirect accounts. Then sell the material to the direct material accounts as the material is used. The discrepancy then comes in, pragmatically, there is an insufficient benefit from knowing the material cost for each direct account – the effort exerted is not worth it: all material can just be an indirect.

The question of direct and indirect was raised by Ron on the ReTRAC project – he had seen materials accounted for using the warehouse and direct accounting method at Atkinson – this was Paul Teicholz's method. At Granite Ron saw the material grouped as indirect material across the board – this was Bob Stallard's method. The question is why the difference. In Ron's experience he could see problems with applying material quantities to direct accounts. Material that will be used by one activity is purchased and the quantity applied to that activity – bypassing the warehouse indirect account. Later, the same material such as forms are reused and each use is recoded as a quantity, so there is no record of the original quantity. If the material is applied as an indirect, there is no record of how much input material was used by an activity – only the production output.

The projects engineer (Darryl Goodson) that stood between Ron and the senior controls engineer at both Atkinson (Paul) and Granite (Bob) had a different explanation. There are lots of these distinctions – reconciliations of quantities that are clearly wrong due to what are most likely theoretical problems such as boundary objects (boundary object is my words not Goodson's) and components that are not represented. The solution for the projects manager was not to reconcile a more perfect planning system between the project engineer and the project control engineer but to provide a forum for the project engineer to resolve and reconcile discrepancies directly with the various project stakeholders. The opposite of tightening and formalizing a better internal representation so the field engineers could better plan and exert a position, the solution is a catch all for any and all discrepancies that are outside the boundaries of what theory allows accounting. The solution is a stakeholder meeting sequence. There are three meetings each week with different aspects of the stakeholders organization. There is a cost meeting for the cost teams – most likely quantities are resolved here as a part of cost. Then a schedule meeting for the supervisory teams – differences in time expectations are resolved and most likely the applied resources are adjusted. Last, there is a quality meeting to identify the expected quality of the workmanship and materials – the schedule and cost meeting materials are used here as part of a holistic decision making process. There is nearly no problem, theoretical, misunderstanding, or mistake that cannot be resolved through this meeting sequence. The cost and effort for the meeting is tremendous – so the focus of the meeting must be on a few items and this is where the automated system is important. The thousand accounts or so that are ignored at the meetings because they are fine are carried by the system for scope-time-cost.

The automated system that supports the stakeholder meetings is a critical component in the Teicholz process. The system requires a direct material to calculate the production and cost to completion. As the project transitions from baseline forecast through the project duration, actual production and cost values are increasingly given significance in a weighted average between planned and actual. At the end of the project only actual production and cost is presented and the original planned has a significance weighting of zero.

Numerous factors affect the performance of this hybrid automated and stakeholder planner. Stallard has seen there is an inverse relation between level of detail and accuracy in quantities and the representation of features assigned. The accuracy depends on the foreman making the measurements – this is counter to the advice of the literature, where the field engineer is recommended. To gain accuracy Stallard moves the quantification process to a higher level of detail. The core function of the Stallard system that provided improved accuracy is reducing the repetitive and tediousness of the quantities system on the field engineer and their foreman. If the system is too tedious, he has found they will begin to game the system and all accuracy is lost. Stallard's focus is on a higher level of detail and consistency in the method of the measurement and adapting the level of detail and method to the already available sources of quantities. For example, haul tickets with scale readings from the quarry – required by law for invoicing and a handy source of quantities. Stallard starts at the top of the monitoring scale and asks, what do I need to know to detect process variation and to reforecast plans. He then continues down that path until he has found sufficient sources of quantities. He outlines the upper levels of this hierarchy, provides this to the project, and lets the field engineers map the lower levels to sources – adding further level of detail as necessary. He then provides an automated audit check that flags deviations for further investigation based on historical ratios between different aspects of the project as-built. The final component of this system is the project final report – a technical report to allow for knowledge sharing across projects.

The systems by Teicholz, Stallard, and Goodson exist in singularity and as I have observed in degrees of hybrid. I believe a system utilizing the theories of all three would form a more complete and robust system for large civil project controls. An automated system coupled with a stakeholder meeting system to accommodate exceptions – all implemented with a pragmatic understanding of what works, the effort required, and the results of overburdening the field engineers.

Next, I will tie the interview knowledge with the pre-survey and questionnaire survey knowledge. From there I begin the next major section where I present my ethnographic experience with the ReTRAC project where the knowledge I have presented in the literature, survey, and interviews was implemented. The key to the ethnography knowledge is the relations provided by the literature, survey, and interviews was missing – the ethnography experience is flat with only observations of reality but without the relation of those observations.

5.2.4 Conclusion to Surveys

The construction industry has formal reference knowledge and innovative published research knowledge: the vast majority of construction knowledge is tacit and learned by doing. There are strong arguments that construction planning cannot be taught in a classroom and the best approach to teach construction is on the jobsite in the real situations. For this reason construction planning is considered a practice based field. Because of this I was not convinced by my literature review – I know the reference text is incomplete and that the research knowledge is incredibly incomplete. To fill these gaps and back-up what I found in the reference texts that was not well validated I decided on a three pronged approach. I used a pre-survey survey, broad questionnaire survey, and a survey of a select group of professionals through open format interviews. While the pre-survey defined the questionnaire questions and the fixed responses, I selected the interviewees based on their relationship with the case project in this thesis – the ReTRAC project. The survey provided the methods of quantification, the cost coding practice, and the typical performance of both of these. The unanswered questions are detailed and specific to the ReTRAC but general to the domain of heavy construction. These are about the neat line quantity takeoff as the source of the reported quantity completed and about the direct and indirect categorization of material.

The answers to these specific questions are clear. The neat line take off from the project plans and reported as the completed quantity was incorrectly used for this contract type. The ReTRAC project is a lump sum project and uses a percentage of completion for progress payments – so there is no reason to create a quantity completed – quantities are collected solely for the use of planning purposes and for this the actual production is the ideal. Neat line takeoff is used on unit cost contracts that pay only for billable quantities – the neat line is a measure of these billable quantities. Anything outside the neat line cannot be billed. Why the ReTRAC project engineer instructed the field engineering team to report neat line billable quantities to the project planning accounting system – I will never understand.

Before digging into the direct and indirect material accounts – I want to look at my findings from the pre-survey and questionnaire surveys. The most prominent finding is the bias in reporting – this echoes the findings by Saidi (20002) and Kiziltas (2006) that I reviewed in the literature review. Bias in reporting can mean quantities that are misrepresented and/or misrepresenting the features of those quantities. Another word for bias is fraud – in the survey there are indications that bias takes the form of everything from taking a shortcut with quantities and reporting something easy though incorrect, to purposefully misrepresentation for a significant financial gain. Several senior administrators for well respected companies - though anonymous - indicated in the survey that bias in reporting is usually directed and with the purpose of fraudulently obtaining a greater financial return than otherwise possible. For this reason, features are an important focus of a construction audit.

The survey provided areas that were commonly suggested as focus areas for future research: these are formalization of the quantification process, technology development for quantification, and technology development for cost coding. Presumably technology that allows for auditing quantification and coding is included in this suggestion.

The survey also provided measures of the current performance. The concept of quantity performance differs between heavy construction (horizontal) and commercial/residential (vertical) construction. Further within both horizontal and vertical construction, there are those administering the project and those actually constructing the project – they further differ in their concept of quantities. The builders of the project work at a monitoring detail with quantification accounts that are ten times more detailed than the accounts used by the administrators of the project. The builders work with 1,000s of accounts while the administrators work with 100s of accounts – this is true for both horizontal and vertical construction. Both had quantities with a magnitude in the 100s to 1,000s. The difference between horizontal and vertical construction is in the degree of confidence they want in the quantities. The horizontal builders need a higher degree of confidence than vertical builders. From the survey I found that horizontal builders measure 90% of their quantities and estimate 10% - the vertical builders measure 50% of their quantities and estimate the other 50%. Both horizontal and vertical believe the accuracy of the quantities is highly important – but this is just not shown by the degree of estimating that occurs in vertical building. I think the difference is based on the type of contracts used in these two construction domains: heavy construction often uses a *hard bid* meaning there are few negotiated changes and if the contractor losses money on the project then that is their loss. In the vertical construction they have *soft bid* meaning the contract is renegotiated often and the contractor is not necessarily expected to absorb huge losses on the project . I think this is the reason for the difference in quantities – the heavy builder must forecast based on their obervations of reality and their expectation for the project needs to closely mirror reality, therefore they have a strong incentive to reflect accurately their work. The vertical builders can negotiate their way out of a bad situation and so are not given the same incentive to accurately reflect their work or have an expectation that parallels reality. How this relates to specialty contractors and general contractors I am not certain.

The survey provides the frequency of the use of different methods of quantification. The common methods are counting individual items, takeoff from the plans (basically neat line takeoff), and a visual percentage completion based on sight and an idea of the scope of the finished activity. Kiziltas (2006) found that counting is the common method and that if counting is not possible then the context of the activity will be adjusted so that it becomes countable. The least common methods are more specific to earthwork and that is probably why they were mentioned less, these are quantities from invoices and quantities derived through formulaic relations.

The representation of material as a direct or indirect account was the last question – the survey missed this topic in both the pre-survey and the questionnaire. My literature review found a few texts that address indirect and direct material but the topic was presented flatly, as this is what is done but without giving the why it was done that way. A brief review – material purchased for a project, for example lumber, is purchased for two reasons, either it is to use on a specific task or I know I need a bunch of lumber to use on many tasks. If it is for one task then that is easy, I apply the material to that task. But, if I will use the lumber on many tasks then when I buy it where do I park my material in the planning system? The solution is an indirect account – a holding account until the material is used. On the ReTRAC project I observed a system that does away with the ability to represent material as a direct – material was never associated with any item, it was an indirect. The planning system still allowed for a production quantity but this was an abstracted quantity that did not have a matching material applied resource. The question I have is why on the ReTRAC there is there no applied material resource in direct accounts?

I looked for the answer through a series of interviews of those responsible for the planner system I used on the ReTRAC as well as an interview with a respected construction engineering and management theorist that had a broad influence on two of the three of those responsible for the planner system I used. From this bundle of interviews I expect to perfectly understand the planner and why material was omitted. The four interviews are with Ron Dukeshier, Darryl Goodson, Paul Teicholz, and Bob Stallard. All three have been field engineers, project engineers, project managers, and in the case of Bob and Paul, senior project controllers. The indirect accounts to Paul were the accounts used by the project warehousing. By warehousing I do not mean an actual warehouse – though it could be. The warehouse is a metaphor for the representation of materials that has been purchased and is waiting for assignment to a direct activity. Items are purchased in bulk, accounted for as an indirect by the warehouse and then the warehouse sold those items to individual accounts and transferred them from an indirect to a direct. These warehouses are used on large projects – the ReTRAC project did not have a dedicated warehouse but was large enough a project that the warehousing function was implemented for material used across a range of activities. The problem with traditional warehousing as described by Paul is that once the project is done, there is no record of the original material purpose – this was relayed by Ron. Each time the material is used – the quantity of material, say form lumber, is recoded on the direct account, if the forms are used five times than the sum of formworks for the project will result in five times the original purchase – a single indirect account resolves this problem. The counter problem with maintaining all the form lumber in one indirect account – there is no record of how much form material was used for each task.

If I dug into the accounting system and looked at the entry level of detail (unique transactions) then I can see the transactions that zero the account – the debits represent the total inputs to the account and the credits are the outputs from the account. This detail cannot be accessed through the job cost report format. My solution to see the distribution of the material is a sub-distribution level for the indirect accounts – there will need to be sub accounts for sources of inputs and listing all the outputs. For example, purchases from material suppliers (or purchased from another project) versus material returned from other activities are two separate inputs. For outputs, each use of the material is a unique line item. This begins to cross into the user interface aspects of quantities so I do not want to go much further into this – the point is that these problems can be resolved.

The solutions I found are the Goodson planner system, the Teicholz planner system, and the Stallard planner system.

The solution from Darryl's standpoint is to let these details go – focusing on details is not how field engineers keep a project going - there are lots of details like this that are nice theoretical puzzles but have no answer. Darryl's solution is to provide a forum where the project team can interact with the other project stakeholders, owners, and subcontractors – there they can negotiate resolutions to these problems if they cause an issue. The core is to eliminate position taking and to work as partners on a project. This certainly solves any problem and is an excellent exception handling approach. Simply let the humans resolve what the computers cannot digest. I did not expect this and at first thought Darryl had not understood my question – though he understood perfectly.

Techolz's solution resides in the use of computing – for him the warehouse sells material to the activity unless the material is purchased specifically for the activity and then it skips the warehouse. The reason this is important is Teicholz's planner uses a function to forecast cost to completion. The final cost is forecast based on the product of the unit cost to date and the units remaining to completion. To account for variability based on sample size – the Teicholz planner allocates the weighted significance based on the duration of the activity completed. For example, early in the activity the expected production and cost drives the forecasting, at the midpoint the expectation and actual are weighted equally for forecasting, at the end of the activity the weighting is fully on the actual production and cost. If material is not represented in the direct account then this system cannot include material cost as part of the cost to completion calculation and that is a problem. The Teicholz system losses the ability to check total material purchased in favor of the ability to track cost to completion. The importance of knowing total material purchased is in audit checks – the unit cost of material is usually well know and any variance from expected unit cost indicates an error.

The Stallard planner is based in pragmatics. This means that Stallard has evaluated the benefit of the Goodson and Stallard systems, then retained those aspects that are providing a significant return on the effort expended. For the most part the Goodson system is used and the practitioners at this point don’t see the relationship with the planner system. The Goodson system fills the gaps in planner theory. The Stallard system for the most part replicates the Teicholz system with the exception of the applied material. Stallard maintains the indirect accounting of the warehouse but does not record the handoff of material from the warehouse to the activity. Essentially Stallard has a pick and go warehouse with no record keeping. The reason is that Stallard found the benefit of A) knowing how much material was used on each activity, and B) the calculation of cost to completion including material cost, as insufficient to justify the effort. Under the Stallard planner the forecast to completion includes the labor and equipment cost, the material cost is calculated separately using a spreadsheet software and then is entered to the planner as an indirect. Stallard did not say specifically, but it makes sense that material cost inherently has less variability to the final cost as has labor and equipment. The material quantity cannot change absent a design change or quantity takeoff mistake. This provides a basis of stability that labor and equipment do not have. Labor and equipment cost are based on quantities that are estimates based on production from some other project with a similar activity – there is no grounding bottom. The labor and equipment are inherently volatile. Stallard makes some core arguments for his pragmatics – I have to agree with Stallard since I saw these issues first hand on the ReTRAC. First, Stallard saw an inverse relation between the level of detail in the quantification plan and the accuracy of those quantities. The reason is the highly detailed quantities - while in theory good - was pragmatically a tedious system to maintain and the field engineers do not have the patience of accountants, so they simply start entering dummy numbers to the system that they think will pass audit checks. The planner becomes a huge gamed system that provides no benefit to the project team other than a database of production rate samples usable in spreadsheets for planning. Stallard’s planner modifies Teicholz’s system starting with the representation of features. Stallard works from the top down – he starts with the question “what must I represent to allow for process deviation detection and forecasting.” He then defines the upper levels of a breakdown structure that allows representing those features. He then extends this breakdown structure downward until reaching the level of detail where there are sources of quantities. Following on Kaziltas (2006) the sources must be countable or the breakdown structure must reach further down. Stallard further looks for sources that are easily obtainable – such as load counts and scale tickets. Since each project is different and to allow the field engineers buy-in to their planning system – Stallard purposefully leaves out the lower breakdown structure levels and lets the field engineers fill this throughout the project. The last aspect is an audit check based on ratios of different aspects of the plan – these ratios hold true for all projects and variances flags a more in-depth audit.

The planners given by Goodson, Teicholz, and Stallard, combined into a hybrid system provides for a robust and pragmatic planner. The indirect subaccount modification Ron identified is the missing component – with advances in automation the inclusion of materials as a direct applied resource should be feasible. I agree with Stallard that with the current theories the material is overly tedious to include. For the indirect accounts, there needs to be an additional level of detail showing the distribution from indirect to direct accounts – and probably some breakdown in purpose of distribution, maybe by material types: permanent (concrete), temporary (forms), and modification (lime). For the direct accounts – the tedious task of quantification and assigning features must be automated with sensors and feature assignment algorithms. The technology for automated sensing is not far off – the use of RFID tags is becoming common. These sensing technologies will remove the quantification task and leaves the automated feature assignment. Again, sensing will resolve some aspects of feature assignment and the remaining aspects will be resolved through model-based feature assignment algorithms.

In this section, I resolved two lingering questions from the ReTRAC project: the use of the neat line quantity and the missing direct material applied resource. Further, through surveys I found the use of quantification methods – to augment the literature review where the methods are given but their degree of use is not.

This is the conclusion to this section on my tacit knowledge search. In the next section, I will add to the literature survey and tacit knowledge through an ethnographic observation of the ReTRAC project. Through the ethnography the deep relevance and meaning of these topics identified through literature and survey will become clearer.

5.3 Ethnographic Field Observations

This section details my experiences in relation to quantities. I will present the features of the project, the method used to represent features, the quantification plan used on that project, the methods of quantification, the quantification features, the post quantification processing of quantities, and the quantities audit controls. The sequence of the topics parallels the sequence I used in the literature review. I use the same sequence to help the reader follow the sequence. The sequence is roughly the sequence of steps followed on the ReTRAC: First, a breakdown structure of features and nomenclature is needed to define the accounts to quantify. Then, a plan to achieve the desired quality of quantities, the quantities are then collected using some method or methods, afterwards additional quantities are derived – essentially an extension of collection methods, and last, controls are put in place for auditing.

For eighteen months starting in June of 2005 I worked on a large heavy civil project as an office engineer – I introduce that project in this thesis as the *Problem Case* (p77), it is called the Reno Transportation Rail Access Corridor (ReTRAC). My role as the office engineer included tasks (very similar to the flowchart given by Saidi, Figure 23) such as representing in Primavera P3[173] the schedule progress and the schedule replans, maintaining the AS400 enterprise asset accounting system, as well as calculating and preparing the monthly progress billings and the monthly project report. In addition, as the office engineer (possibly due to my previous field experience this was an exception for me) I carried a field engineer's workload for a project discipline, in my case the earthwork. By chance, due to the early retirement of a senior equipment manager coupled with most of the equipment being used for earthwork, I found myself responsible for the equipment department. Towards the end of the project, all the other field engineers as well as the construction manager, the superintendents, and the project engineer departed for new projects for promotions or to secure early project positions for promotion later. Again, I found myself with more responsibility and now jointly responsible with a project manager, business manager, and a few newly promoted field superintendents for all aspects of a large project. This placed me in a unique position of observation - more so than the company policy allowed[174].

In the next section, I will present the context of my ethnographic observations. This is important to establish the type of construction activities my observations should be applicable. After establishing the context of my observations I will present in each of the following six sections aspects of the quantification process I observed on the ReTRAC.

[173] Common ghantt chart style scheduling software with critical path method anayliss.
[174] I never saw it in writing but I was told that for security reasons no one person was supposed to perform an entire job function themselves – let alone multiple jobs, it had to be split amongst three people so to prevent figuring out the system and gaming it.

5.3.1 Context of Observation

First, I will present the context of the project that formed my ethnographic experience. The context is important for reusability of this ethnography – I will show what comparable activities this applies and provide some indication of the generality to other domains of construction, such as vertical construction.

5.3.1.1 Relevance

After working as a field hand for ten years, I enrolled in a university construction management program and at completion accepted a field engineer position. This chapter presents the ethnographic observations of the quantities monitoring methods practiced on the one project I was employed as a field engineer. Throughout this chapter the discussion centers on project accounting, also known as job cost accounting, rather than financial accounting or managerial accounting[175]. Job cost accounting differs from the financial accounting practices found in the corporate offices of heavy civil companies[176]; the output of job cost accounting is the forecasted revenue or loss at completion and feeds into the financial accounting process (wiki Cost accounting). A conservative assumption is that only heavy civil contractors use the job cost accounting method, therefore excluding commercial specialty subcontractors from this study. With this assumption and the 2006 U.S. construction industry population (IRS corporate tax returns with net income), 17% of U.S. construction, and 27% of U.S. commercial and heavy construction use the job cost accounting practice. Because of my background in construction as a union Laborer working on the same types of activities as on this project, and in some cases having worked alongside some of the same Laborers that I was now responsible.

5.3.1.2 Scope of Observation

The ReTRAC project scope was for both design and construction of improvements to a preexisting rail access corridor through Reno, Nevada. The improvements consisted of depressing into a trench the historical Overland Route[177] double track rail corridor below the street level through the Reno urban downtown center. Reno is a medium sized city in the Western United States, located in an arid high mountain region known for sparse populations and rugged terrain.

The project was competitively bid - as is normal for large public works projects within the Western United States - with the lowest bidder awarded a contract to construct the project. A contract competition can be based on metrics other than price to adjust bid score but usually

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[175] These are focused on reporting to the corporate executive staff.
[176] If you are unfamiliar with these accounting practices, please refer to a construction textbook or reference the citation in the bibliography (wiki Project accounting).
[177] Now owned by the Union Pacific Railroad.

price is the sole criteria. The contract was a design-build type for a lump sum of $190 million, over a 60-month duration, with a monthly percentage of completion progress payments. The contractor that won the bid completion was a vertically integrated contractor – Granite Construction – who self-performed with their field crews and equipment, there was minimal subcontracting, Table 38. Even the concrete was produced by the project from an onsite rock quarry and cement shipped by rail directly from the limekiln to a rail spur for the batch plant.

Table 38 Demographics context allows an *apples-to-apples* comparison of the observed project with other project observations.

Observer role: Field engineer
Observation duration: 15 months
Observed project: Reno Transportation Rail Access Corridor (ReTRAC)
Project type: 2.3.7.0.00 (BLS code) heavy civil transportation
Product: inverted transportation corridor 60 ft. wide, 30 ft. deep, 3.5 miles long containing double tracks through an urban downtown
Funding: public bond
Bid: competitive bid
Contract type: design-build
Labor: multiple union trades paid union wages (nearly identical to prevailing wage)
Payment: lump sum, monthly percent of completion progress billings per schedule of values
Oversight monitoring method: Earned Value Management (EVM) type
Change Orders: 84 representing 4% of contract value

For the degree of accuracy and consistency required from their estimates to be competitive, the contractors that bid these projects have intricate project monitoring systems. These monitoring systems feedback project quantities to historical libraries in the estimating department. The current standard for estimating is a +10%/-3% (Akinci & Fischer, 1989) degree of forecasting ability to monitor project progress. The quantities on this project served as inputs to multiple project control and recording systems such as monitoring unit cost and productivity, process schedule updates, progress billings, cost to completion forecast[178], and a historical cost and production library[179].

The ReTRAC bid winner was the Granite Construction Company (GCCO) Heavy Construction Division (HCD) Western Regional Office (WRO). Granite is a large western United States civil contractor that had 2,000 salary employees in 2005 and a vastly larger number of seasonal union tradesmen. In 2006, the company had gross revenues representing 1.5% of the United States heavy civil industry, Table 39.

[178] The cost to completion attribute is due to the forecasting process and its impact on the revenue reporting of a publicly traded company.
[179] Used for estimating future projects.

Table 39 Observed project's cost in relation to the 2006 U.S. construction industry. The 0.1 confidence interval indicates the project practices are representative of civil methods. The remaining question is if the scope of observations is actually this representative of civil methods.

Granite Construction Company (GCCO); Heavy Construction Division (HCD); ReTRAC Project

Organization	Year	Revenue	Duration	% of US Heavy	CI @ 95% CL
ReTRAC project		$190M	60-month		
ReTRAC project	2005	$ confidential	12-month	0.05%	0.5
GCCO HCD	2005	<unknown>	12-month	~1%	0.1
GC Company	2005	$2,640M	12-month	1.5%	0.1

The Granite engineers designed for the bid a depressed corridor with a double cantilever concrete retaining wall structure 33 feet deep, 54 feet wide, and 2.25 miles long, similar to the drainage canal example in *Estimating* (p388). The competing bid they won out was a caisson wall design – the risk taken by the Granite team was that they could hold the excavations with soil nails and shotcreat in place of a caisson wall.

The construction activities progressed through site clearing, utility relocation, excavation and a shotcrete soil-nail retaining wall, cast in place cantilever retaining walls, and reconstruction of surface streets. The Granite team received the ReTRAC notice to proceed in 2002 from the City of Reno and completed constructing the originally contracted scope four years later in 2006.

My ethnographic observations of the ReTRAC project appear statistically significant. The ReTRAC project revenue for 2005 represents 0.05% of the 2005 United States heavy civil industry. Observations of the methods used on the ReTRAC project are within a 1% confidence interval for methods used by 75% of the United States heavy civil industry. This indicates it is not likely there are methods used that are not represented here or methods represented here that are not used anywhere else.

I was assigned to the project in June 2005 and left to attend Stanford University in August 2006. The following list is to establish the scope and depth of my observations, during my 18-months on the ReTRAC project I was increasingly responsible for the following tasks and was the last field engineer on the project:

- project, annual, 3-month, and 5-week lookahead schedules,
- coordination and controls for design, quality control, landscape, & haul subcontractor,
- hotel casino & storefront business relations,
- weather historical library,
- heavy equipment fleet management,
- earthwork, flatwork, & laborer field support,
- designated project enterprise cost engineer,
- job cost journal adjustments,
- project operations profit maintenance,
- project progress billings & submittals,
- executive project monthly reports (PMR),
- subcontractor progress billings (subpay) validation,
- quarterly cost forecast,
- stakeholder (partnering) questionnaire survey analysis,
- partnering meeting coordination & meeting material preparation,
- project final report (PMR), partial, project was not finished,
- enact the directives of three managers (Project engineer, Business Manager, and Superintendent),
- apprentice and incrementally assume responsibilities for the earthwork, underground utilities, structural, and flatwork field engineers,

As a field engineer I tracked the quantities for the earthwork discipline – most of the activities I monitored were supervised by the same superintendant. The earthwork scope during that project timeframe included 120 direct and 400 indirect accounts. A comparable number of activities - each with multiple operations represented in the 5-week lookahead schedule - were monitored for schedule updates of the direct activities. The quantities were measured in 48 units of measurements. Reporting periods were daily, weekly, monthly, quarterly, yearly, and project, I did not observe the use of multi-project reporting periods.

Each account contained three types – labor, equipment, material - and two subtypes – regular | premium time, internal | external material or equipment - sometimes more, resulting in 2,800 individual accounts. In addition, there were meta-accounts I updated monthly that summed multiple accounts. There was no location breakdown structure for the accounting system. Quantities were tracked by location and workzone - if beneficial - so in practice there were 30 workzones * 2,800 accounts for 90,000 individual accounts. Reporting was in 48 units of measure, implying an additional 48 methods of measurement, post-processing, and source combinations.

The dollar value of the activities I monitored ranged from 353 dollars to 1.5 million dollars ($2005)[180]. The direct accounts I monitored totals to $10 million, the indirect accounts were less. In total the indirects sum to 6% to 10% of total project billings, another $18 million, I monitored a portion of these indirects. The complexity of the project activities I supported ranged from city blocks of street curb and gutter to the 156,000 cubic yard structural backfill of the trench walls. The project manager was not comfortable with a new engineer responsible for this scope but due to several large projects starting, the project engineer, the superintendents, and the other field engineers were transferred. At the same time a couple longtime large projects managers retired during a highpoint in the corporate stock price. Since I was planning to attend the Stanford University Construction Engineering and Management program – the next year a large project was planned at the San Jose airport with the same large projects group[181] – therefore I was not scheduled for a new project and so closed-out the last $3 million of the project contract and $3.5 million in change orders.

The experience of the engineers and field hands I observed on the ReTRAC project varied from over 30 years to one year, Table 40 on page 202. The project managers had greater than 15 years of experience with large projects contractors[182], such as Atkinson Construction (mid 1980's $9B), Washington Group (now URS $10B), Peter Kiewit ($5B), and Granite Heavy Civil Division (HCD) (all GVA $3B); the four are well-established heavy civil companies. Since I joined at the project midpoint, the opportunity to pick up knowledge from engineers as they left for other projects allowed a broader domain of experience than Granite allowed for security reasons. I learned and assumed the responsibilities from eleven engineers and supervisors, and learned from four managers. Each shared their methods and philosophies on quantities tracking.

At the end of the project, the project manager allowed me discretion and responsibility for the project field operations. For this reason, I learned and gained experience in a broad range of activity types and different tracking systems [such as electronic format, ERP AS400 EDJ, P3, equipment, indirect accounts, direct accounts] and methods. I then helped a *Local 3 Operator* - Operators are a trade-union, Local 3 is the west coast region - foreman learn construction management for several weeks prior to leaving the ReTRAC project. As the replacement field engineer I supported this Operator to learn quantities monitoring and then provided support by

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[180] $2005 is notation for the year that the value in United States dollars is given. Adjusting for inflation or deflation is necessary to compare the amounts with values from some other year.
[181] The San Jose Airport project was constructed by the Granite Construction Bay Area Branch rather than the Heavy Construction Division – so I left Granite at that time.
[182] Annual revenue given in 2008 billion per year.

phone and email for another three months – at that point he was sufficiently experienced to no longer need help[183].

Table 40 The transfer of knowledge and accompanying learning from supervisors and departing engineers provides the basis of ReTRAC project direct and indirect observations. This table does not represent a *chain of command,* it represents the knowledge transfer.

	Learned from	Exp. (yr.)	Topic	Takeaway / Key Lesson
1	Intern Field engineer A	1	Indirect job cost material monitoring	Accuracy and precision is a myth, completeness rules
2	Intern Field engineer B	1	Indirect job cost material monitoring	Accuracy and precision is a myth, completeness rules
3	Field engineer A	2	Schedule updates, Job Cost Adjustments (journals), Sub-pay, Enterprise cost accounting	Corrupted codes, non-robust systems, project monthly report errors, quantities errors
4	Field engineer B	3	Street improvements	Monitor by scaling from plans
5	Field engineer C	5	Progress billing	Estimate quantities, CAD as a CM tool
6	Field / project engineer	5	Haul truck, cost forecasting	Relevance of value to final, neat line takeoff
7	Field engineer D	5	Partnering	Electronic spreadsheets
8	Field engineer E	10	Earthwork Quantities, Haul trucks, Cost coding, Weather tracking	Percentage of completion, assembly monitoring
9	QC engineer	10	Sub and Quality control	Communicate w/ subcontractors
10	Earthwork super.	15	Field monitoring and control	Production rates do not exist
11	Carpenter super.	15	Field monitoring and control	Tree hierarchy breakdown structure
12	Equipment Mgr.	40+	Equipment Management	Equipment cost management
13	Project Manager / Project Engineer	30	Quantities takeoff Quantities monitoring	What matters is that the quantities, labor hours, and cost is coded correct
14	Construction Mgr.	40+	Field Operations	Heavy civil field operations requires a degree of indifference
15	Office Manager	40+	Business Management	Completeness of documents

5.3.1.3 Conclusion to Observation Context

In this section, I presented my experience that prepared me for my ethnography, the scope of my observations, and the context of my observations. The ReTRAC project was a design-build railroad reprofiling project through an urban downtown. The project was a 2.25-mile double cantilever 30-foot high retaining wall corridor. The city context presented constraints for allowing public access to commercial buildings and working around live traffic. The project was competitively bid and constructed using unionized labor – both typical of public works in the western United States. The scope of this project and the context of the observations provided for a better than typical sample. By scale the ReTRAC represented 0.5% of the 2005 United

[183] When I told the local San Jose Branch of GCCO that I'd been helping the ReTRAC and asked if I could use those hours in place of hours I was working at the branch he told me to bill the ReTRAC. It was a strange comment and showed how internally divided the company was.

States heavy construction put in place. Because I was on the project from to mid-point to completion I gained the knowledge and role of each departing field engineer. At the completion, I was the sole field engineer and responsible for all aspects of the project – providing an objective view that otherwise would have been very narrow. Further, this project had a project team that had worked with some of the largest heavy construction contractors in the United States - again giving a broader perspective.

The importance of this observation is that this is probably a more complete ethnographic observation than typically available. In the literature review both Saidi (2002) and Kiziltas (2006) relate ethnographic type experiences on the projects they were embedded. I see in their experience that they had a narrower view of the project planning process, Saidi appears to have a cost engineer focus and Kiziltas appears to have a scheduler focus. This may simply reflect the project team they worked with and the focus they used in their specific approach to project planning. My ethnographic observation provides through the scope of work a depth of observation. Based on the literature review and survey results, my observation are representative of the methods used throughout the heavy construction industry. The generality of these methods to other heavy construction project types, to industrial process plants, and to vertical construction is uncertain. From the literature review and survey there is a degree of crossover but the significance and relations are different.

In the next section, I will present the representation of context features through the use of a breakdown structure and a nomenclature to represent the features. I begin this process by explaining what a quantity is and present the breakdown of the features into a hierarchy. The development of a feature hierarchy is the first step in quantification and defines what will be measured.

5.3.2 Representation of Features

In this section, I will present the representation of quantification features – essentially the features to relate the meaning of the measurement. I will first review the concept of the quantity features, then present the breakdown structure used on the ReTRAC, then the chart of accounts, the location breakdown structure, conditional statements, and last I will present the process schedule's breakdown structure.

Without features, a measurement is a number with no unit of measure or other features. With features, I know the unit of measure and on the ReTRAC project I also know the time, the work discipline, the component, and the operation, as well as the applied resource. With these features and knowing nothing else about the measurement, I can map this measurement to the equivalent features in the planning system and reuse the measurement for planning.

The quantities must be associated with a monitoring system. The field engineer can associate the quantities with an account using a matching nomenclature code – codes come in three types, sequential code, indexical ontology code, and *natural language*. The Overland railroad report represents the work and material by natural language, Table 41. The reported quantities use one word such as excavate and lay to represent work actions. Examples of the materials representation are rock and earth. There is a breakdown structure in the Overland project report representation with the example of 'rock excavated,' that is, resource and action; the type of foundation that Darwiche (1989) added object to form OAR, object, action, resource.

Table 41 The action is represented with operation and material in the "Progress of the Work" 1865 project report of the Central Pacific Railroad portion of the Overland Route transcontinental railroad transportation corridor project.

The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date:

Earth excavated—No. of cubic yards	1,465,970
Rock excavated—No. of cubic yards	821,984
Stone masonry—No. of cubic yards	21,299
Culverts, No. 215—length in feet	12,626
No. of brick in the work	389,894
Timber and lumber in structures, feet B. M.	2,034,106
No. of ties laid	135,000
No. of ties contracted for	125,000
Tons of iron laid	6,000
Tons of iron purchased and not laid	2,000
Pounds of iron in bridges	162,700

As a mapping function between aspects of reality and planning: Codes are used to identify components in the product model, to identify activities in the process model, and to identify cost in the cost model. The feedback of reality through project monitoring back to the product, process, and cost models requires applying codes to the measured actual quantities. If the field engineers apply codes to the measurement, they organize the codes into buckets based on the level-of-detail applied for monitoring the activities. The level-of-detail is defined as a breakdown structure. The more levels then the finer grained the monitoring and the deeper the levels reach the more detailed the monitoring. The project engineer can represent each account by a derived ontology nomenclature or a sequential nomenclature. A sequential nomenclature does not contain indexicality and therefore sequential nomenclatures do not represent the relationship of two items.

First, I will discuss in more detail the types of quantities and then I will present the breakdown structure and the derived chart of accounts, followed by the location breakdown structure, conditional statements, and last the process schedule breakdown structure.

5.3.2.1 Types of Quantities [Product]

Before presenting the method the ReTRAC project used to represent the features of a quantity measurement I will cover the case of three basic features representation. The first is the concept of a quantity as it was understood on the ReTRAC. I expand this concept through a logical discussion to include cost and time – two concepts that are not usually thought of as a quantity. After introducing the concept of quantity I will present the indirect quantity account and then the direct quantity account. I present the concept of a quantity here to ensure there is not confusion about how I use the term quantity throughout the rest of this ethnography report. The indirect and direct quantity types are good to present here as well since these are high level divisions of quantities and defines how the quantity will be used. From the survey interviews, I now know that the indirect quantity is a warehouse quantity – at the time of the ethnography this distinction was not fully understood by anyone on the project.

5.3.2.1.1 Quantity Categories

The transcontinental railroad Overland Route project progress report uses six units of measurement. The stone masonry activities - comparable to today’s mass concrete placement - are given in cubic yards, Table 47. These units of measurement such as count and tons, are similar to what was used for measurement on the ReTRAC project.

Table 42 The Central Pacific Railroad's 1865 transcontinental railroad Overland Route project "Progress of the Work" report.

The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date:

Earth excavated—No. of cubic yards	1,465,970
Rock excavated—No. of cubic yards	821,984
Stone masonry—No. of cubic yards	21,299
Culverts, No. 215—length in feet	12,626
No. of brick in the work	389,894
Timber and lumber in structures, feet B. M.	2,034,106
No. of ties laid	135,000
No. of ties contracted for	125,000
Tons of iron laid	6,000
Tons of iron purchased and not laid	2,000
Pounds of iron in bridges	162,700

The term *quantity* describes more than material quantity. Quantities are a measurable indicator of project scope and progress. The engineer reviewing the project record can infer the methods of construction used on a project from the chart of accounts values; the lack of quantities applied to an account implies the field crews did not use a method or operation and the presence of a quantity implies the field crews did use it. For example, the Overland Route report does not list cubic yards of dredged material, implying dredging – an activity in California at that time - was not within the project scope. Notice that the quantities are physically measured units, such as cubic yards, units of time and money, and ratios, such as percentage of completion, Table 51 page 234. The variation in units or lack of units raises several questions:

- If the account does not have a unit of measure of time or cost, then is this still a quantity?
- Are time and cost considered quantities or is quantity constrained to describe only the reported unit of measure?

Because the measured time and cost can be post-processed to derive a reported quantity in a physical unit such as cubic feet, then I proposes that yes, time and cost are quantities, Table 44. In the heavy construction tradition, each tracked item is a component of the project scope, time, and cost, also termed, bill of material, lookahead schedule, and budget, Figure 30.

Table 43 Quantities; the actual quantity is immeasurable and similar to Plato's *Theory of Forms*. In sequence are the quantities, these are planned, estimated, measured, post-processed, reported, and forecasted (planned or expected). The repeating loop from forecasted to expected is inherently tainted with bias and errors; field engineers strive to represent the actual.

→actual (immeasurable true value)
→theoretical (takeoff)
→estimate/budget (bias/errors)
→measured (error/quality)
→post-processed (recipe-formula, endogenous assembly, ad-hoc)
→ reported for billing & accounting (bias/errors)
→expectation (forecast)

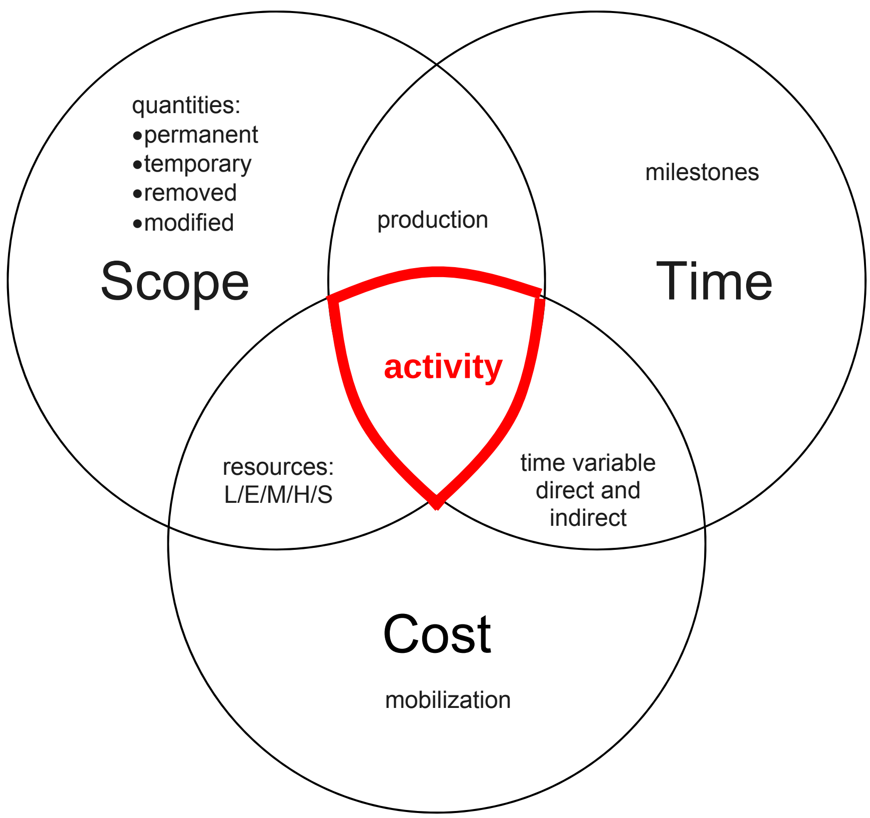


Figure 30 Graphic argument for the intuitive understanding of the accuratley and consistently quantifiable role – absent change in scope - quantities plays. Resources are labor, equipment, material, haul, and subcontractor; capital is implied available.

The combination of quantity with labor or equipment produces a production rate. When combined with cost, the quantities become unit cost. The quantities of time-cost items are measured in durations, these are termed 'time-dependent' quantities, the previous two categories of quantities are time-independent, Table 43. On the ReTRAC project, I observed that the scope, time, and cost were not integrated. These three topics were treated as separate fields; in-practice they must be integrated in at least the field engineers' minds. The field engineers used a code to organize the takeoff, labor hours, and cost but not the schedule. The project engineer divided the project quantities into indirect and direct. The *production quantity* for indirects are often time-dependent and directs are time-independent.

Table 44 The subcategories within project dependent and independent features. Measuring quantities is not as simple as just measuring the work-in-place. There are multiple types of quantities, each with distinct characteristics.

Project Dependent Quantities

- Undistributed Job (direct): Low level of detail
- Distributed Job (indirect) Material (invoiced UOM)
  - Permanent Material (not specifically defined)
  - Temporary Material
  - Removed Material (not used)
  - Modified Material (not used)
  - Overhead
- Distributed Direct Job (quantity)
  - Labor (quantity): Reported Time Increment (man-hour)
    - Trade (not used)
    - Prevailing / non-prevailing
    - Regular time / premium time
  - Equipment (quantity): Reported Increment – rent:month, highway:miles, own:hour
    - Internal
    - External
  - Haul (Quantity): Reported Time Increment (hour)
    - Onsite (criteria for prevailing/non-prevailing)
    - Offsite (criteria for prevailing/non-prevailing)
  - Subcontractor -Internal / external
- Work Completed Quantities
  - Actual work completed (technically immeasurable)
  - Activity (quantity) states:
    - Estimated (forecast) - UOM
    - Activity (driving production) - UOM
    - Budget (measurable) - UOM
  - Measured quantities (preprocessing)
  - Reported quantities (post processing)
  - Support work (non-payable)
  - Billable work (bid Items)

Project Independent Quantities

- Dictated by project independent factors: Standard specification quantity
- Measurable indices/resource scarcity – used to calculate cost (not a quantity)
- Calculated cost (quantity) for monthly overheads, depend on measured resource scarcity.

5.3.2.1.2 Indirect Quantity Type

The indirects, also known as undistributed, Figure 31, often have a time dependent production quantity, for example, the external equipment measured in months. As indirects: temporary material, permanent material, and overhead supplies were tracked on the ReTRAC project. I define *temporary* materials here, as those required for project completion though not part of the final product or overhead supplies. Permanent material is the actual delivered product. Overhead supplies include small tools, safety material, maintenance, and office material. In the context used on the ReTRAC project, overhead supplied are those items that field crews and office staff consumed in the production of the project but are not *temporary* or *permanent* material. I observed that removed material was tracked as a direct quantity. An example of modified materials is the trench excavation material. The earthwork field engineer had the trench spoils hauled to an on-site stockpile where a subcontractor processed the material to remove cobbles over 3”. The earthwork field engineer then had the material hauled back as backfill for the structural retaining walls. The field engineer tracked the modified material as an indirect quantity.

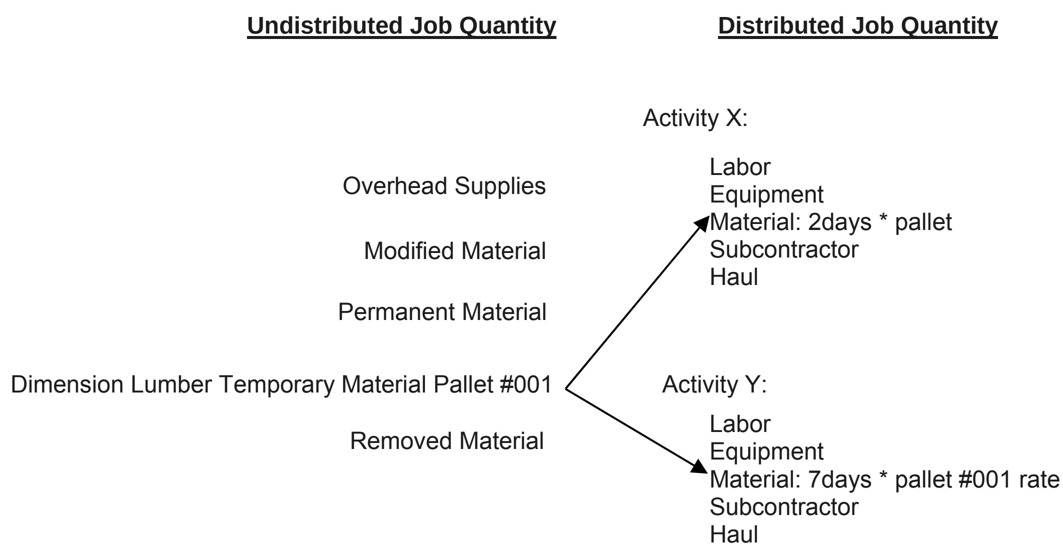
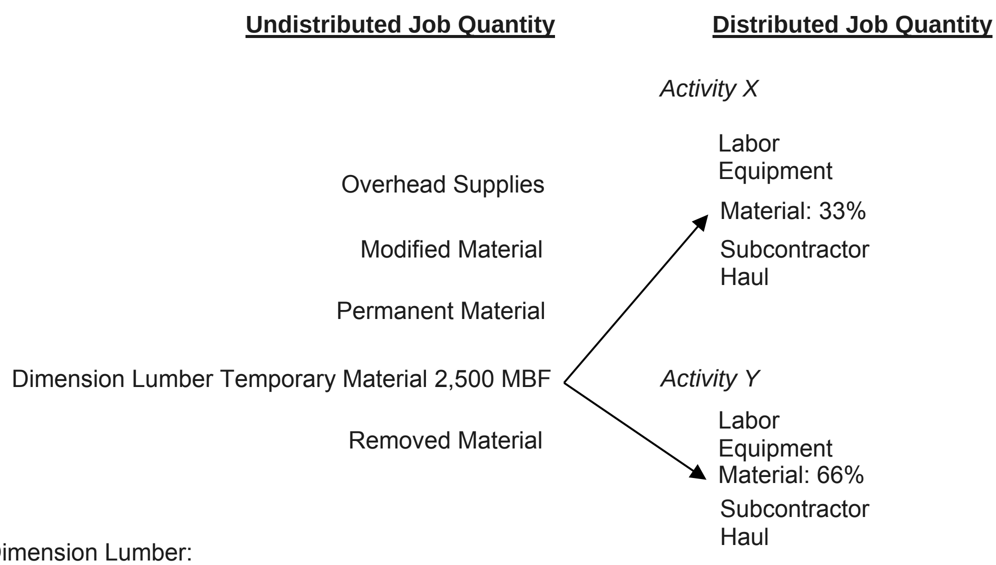


Figure 31 Undistributed accounts distributed to the accounts through a measured degree of usage applied with a rental rate. The field engineer must establish the material asset identification, total use, maintenance cost, and rental rate for each temporary material.

Carrying material as an undistributed quantity requires distributing the material from one indirect account to multiple direct accounts. The benefit of carrying as an undistributed quantity is a project-level of detail is available to monitor material such as aggregates or forms used on multiple operations. A drawback is quantities must be reported redundantly to two accounts as the direct material and the indirect material. Distribution may impede reuse of project records if there is no record of the account associations and the quantity distribution. One solution is to maintain a distributed material account type and sum these in an undistributed material account, Figure 32. The field engineers could have monitored temporary materials used on multiple operations by “renting” to individual operations. The rent solution adds complexity by the need to establish – a process with its own attributes of accuracy and consistency over time - asset centers and rental rates.



Dimension Lumber:

Purchase Value	$10,000	
Quantity	2,500	MBF
Salvage Value	$500	
Maintenance Cost	$2,500	

Pro-rate total to activity based on % of time, quantity or other metric

Figure 32 The ReTRAC solution to the specific issue of distributing temporary material, therefore capturing the cost and quantity at the source of use. The undistributed quantity records the baseline quantity purchased and cost. This solution differs from the proposed rental solution in Figure 31.

5.3.2.1.3 Direct Quantity Type and Work Completed

The direct or distributed quantities I observed on the ReTRAC project: demolition (work and material), work-in-place[184], labor hours, equipment hours, and subcontractors, Figure 31. Work completed quantities are the actual work put in place as part of an activity. Example cubic yards of concrete placed or square yards of graded surface. There are also quantities of actual work completed that are not billable work but support the billable work. A record of these operations is beneficial for project control and estimating; the measurable metrics are

[184] Be aware that the direct material topic has further nuances that I cannot explain fully.

production, resources, and cost. As an example, consider forming and stripping concrete formwork. Cubic yards of concrete placed are a billable quantity while the permanent and temporary support work prior to and subsequent to the concrete placement is not billable. Examples of permanent support work that are not billable are grading the footing pad, the structural reinforcing steel, and curing the placed concrete. Examples of temporary support work that are not billable are the forming and striping of forms and moving to the next concrete placement location. The ReTRAC project had a lump sum contract with p[ay items calculated as percentage of completion: billable and unbillable work was not a conscious issue for field engineers since the owner released progress payments based on the project percentage of completion and there was no direct reporting of the work completed quantities from the contractor to the owner[185]. The quantities collected on the project were for internal cost tracking for variance checks, forecasting this project, and estimating future projects purposes.

5.3.2.2 Observed Breakdown Structure and Chart of Accounts

The ReTRAC field engineers understood the feature sets as five types, these are cost code, activity code, plan sheet code, resource code, and resource identification code. The chart of accounts I observed on the ReTRAC project was applied to an enterprise resource planning (ERP) system (JD Edwards). In practice, field engineers assigned the features to quantities – if not measured by the field engineer - and assigned the quantity to features if the field engineer measured the quantity, Table 45. If the field engineers calculated the activity duration from production and scope takeoff, they organized the duration by the feature set. The process model software tool - Primavera P3 - assigned the activity codes sequentially. The field engineers ignored the P3 activity codes. Sheet number and a description for the component identified the 2-dimension product drawings. The field engineers used the plans sheet numbers for reference when reviewing takeoff quantities. Resource distribution codes, defining labor, equipment, material, haul, subcontractor, and other resources, were within the ERP system and the field engineers used these to code material and service invoices and equipment timecards. The last level of identifying code is the specific applied resource identification. Examples are employee number, equipment number, purchase order (PO) number, invoice number, and contractor number. The field supervisors placed the labor and equipment specific identifying codes on the timecards, the vendors placed invoice numbers on the invoice, and contractor numbers were on file. The details of coding a measurement may not be observable to every individual on the project; the code is represented in the historical record for every reported measurement so everyone is affected by the coding even if they are not aware of it.

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[185] This author did not monitor the structural concrete operations but received the progress quantities from the structural engineer.

Table 45 If quantities are provided by field crews then the quantity is known and the code is not. If the field engineer measures the quantity then the code is known and the quantity is not, each scenario requires a different specific method of coding.

The codes are known but the quantities are not:

Code	Quantity	Units
840151		BCY
411331		BCY
411334		BCY

The quantities are known but the codes are not:

Code	Quantity	Units
	500	LCY
	500	LCY
	500	LCY

5.3.2.3 Observed Chart of Accounts Breakdown Structure

On the ReTRAC project the breakdown structure is defined to the last level that then is assigned a sequential suffix group of digits representing the applied resource and then the unique identifying code for that specific resource. Once the estimators have represented a project plan as a bill of quantities, process schedule, and budget then each item within the scope-time-cost documents needs to be identifiable. On the ReTRAC project, I observed that the takeoff was identified by location, plan sheet, and component, an activity description represented the schedule, and a feature set based on a breakdown structure represented the cost estimate and budget items. The process of matching the project plan subcomponents of scope-time-cost was ad-hoc since these did not share an identifying method, identifications, or level of detail. The process of updating the takeoff quantities for a budget item, updating the schedule with project progress, and associating field measurements with the budget was ad-hoc and done as three separate tasks. Learning how to match codes to quantities involved the transfer of tacit knowledge from one field engineer to another with reinforcement from the project engineer. A definable process within these three was coding the field measurements and vendor invoiced cost, a process called *cost coding*.

Table 46 The observed ReTRAC Work Breakdown Structure used for the Chart of Accounts Only levels 8 through 12 were explicitly coded; the other levels were included as additional documentation or inferred. For example, a timecard obviously records labor and anything over 8 hours is premium time.

17-level breakdown structure

1. Date
2. Company (implied)
3. Company Division
4. Division Region
5. Project (sequentially assigned)
6. Location (not formal)
7. Sub-location (not formal)
8. Discipline (8 classes)
9. Activity
10. Resource
11. Object
12. Operation
13. Method (not formal)
14. Workzone (not formal)
15. Object Type (labor, equipment, material, haul, subcontractor, fees)
16. Sub-type (internal / external | regular time/premium time)
17. Unique Identifying Code, for example, labor social security number

5.3.2.4 Observed Location Breakdown Structure

I observed that the project used a location breakdown structure for locations in the x, y plane and the z plane. The location breakdown was not recorded in the project enterprise asset system, reported quantities had the location feature removed. The field engineers recorded locations only in the schedule and the production monitoring spreadsheets. The project engineer defined three distinct location breakdown structures. He based the first breakdown structure on survey stationing and followed the project rail alignment; organized by divisions in length, for example 100 feet. He defined the second breakdown structure by the retaining wall panels sequentially numbered from left to right. He defined the third breakdown structure for use outside the trench and reused the city street grid including one city block on each side of the trench for the project length; 28 city blocks, each a 1.5 acre rectangle, Figure 33. The field engineer subdivided the trench survey stationing into a second breakdown level as a z coordinate defined as subgrade, grade, and super-elevation. He subdivided the retaining wall panels for North and South locations and added a final level for the z-coordinate as invert slab[186], wall panel, and barrier panel. The project engineer subdivided the breakdown structure used outside the trench by sublocations for North and South of the trench. He then added an additional level for workzones to allow sequencing the schedule for contract constraints, such as casino entrances, these could not be closed - if double doors the workzone boundary was the doorframe in the center - and valet parking entrances and exits. The casino hotel

[186] The invert slab stationing followed a different interval breakdown from the wall panels and barrier rail – most likely due to the different production monitoring ‘chunk’ needed for each.

ventilation air intakes also should have been represented as special zones sensitive to sprayed chemicals such as concrete cure compound.

Figure 33 The two distinct location breakdown structures observed used on the ReTRAC project. The invert uses the central breakdown and is by survey stationing, orientation sublocation, and panel workzones. The second breakdown is by street location, orientation sub location, and constrained workzones. The ghantt schedule had trouble representing these two distinct location breakdown structures where they crossed.

5.3.2.5 Chart of Account Conditional Statements

The chart of account descriptions contained one or two words, such as *on-site haul* and the project engineer left to the coder to infer the application, Figure 34. Established tacit practices govern how the codes are initially established, these practices while not understood specifically as such by the ReTRAC project team, are:

- project independent, reused codes from previous projects
- project specific, at estimate/budget created for this project and possibly added to the project independent list
- customized project specific, created during the project as necessary and possibly added to the project independent list

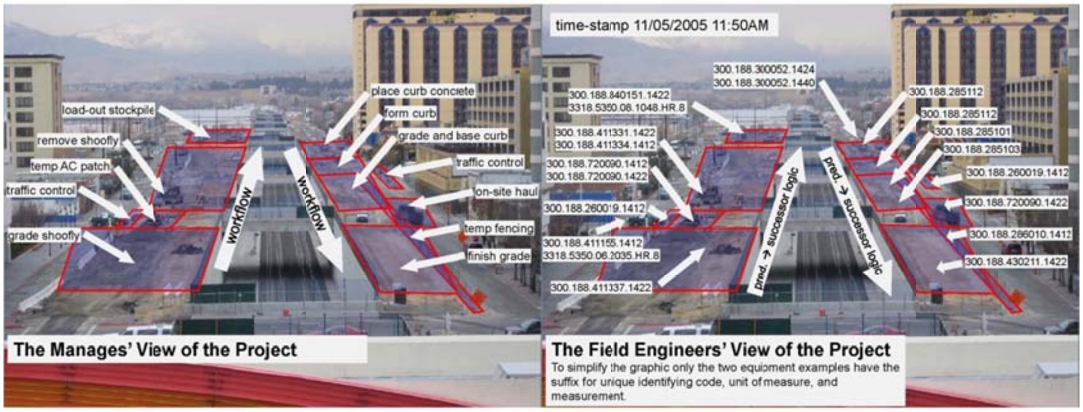

Figure 34 On the left, actual chart of account (COA) descriptions the field engineers used to assign codes to measurements. This example includes the time component by displaying the concurrent activities that must be discerned from each other on this specific day; on the right are the numerical ontological codes for the same operations.

On the ReTRAC project the only additional guide to the short description are the two-level, four-digit, numerical cost type designations, and their two word descriptions. The cost type suffix opened or closed the code to internal and external labor, equipment, material, or haul quantities. There may have been short text descriptions in the budget spreadsheet; I did not retain a copy from the project and if it did exist, it was rarely referenced.

Notice that an abstract and not clearly understood concept to codes is the resource features. An activity has resources, which give form to components (Mourgues 2008), which field crews then constructed with an operation by a method using applied resources (different than the resource that gives shape). For example, the field engineer could have excavated the rail trench with excavators and haul trucks or by shovel, basket, and mule cart as the original 19th century excavations were done. These two methods are the same operation to construct the same component with the same resource, that is, soil, and is part of the same activity, for example, construct rail line earthworks cut.

Examples of descriptions that the project engineer could have provided for the project are in the DOE 430.1-1, 1997 guidelines. The main improvement in the DOE guidelines is the addition of conditional statements to act as a guideline. Each measurement has a range of subcategories that define the features beyond the project, location, and activity, these define what specifically is applied as a resource:

- utilizing resources: labor (L), equipment (E), material (M), haul (H), & subcontractor (S)
- each resource subtyped as internal or external
- labor subtyped as trade (Laborer, Teamster, Mason, Carpenter, Operator),
- subtyped time as regular or premium time
- unique identifying code for: labor (emp #), equipment (equip #), material (inv. #/SKU), haul (truck #), sub (lic #)
- unit of measure

The field engineers used the codes and their subcategories as verbal descriptors when talking with each other. The codes were used verbally due to their accurate and consistent definition of an activity. The field engineers made informal agreements with each other to fine tune what a code represented. The exactness of the code reduced the ambiguity for what the text description described. What an engineer applied a code to changed based on the coder and so the field engineers relied on the project engineer to maintain the application of each code across engineers. Through the division of tasks amongst engineers, to maintain consistency in application of codes the goal was for each code to have one engineer coding to it.

5.3.2.6 Process Schedule Breakdown Structure

The process schedule I observed on the ReTRAC project did not share the nomenclature, breakdown structure, nor text descriptions with the budget or plansheets. The schedule used ad-hoc text descriptions without a formal breakdown structure nomenclature for features. The field engineers ignored the codes Primavera automatically assigned sequentially; these codes were useless or worse on the ReTRAC project. Primavera automatically assigns the codes, the field engineer must double click and change each, and it takes the field engineer too long to key a nomenclature that represents a feature set. The schedule and the budget represented the same scope of activity so intuitively there are correlations and a mapping from schedule 5-week lookahead activities to budget operations was possible, though it would have been ad-hoc. The difference between the schedule and budget format is the budget followed an breakdown structure derived from past projects, defined at the project start, and evolved with project progression. The baseline schedule had master schedule activities and then evolved as the scheduler increased the schedule level of detail to the six-month, two-month, and finally from the component to the operation level of the 5-week lookahead. The operations at the 5-week level (operations level) reflected the specific culture and preferred construction methods of this specific project team. An example of a breakdown structure nomenclature that the field engineers could have used to help associate an activity's field operation with its schedule operation is the CIFE-AROW (Mourgues 2008), Figure 35. The project engineer - depending on the project phase - defined a two and three-level breakdown structure in the project schedule. These were preliminary utility relocation, trench excavation and placement, and city streets.

Figure 35 What is this crew doing? They are located on the East-end, on the North sub-location, they are the earthwork discipline, engaged in the backfill activity, with aggregates resource, for structural backfill, narrow fill operation, conveyor method, internal laborers crew on regular time, and internal material and equipment; haul type is not visible. The CIFE-AROW[187] activity name for this operation: *place ¾" aggregate trench-wall structural backfill, east-end north*.

5.3.2.7 Conclusion to Representation

In this section, I presented the representation of features on the ReTRAC project. The ReTRAC project team represented features using a breakdown structure with feature groups such as undistributed and distributed, location, discipline, component, operation, method, and applied resources. This breakdown was represented in a chart of accounts for a list of accounts that would be used to both monitor the project for variance from expectation as well as reforecast the expectation to completion. The approach of using a breakdown of features and listing these as a nomenclature chart of account is widespread. The ReTRAC chart of account is unique to the ReTRAC project and I think it was developed specifically for this project and was not reused on previous or subsequent projects though I am not sure about subsequent projects. The process schedule and the quantities feedback used a location breakdown structure. This allowed defining a quantity for a sublocation of the project – for example, the project has 90,000 CY of concrete, but a specific concrete placement might be 28

[187] See Mourgues, 2008.

CY of concrete. With the quantities by location – once that specific placement is completed, then I know close to 28 CY is completed. The process schedule did not share the chart of accounts with the rest of the project planning system and this created schedule accounts that did not map to cost or quantity accounts. Usually a schedule account mapped to several cost accounts due to the inherent difference in level of detail. Outside quantities the cost accounts did not include locations. The mismatch and patchwork of work breakdown structure (including applied resources) and location breakdown structure across the planning softwares was annoying. Though with the commercial technology available and the theories – not much more could have been done without a concerted effort to do something special.

In the next section, I will present the quantification plan for who collects quantities, the level of detail, and the frequency of quantities measurement.

5.3.3 Quantification Plan

In this section, I present my observations on the ReTRAC for how the quality of the quantities was maintained. The features that defined quality were responsibility for quantities, the level of detail of the quantities, and the frequency of measurements.

In the literature review, I found that level of detail and frequency are two of three features that define the quality of a quantity. The consensus in both the reference text and the research publications is that field hands and their trade supervisors should never be responsible for quantities - here on the ReTRAC the person responsible for quantities is a variable. The Rockly Flats Project reviewed in the literature also placed the quantity responsibility with the trade supervisors and they had trouble with that. Possibly, quantification is not a favored task and it slides out onto the field supervisors because the field engineers do not want to do this task. In the survey interviews I found that Stallard has found an overly tedious quantification breakdown structure will result in gaming the quantities and reduced accuracy – again possibly as a result of an overly tedious breakdown structure the trade supervisors on the ReTRAC found themselves doing the quantification.

The third aspect of effort is completeness –from what I saw during my ethnographic observations – on the ReTRAC completeness' was not variable and was a constant perfectly complete.

5.3.3.1 Who Collects Quantities [Organization]

First, I will present the responsibility for quantities – this rests with the field engineers. Second, I present the measurer of quantities – by recommendation of the literature this should be the field engineer but pragmatically the measurer of quantities is a broad range of people.

5.3.3.1.1 Responsibility for Quantities [Form]

I have divided the responsibility for quantities into the organization, the division of labor, and the auditing process. To begin I will present an Overland Project example.

In 1865, Leland Stanford presented to the United States Congress a project progress report of the western portion of the North American transcontinental railroad; referred to as the *Overland Route* (Leland Stanford's Statement, 1865), Table 47. The project report contains the quantities for permanent material, temporary material, and work completed. Apparently, on that project Leland Stanford was responsible for the quantities. I cannot find who exactly was responsible for the specific measurement of each quantity[188].

Table 47 The "Progress of the Work" table reproduced from an 1865 project report of the Central Pacific Railroad portion of the Overland transportation corridor project.

The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date:

Earth excavated—No. of cubic yards	1,465,970
Rock excavated—No. of cubic yards	821,984
Stone masonry—No. of cubic yards	21,299
Culverts, No. 215—length in feet	12,626
No. of brick in the work	389,894
Timber and lumber in structures, feet B. M.	2,034,106
No. of ties laid	135,000
No. of ties contracted for	125,000
Tons of iron laid	6,000
Tons of iron purchased and not laid	2,000
Pounds of iron in bridges	162,700

On the ReTRAC project, the project manager subdivided the support of field operations amongst the field engineers along discipline lines. For example, the earthwork superintendent had a field engineer providing technical support, quality control, material purchases, ensuring delivery, collecting quantities, coding (material invoices, timecards, and quantities), forecasting 5-week schedule progress, and budget forecasting future applied resource demand. Each discipline had a superintendent; these were earthwork, structures, underground utilities, and labor; aligning with the civil trades. This project did not follow the management "rule of three,"[189] but components of the rule were in place. There were four field engineers one each for earthwork, structures, and underground utilities; with the fourth supporting, a train station building constructed on-site with subcontracted specialty trades. The labor superintendent was not provided a field engineer.

5.3.3.1.1.1 Organization Hierarchy

Similar to a matrix organization structure, the field engineers responded (in order) to a project engineer, a superintendent, an equipment manager, and to 'all intents and purposes' a business manager[190]. The four managers aligned with the three things the field engineers had on their mind, engineering, field operations (labor & equipment), and business. A

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[188] UC Irvine has a project technical report written by the Overland Route project engineer.
[189] Each manager has three people to contact with.
[190] The superintendents answered to a construction manager who with the project engineer, and business manager then answered to the project manager, who then responded to both a projects manager (regional manager of multiple projects) and a regional cost controller. The equipment manager was an interesting position since he also answered to the regional manager rather than the project manager. Also, there was a batch plant and material yard, the batch plant operator traditionally doubles as the material manager; he seemed to work with the construction manager and equipment manager.

subcomponent is the quantity, Figure 30 page 207. For example, prior to an activity, the quantity of material is ordered. Then during activity progress, the quantities of work-in-place are measured and then at each reporting interval assembly calculations are made with recipe and ad-hoc formulas – the field engineers did not use the terms assembly or recipe-formula - to derive the reported quantities and prorate if necessary. In practice the aspects of quality for material, product, equipment, and labor was not a core component of the field engineers responsibility. A company was subcontracted to provide testing and quality control of materials and product who communicated with the superintendents. The equipment maintenance was the responsibility of the equipment manager but in practice, the master mechanics took equipment wear seriously and relied on experienced equipment operators to keep their equipment from breaking due to abuse. The labor safety was the domain of a dedicated safety engineer and so safety was – within reason - outside the scope of field engineering. As best I can tell nobody was specifically responsible for the environmental aspects of the project. The quality inspectors seemed to have the most knowledge in this aspect and in practice addressed environmental issues. For example, a large number of mercury contaminated gold assesors crucibles were unearthed from what looked like was once a ditch. The inspectors immediately warned everyone back due to the mercury and on their advice, I had the crucibles rebuired – they are under a city street on the east end of the project. As field engineers we dealt with community issues, most prominently with casinos. The casino hotels in downtown Reno are open 24-hours and must maintain access through all of their entrances to the casino floor and the parking garages. This required the field engineers to define workzones that allowed scheduling the activity sequence through these constraints – most doors and driveways were double so the structures engineer devised a workzone plan that split the entrances and blocked one door at a time.

On this project, the management organization structure differed from my observatons of smaller projects at the Bay Area region branch. The ReTRAC project heavy civil organization structure was equivalent to the entire regional branch's structure. The difference between the large heavy civil project and the regional civil projects branch appeared to be terminology for level of detail descriptions. For example, the large projects used the term activity to describe $1 million (US2005) of work-in-place (+/- $500,000), while the regional office saw this as a project size scope of work. Also, the titles given to the engineers differed; the large projects have a project engineer that is responsible for $40 million in operations per year, distributed amongst field engineers in chunks of $8 million per year. The regional office project managers are responsible for the equivalent of the large projects' project engineers, and so on up and down the organization titles. The accounting system reflected similar scale adjustments on large projects compared to the regional branch. The large projects breakdown structure chart of accounts used a five level feature set while the regional chart of accounts used a two level feature set.

5.3.3.1.1.2 Division of Labor

On the ReTRAC project I observed that each field engineer was responsible for a specific type of activity, divided along the discipline feature similar (but different) to the Construction Specification Institute (CSI) MasterFormat. Examples of these activity types and the accompanying titles are structural engineer, utilities engineer and earthwork engineer. The disciplines breakdown used on the ReTRAC project differs from both the 2004 MasterFormat and earlier 16 divisions MasterFormat[191]. Based on a follow-up discussion with Darryl Goodson (VP of HCD) I found that from his experience the divisions used on the ReTRAC project evolved over numerous projects from financial accounting categories that worked their way down from executive reporting to the project and activity reporting levels[192]: if this practice originated at Granite, Atkinson or Kiewit is unclear. The project engineer assigns these activity types according to field engineer experience. Structures required the most experience and earthwork the least experience. Possibly the experience requirements associated with each activity type was based on a stereotype or prejudice, but was the practice on this project.

5.3.3.1.1.3 Auditing Measured Quantities

The field engineer does not need to physically collect quantities measurements of the work-in-place; they need to provide support and resources for the person who is making the measurements so they can do their task consistently to a sufficient degree of completion, reliability, and accuracy. As a field engineer, I measured quantities by physically walking the jobsite with a measuring wheel, tape measure, pencil, schedule, and printout of what needed to be measured and where it was. I measured my quantities so not to burden the field hands with a task they were not supported or proficient. Saidi in his 2002 *Field Observation* (p133) reiterates the sentiment that field engineers should not give field hands responsibility for quantities.

On the ReTRAC project, the formal process of validating quantities was through a triple check process. The field engineer verified the quantities prior to reporting, the project engineer checked the quantities report for completeness and errors, and the project manager audited the quantities through cross-referencing, reality checks, and other methods they deemed practical, Figure 36. Also, a construction manager (CM) who supported the fieldwork, and a business manager (BM) who supported the clerical processes and maintained cost controls on

[191] The 1995 16-division format is not suitable for civil works (Kang & Paulson, 1995) and was expanded to include civil works in the 2004 MasterFormat.
[192] From interview with Darryl Goodson.

the office processes audited the quantities. Additional checks were in place at the multiple projects level (regional division office) and possible variances were recorded and returned through the management hierarchy, returning to the field engineer and potentially passed to field hands to investigate a potential variance. Vendors, owner's representatives, oversight agencies, the inspectors, the field hands, and the business office through their own control systems occasionally noted errors in quantities.

Within the ReTRAC project culture the managers expected to find no errors. They expected that mistakes were not mistakes and only appeared to be mistakes with suitable explanations for why they appeared to be a mistake. If they found an actual mistake, a discussion followed on if it was due to process, resources, or a lack of tenacity. As written in Meredith & Mantel (1995) "the project manager must make sure that the bearer of bad news is not punished; nor the admitter-to-error executed" and "the hider-of-mistakes may be shot with impunity - and then sent to corporate Siberia," the managers on the ReTRAC project followed a similar philosophy. Unfortunately, the bearer of bad news and admitter-to-error, while not executed was sufficiently discouraged and the hider-of-mistakes was adept at deflecting blame, even when not necessary, and sometimes to the bearer of bad news. Possibly the former scenario is an ideal and the latter is human reality.

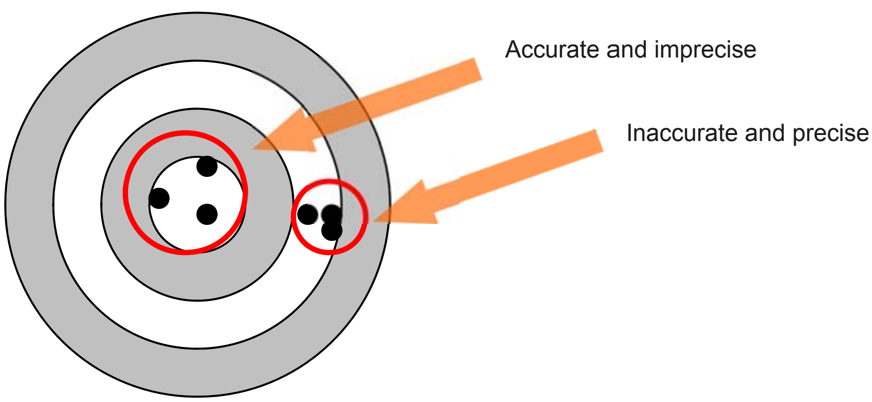

Figure 36 The well-known *bullseye* illustration of accuracy and precision [consistency or repetability]. Bob Stallard's instructions for the 2006 project forecast: Accuracy and imprecision implies poor measurement quality. Inaccuracy with precision implies a mechanical problem with the measuring method. Precision with inaccuracy is better than imprecisely accurate measurements; a variance analysis with precisely inaccurate measurement inputs is usable.

5.3.3.1.2 Measurer of Quantities [Function & Behavior]

I present the measurer of quantities as who makes the actual measurement, the complexity factors that contribute to this designation and assigning the task or measuring quantities.

5.3.3.1.2.1 Who Actually Makes the Measurement

I observed that who monitors the quantities for an activity on a day-to-day basis depends on several factors. The first factor is the preference of the field engineer responsible for that activity. At the engineer's discretion with a concurrence of the project engineer or project manager, actually measuring the quantities could be left to an intern, technician, or field hand, Figure 23 page 140. The project engineer established monitoring metrics or reviewed metrics developed by the field engineers and supported the field engineers' technical support of field crews. The project engineer is theoretically experienced in quantities, provided or delegated baseline and cross learning to the field engineers.

On the ReTRAC project – possibly due to the fast advance of technology into large civil projects - the project engineer was not able to help the field engineers learn scheduling with Primavera[193] and did not have anyone available on the team with sufficient knowledge to help, and so hired a consultant to teach the field engineers. The disconnect between engineers and management technical skills provided for misunderstandings between management and the engineers on the role of technology and the resources needed to support technology. It was difficult to advance technical competency because there were not technology literate engineers to collaborate. Those that had similar knowledge were busy with their assigned tasks so could not provide assistance and even then may not have knowledge in the non-technical aspect of the application of technology. The gap between the engineers' and managements' technical skills created an environment that did not promote incremental innovation on the supported learning received.

The field engineers reassigned the task of collecting quantities to technical and field staff. During the summer months, interns were available to assist the field engineers and field engineers assigned them the task of collecting quantities. The interns collaborated with field hands to collect the field measurements. Past the field engineer, tracing the path to who physically measures the quantity is obscure. Whoever is positioned to measure quantities with the least effort is selected.

5.3.3.1.2.2 Considering the Complexity and Difficulty of Collection

The complexity of measurement affects the selection of the source of quantities measurement. I observed that - similar to findings by Kiziltas - simple measurements, such as count or length that do not require arithmetic were considered suitable for field hands. Measurements requiring simple post-calculations, such as area or volume were restricted to field supervisors and interns. The field engineers did the calculations more complicated than multiplication, such as

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[193] PCI Solutions in Las Vegas provided basic and advanced Critical Path Method scheduling courses in Primavera P3.

division (p262). In addition to considering calculation complexity, the difficulty of making the actual measurement is considered, for example, the window of opportunity to make a measurement. The ReTRAC project engineer considered quantities were suitable for field engineers with less than a couple years of experience if the measurement has a low risk of error in measuring and recording, are routine, and/or have a low probability of contributing to a critical error. An example of a routine activity is one spanning months or years, the reasoning is that the collection process becomes standardized and the measurer can follow a set of instructions. Another example is rather than long duration, the activity occurs frequently and so while a short duration, a process of collecting the measurement is pre-established. An example of a measurement with a low probability of making an error due to simplicity in making the measurement is the hours from equipment, the equipment number, and odometer meter, due to the stationary nature of parked equipment.

Table 48 Factors affecting if a field hand, field supervisor, or field engineer measures the quantities. The significance of each factor is not determined.

Factors of quantities complexity

- Post calculation complexity
- Difficulty to make measurement
- Risk of error
- Routine (duration or frequency)
- Risk of contributing to critical error

5.3.3.1.2.3 Assigning Measurement Task to Field Hand

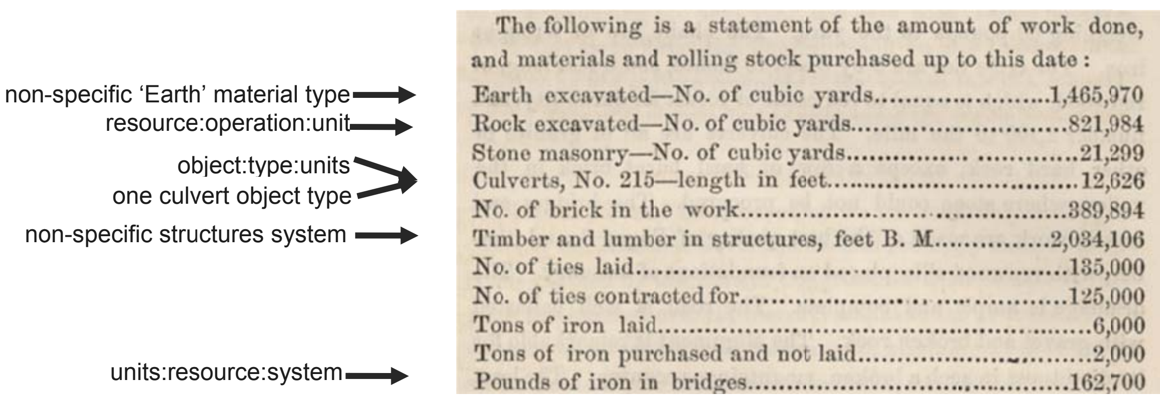
The source – there are 5 sources (p255) - of the quantities that affects who will collect the quantities; the reasoning is that if the quantity is already measured or could be measured with minor additional work as part of an existing activity then they are a source of quantities, for example:

- The Mason foreman calculates the cubic yards of concrete she needs for daily concrete placements as part of her activity. If she makes the calculation on the timecard then the quantities are recorded and prevents the need to repeat.
- The Teamster haul truck driver as part of the payroll processes must provide a timecard record accounting for her time. The start and finish times of each haul are recorded, which are then billed to whomever the haul was for; possibly there are multiple haul customers in one day, the ReTRAC project had the trucks for the entire day. Without extra work for the driver, the timecard contains a record of the load count by counting the start times.
- Equipment that does not have a specific start and finish time, such as a scraper cycle, the field engineer can ask the Operator to keep a ‘counter’ to record the number of cycles during the day.
- The field engineers and office clerks receive and process invoices as a regular part of their day. While processing an invoice it is necessary to verify for correctness in quantities, cost, and location and to assign a code. During the verification process the additional resources needed to measure and record the invoiced quantity is discounted by the dual purpose of billing and monitoring progress.

5.3.3.2 Level-of-detail

Construction crews built the Overland Route corridor with manual methods such as the pick, shovel, and mule cart method, and the unit of measure was likely at the small tool level of detail. For example, an 1866 newspaper article documents that the laborers could lay a rail in 30 seconds and each spike took three strokes of a maul to drive (CPRRb). The progress report to congress represents specific levels of detail in the quantities; half the items are within one unit, Table 49. The report distinguishes the abstract material types of rock and earth; the report does not define the specific type of rock or earth. For example, there are blue, granite, sand, and volcanic rock formations along the rail alignment, each have structural properties that define reuse. The report gives culverts as one type, the No. 215, are there additional types of culverts. Is 215 the number of culverts constructed? While the report represents possibly eight disciplines[194], on nine activities[195], and the use of five resources, missing are the component, operation, method, and – other than material – the applied resource levels of detail. Metrics are not given, such as the number of labor hours, equipment hours (including draft animals), and components by type[196] that were constructed.

Table 49 The Central Pacific Railroad's 1865 transcontinental railroad project "Progress of the Work" report. Notice the naming format changes from resource:operation:units to component:type:units, and then to units:resource:system. The significance in measurement changes from accuracy to the brick to accuracy within 2,500 rail ties



The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date :

Earth excavated—No. of cubic yards	1,465,970
Rock excavated—No. of cubic yards	821,984
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No. of ties laid	135,000
No. of ties contracted for	125,000
Tons of iron laid	6,000
Tons of iron purchased and not laid	2,000
Pounds of iron in bridges	162,700

In the following sections, I present the factors to consider in selecting level of detail, the level of detail I observed on the ReTRAC, the applied resources needed for that level of detail, and the processing of quantities to elaborate to a higher or lower level of detail.

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[194] Laborer, Teamster, Stone Mason, Bricklayer, Carpenter, Rail worker, Ironworker, and Operator (depending on the use of horse drawn draglines or steam powered winches as cranes).

[195] Excavation and offhaul, blasting and mucking, stone laying, culvert cut and fill, bricklaying, wood framing, tie laying, rail laying, and steel erection.

[196] Bridges, causeways, embankments, tunnels, ledges, walls, railbed.

5.3.3.2.1 Factors in Considering Measured Level-of-detail

During the ReTRAC project, I observed that the quantities tracked in the past were a component of a later change order negotiation. When the field engineer recorded the quantities, the method[197] and frequency of measurement was appropriate to the level of detail for the initial purpose of the measurement. When the project engineer reused the quantities such as for a project scope change negotiation, the reuse was constrained by the level of detail and accuracy in the original measurement. Sometimes the level of detail was greater than necessary and with post-processing, was rolled-up to the necessary level of detail. For reuse of quantities and the greater accuracy when rolling-up values rather than the assumptions involved in rolling out values field engineers must consider applying extra resources[198] to make measurements at a higher level of detail than expected necessary.

For estimating future projects, the ReTRAC contractor (GCCO) values production quantities and the surrounding features of the quantities. As a result, when the field engineers record the quantities they also record context features. For example, I observed monitoring features such as weather, material, operations, hours of use, maintenance, labor, equipment, accidents, quality control, changes, crews, and soil contamination. Each level of detail in the breakdown structure is an additional level of detail in quantities and either increases the depth of the detail or increases the fineness of the details. Once the project engineer defines the appropriate level of detail depth and fineness, the field engineer achieves the goal depth and fineness with a tradeoff between[199] the frequency of measurement and the method of measurement, Figure 37.

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[197] Methods of measurement, page 137 and Figure 40 page 137.
[198] Section: Integrated Coding Process page 118.
[199] Suggested investigation of the correlation between work breakdown structure, level of detail, and measurement method, page 232.

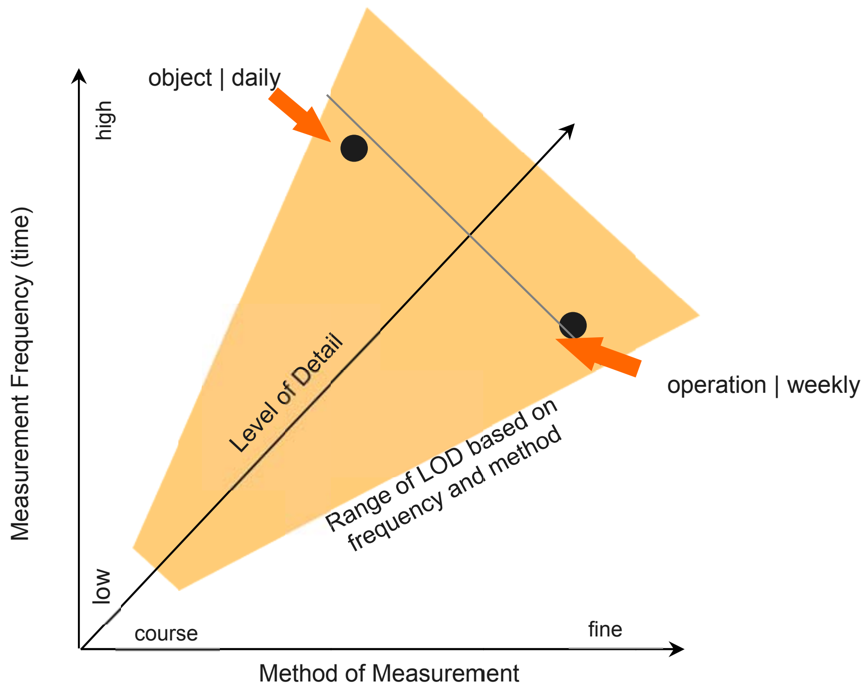


Figure 37 Graphical arguments for the triangular relationship between method of measurement, measurement frequency, and level of detail; the literature review provided no reference to the interrelation of detail, frequency, and method.

5.3.3.2.2 Observed Level-of-detail Measured

The quantities tracked and level of detail used are different for various items. I observed on the ReTRAC project that materials were tracked, such that similar to the Overland Route project it is possible to know the quantity of lumber purchased to the board foot. The field engineers tracked other items at an abstracted depth of detail such as percent complete, with no record of the actual quantity. There is a discussion on page 217 relating to the complexities of recording the quantity of material purchased versus the quantity of material used, including reuse. I did not observe how the defined level was determined; the specific level varies by operation and field engineer, Figure 37. The measured level of detail varied from day to day, person to person, and quantity type to quantity type. From class lectures and the comments made by other engineers it appears that each company, project or end user of quantities has a different degree of detail required. For example, on the ReTRAC the project engineer detailed the earthwork chart of accounts to the method level of detail - by labor and equipment type - though in practice the method level of detail was difficult to measure. For example, was a 950 CAT loader or a JD710 backhoe used to load-out material, this question determines which account the quantities are applied to – either could have been used and a couple of each were on site. The measured level of detail correlated with the operation level of detail, though this could actually be at the component level for some measurements and at the method level for other measurements. The field engineers used the component method by visual percentage of completion on a daily basis since it only required a table of components to observe and noting the percentage of completion for each component while making a regular sitewalk (p260). The second method, operation, often was measured from invoices and required dedicated time seated at a desk therefore consuming at least half a day to several days depending on the scope.

5.3.3.2.3 Applied Resource Considerations for Level-of-detail

Though not certain, it is logical that the greater the level of detail the more reusable the quantities, given the other variables are held constant. Intuitively, the applied level of detail is a function of resource utilization and therefore, indicates the degree of difficulty field engineers will have obtaining a true measure. It is impossible to obtain a perfectly repeatable measurement free of errors or mistakes and at an infinite level of detail. Intuitively, two logical constraints determine the level of detail to apply, short-term and long-term use of quantities: In the short-term, on the ReTRAC project the quantities was a risk-mitigating agent to provide feedback of project variance from plan. The 4^{th} dimension (4D) variable of time then becomes an issue, the measured quantities are more valuable if available in-time to improve the quality of the project control decision-making process.

It is logical the shorter feedback latency requires additional applied resources. For example, a one-year feedback delay, allows a lower field engineer productivity rate than a one-week delay, that is, reduced resources applied for measurements post-processing, error checks, and compiling into a report. To achieve a shorter delay in feedback such as less than one day, the project engineer must provide an increase in the applied resources such as engineering labor, coordination resources, management and clerical support, and/or technology tools - absent innovation.

For the long term, the project engineer balances the applied resource investment in the quality of the project quantities with the value for future uses such as estimating a proposed project's applied resource requirements (crews), the expected crew production rates in the proposed project context, and therefore, with the local resources expected prices, the expected project scope, time, and cost.

5.3.3.2.4 Observed Level-of-detail Processing

I observed on the ReTRAC project that level of detail was predefined as the chart of accounts prior to the project notice to proceed. During project execution, the project engineer pushed the field engineers to achieve 100% completeness, 100% accuracy, and 100% consistency for the provided level of detail, the limiting condition was the field engineers' ability or bias. The project engineer had the measured quantities reused for multiple purposes and the level of detail the field engineers initially collected the quantities at affected the degree of post-processing necessary.

Reducing the level of detail through post-processing is achievable. Increasing the level-of-detail through post processing implies the addition of assumed quantities. For example, the office engineer used the quantities for the monthly progress billing. Due to the difficulty matching billing items with specific measured field activities this approach was abandoned at the project mid-point. Also, because the project contract was design-build and the project was self-performed the baseline schedule changed as actual project conditions were encountered, each change required revising the billing schedule. As a solution, the project engineer implemented a special billing schedule and table of values separate from the construction schedule[200]. To reduce the resources demanded by the direct matching of billing progress from measured project progress the project engineer had the field engineers measure at an abstracted percent of complete method with a rollup of the billing quantities level of detail from the measured quantities level of detail.

The quantities methods I present in this study are the precursor to post processing quantities specific to the billing process. The billing process has conditions, constraints, goals, interests, and strategies that are outside the scope of project monitoring, though they appear the same topic. In this study, I do not review the post processing of the percent of complete field engineers reported for the billable work because it is a specialized condition with its own domain of knowledge comparable to the scope of this study. There are games in the post processing that makes this a comparable research topic, untangling the games and fraud is complex. There are comparable strategies for other methods of progress payment, such as payment by unit.

5.3.3.3 Frequency of Measurements [Process]

The frequency of tracking a quantity varies with the item. There are daily, weekly, monthly, quarterly, yearly, and project quantities. As observed, several activity items needed daily tracking for two reasons; these two examples of the determining factors for the frequency of quantity updates are only two possible factors. First, the field crews covered the work by succeeding operations, for example backfill of a pipeline. Second, because the task of

[200] In vertical construction, some think of the construction schedule as a 'lean' schedule and think of the billing schedule as the standard schedule – in self performed work there is nearly always two schedules, one for billing and a second that may or may not be a printed schedule, that is the construction schedule.

measuring the week's quantities took several days and there were other responsibilities during the same period. To level the field engineer's workload, the field engineer could make measurements daily and then sum the daily work items as the week's value. For the Overland Route project the frequency of measurement is not implied or stated other than the report is for the second year of the project and an invoice for a progress payment was submitted every 20 miles, though multiple frequencies are likely represented, Table 50. The Central Pacific Railroad portion of the Overland route is 690 miles and was constructed in 77 months, for an average of 9 miles per month. Therefore, a progress payment was typically submitted every two months for a total of 35 payments.

Table 50 The Central Pacific Railroad's 1865 transcontinental railroad project "Progress of the Work" report.

The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date:

Earth excavated—No. of cubic yards	1,465,970
Rock excavated—No. of cubic yards	821,984
Stone masonry—No. of cubic yards	21,299
Culverts, No. 215—length in feet	12,626
No. of brick in the work	389,894
Timber and lumber in structures, feet B. M.	2,034,106
No. of ties laid	135,000
No. of ties contracted for	125,000
Tons of iron laid	6,000
Tons of iron purchased and not laid	2,000
Pounds of iron in bridges	162,700

The frequency of measurements as observed on the ReTRAC project where not formally defined. The frequency depended on factors, such as accessibility for measurement - at the time of work and afterwards - resources necessary to measure, variability in the work-in-place, duration of operation, and risk of the operation to affect project success, such as uncertainty in critical path time, scope of work, and resource intensity. An example of the reasoning behind what frequency of measurement to select is as follows: an activity of a relatively short duration or high variability or high risk or a combination of these, the field engineer could mitigate risk or improve accuracy and consistency by taking measurements at a shorter interval than otherwise would be used. In contrast, material or indirect quantities often had consistent values, were low risk to project success, and could be tracked on a longer interval such as monthly or quarterly.

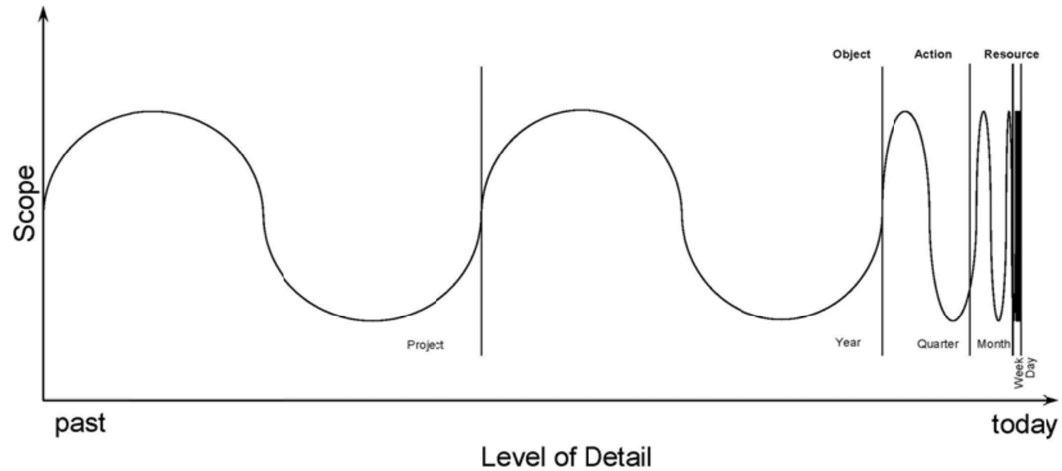


Figure 38 Progress quantities are collected at varying intervals of time; this time scale begins at the start of the longest collection period – project - and ends at the reporting of the shortest reporting period, that is today. The level of detail should increase with frequency due to the smaller increment of measurement.

The field engineers did not measure the quantities on a daily interval unless measurements were difficult to make afterwards. For example, underground utilities were often covered up as laid, making direct measurement difficult. There were half a dozen project-level quantities, for example, one-time payments such as permits. The field engineers measured production and overhead quantities at weekly, monthly, and quarterly intervals. The project engineer reserved the yearly intervals for reconciliation of existing quantities or adjustments to reflect found errors. Examples of short-interval and long-interval as used on the ReTRAC project are as follows.

For a short interval example, the roadway over-excavation operation proved to be problematic in tracking due to the activity context. Roadway over-excavation is the material that field crews must remove from the roadway sub-grade due to its substandard compaction qualities. On the ReTRAC project, the roadwork was during the winter months. Whenever it rained, the sub-grade became wet and did not pass the compaction density testing. It was then necessary to remove the subgrade to a depth of several feet, place geomesh, and fill with type II base aggregates. Measuring the amount of material removed from a roadway was problematic due to the short-duration and irregular time intervals with which the field crews encountered nonconforming subgrade. The quality control subcontractor inspectors tested the subgrade density as it was graded and compacted, and tested again prior to placing asphalt or concrete over the base material. An inspection team was on-site as their permanent workplace and inspected according to industry standards, the project specifications, and additionally as each individual inspector thought necessary based on their personal expertise, resulting in multiple inspections during the day. The intervals between failed sub-grades could be several a day during a particularly wet storm to several a month during dry weather or areas of suitable quality existing sub-grade. For the degree of accuracy the project engineer wanted for the roadway subgrade quantities it was necessary to physically stand within several meters of the workzone throughout the workday, wait for a test failure, and then measure the dimensions of each excavation.

As an example of a long interval tracking are the indirect non-material quantities such as overhead labor and equipment; the field engineers tracked these on a monthly basis. Presumably, the project engineer specified the monthly interval due to the consistency of the indirect measurement. Examples of these well-documented, low volatile, low risk monthly quantities are heavy equipment hour meters, project truck odometers, and cell phone count.

I observed that quantities were tracked between a constant basis and a yearly basis. The determination of what the measurement interval should be was dependent on the quantities impact on the ability to represent the project progression[201]. The field engineers used the quantities measurement interval as a control for the quantities accuracy. The field engineers reported the work-in-place weekly or daily, indirect-material and overhead monthly - entered daily or weekly - and, bonding quarterly and/or by the project, Table 51.

[201] Monitoring interval was varied as the independent variable that was controllable to produce the dependent variable degree of accuracy; this was intuitive, ad-hoc, and traditional practice, no validating studies, or experiments have been found to support this claim.

Table 51 Observed types of quantities and frequency measured on the ReTRAC project. The colors correspond with the perceived criticality of each reporting period. Note: I observed the root case of no unit of measure on 25 accounts, for example, *paint K-rail*. Several are errors and should have had a unit of measure since the field engineers reported a quantity.

Reported Units of Measurement n = 26

			daily	weekly	montly	quarterly	
duration	MH	Man-Hour			X		small tools/PPC
	HR	Hour			X		outside labor
	DA	Day			X		outside labor
	WK	Week			X		haul road maint./MOT
	MO	Month			X		undistributed cost
	QM	Quarter - MH/n				X	benefits
length	LF	Linear Foot	X				pipeline
	VF	Vertical Foot		X			dewatering/test wells
	TF	1,000 Feet		X			rail-line
area	SF	Square Foot	X				curb & gutter base
	MB	1,000 Board Foot			X		lumber
	SY	Square Yard	X				site grading
	AC	Acre		X			seeding

			daily	weekly	monthly	quarterly	
volume	CF	Cubic Foot		X			grout
	CY	Cubic Yard		X			concrete
	BC	Bank Yard	X				excavation
	GA	Gallon		X			cure/epoxy/seal
	MG	1,000 Gallon			X		water royalty
weight	LB	Pound			X		Reinforcing steel
	TN	Ton (US)	X				aggregates
count	EA	Each	X				tree grates
	LD	Load	X				dump Fee
	SK	Sack			X		sand
	LS	Lump Sum ($)			X		extra work
	M$	$1,000 (US)			X		benefits/bond
%	PC	Percent Complete				X	abstracted accounts

5.3.3.4 Conclusion to Quantification Plan

As a field engineer I measured my quantities but some of the field engineers gave this task to interns or trade supervisors then audited those quantities. The project administrators expected to find no perceivable errors in the quantities. The error checks were for internal consistency, unit cost comparisons with known costs, and the application of historical ratios to look for large pattern errors to investigate in detail. The end result was the need to maintain a farily high degree of correctness.

The basic rule for who measures the quantities if it is not the field engineer is the perception of who is best positioned to capture the measurements. For example the concrete mason ordered the concrete and so had to calculate the days needed concete and so also reported this as their quantity to the field engineer.

Deciding on the features of level of detail and frequency of measurement was already established by the time I joined the ReTRAC project. The quantities were reported at a high degree of detail and at a weekly interval. The completeness of the quantities was fixed at perfectly complete. At the beginning of the project the project engineer and project manager defined the process of quantification with the frequency, completeness, and level of detail in the quantities. The discretion left to the field engineer to adjust their effort needed for quantities was who would measure the quantities – outside the bias and other games I found reported given in the literature review and surveys. The factors in deciding who made the measurement are based on the difficulty in making the measurement, such as window of opportunity. For example, underground utilities are covered each day – leaving a small window of opportunity to measure the daily quantities that are summed for the cumulative weekly quantity. The risk of error in the quantity, for example haul truck tickets leave little room for error. The risk of the quantity to affect the project planning sensitivity. How routine the quantity was made – if a weekly measure done for several years, the routine is well established. Last, the complexity of the measurement. The complexity rages from counting - if field hands are given quantities against the advice of many, then counting is suitable for field hands as also found by Kiziltas (2006) - to complex post processing calculation which are done by the field engineers.

These are the factors that I observed on the ReTRAC project relating to the design of a quantification plan. The discretion of the field engineer to adjust the source of quantities is a crossover between the quantification plan and methods of quantities. The effort exerted by the field engineer is also changed by the method of quantification used. The features of level of detail, frequency, completeness', source, and method, certainly are all contributing factors to effort exerted. This differs from the finding solely from the literature review where method and source are not contributing factors to effort exerted on quantities.

In the next section, I will present the methods I observed used for quantification as well as the communication process of quantities from field to planner and the sources of quantities.

5.3.4 Methods of Quantifying

When I first documented this study, I wrote the ethnographic observations first. From the observations, I formed a draft grounded theory. I wrote the literature review next and compiled the publications into a synthesized structure of how those researchers represented quantities. There are contradictions between my grounded theory and the synthesized publications. For example, the Plan Set Takeoff is considered a method of quantities in my theory but is a source of quantities in the synthesized publications.

On the ReTRAC project the project engineer wanted the quantities scaled from the the plans for activities completed each week. Then for the final as-built quantities he wanted the neat line takeoff reported. This was confusing for me because at the same time the project manager expected me to walk the jobsite and measure my quantities from the field as actual in-place quantities. Intuitively the project manager seemed correct based on the context of the ReTRAC project but the field engineer was adamant that he was correct – I explore this issue further.

In this section, I first present the historical context of measuring quantities to show that field engineers today face the same criteria that field engineers faced a hundred years ago building the original rail alignment. I then present the methods of measuring quantities I observed, a bundled method approach, the communication of quantities back to the planner, and the sources of quantities.

5.3.4.1 Historical Context

The City of Reno hired a contractor to rebuild their rail corridor through the city's downtown. Similarly, the original railroad owner did not construct the entire Overland railroad themselves; they also hired contractors (Crocker). The Central Pacific Railroad put for bid sub-projects such as bridges, cuts, fills, and tunnels for completion prior to the Central Pacific track crews arrival (CPRRb)[202]. The U.S. Congressional act of July 1, 1862 set the project compensation per mile of rail: For every 20-miles of rail placed[203] the U.S. government granted the railroad company

[202] The geography and geology of the Sierra Nevada pass along the rail line alignment is characterized by steep granite cliffs, deep river canyons, and a steep dropping grade on the Eastern face. This route was a wagon and mule train route prior to the railroad and has been a natural transportation corridor prior to the railroad and since. The mountain pass where the recognized feats of construction by the Central Pacific Railroad is 40 miles away and 2,500 feet above the ReTRAC project portion of the rail line. This pass acquired the name *Donner Pass* from the name of an ill-fated 1846 wagon train party (Donner Pass). Today the Interstate 80 highway corridor follows the same valleys and passes over the same mountain saddle as the wagon-trains and railroad - the railroad technically passes under.

[203] The measure for payment is miles of rail, the alignment grading, earthen structures, cuts, masonry, steel, and timber structure, and the railbed are not payable items, it is assumed these must be inplace to allow the rails placement. Later this definition for measure of payment became an issue since the Union Pacific railroad engineers loosely interpreted the meaning of rails placed and simply placed the rails on a few logs laid directly onto the prairie, when necessary constructing wooden structures just sufficient to temporarily support the weight of a steam locomotive.

12,800 acres[204] and loaned them $48,000[205] ($1862) as 30 year 6% government bonds. To provide for the fuel and energy transmission used by the steam engines the railroad company was deeded the natural resource mineral rights within the 400-foot wide rail alignment[206] (American Experience, Central Pacific Railroad, 1883 Annual Report). The natural resources used for the steam engines are the timber, coal, and water resources. The deed was for all natural resources; therefore, the Central Pacific Railroad acquired gold deposits in the California mother lode. This provided an incentive for the railroad to shift their alignment towards profit opportunities rather than follow the strictly engineering alignment.

The Overland projects annual 20-mile billing submittal requires submitting an updated map of the rail line corridor. I researched for how the Central Pacific paid the project subcontractors, the process of scheduling activities, and how the railroad engineers monitored the activity progress; my research found few documents outside of the mile-reporting unit of measure, Table 47 page 220. The progress report to congress likely represents at a minimum five methods of measuring quantities, Table 52. The exactness of the quantities provides an indication of the method used to measure the quantity. The contractors were likely using survey instruments to obtain the quantity of volumes. Field crews likely measured culvert length with a survey chain, the millers also likely used a survey chain to measure by the board feet of lumber, and the quantity reported is likely the invoiced delivery to site. The laborers likely counted the quantity of bricks and like lumber, the quantity reported is likely the invoiced delivery to site. The quantities given to the rounded hundreds or thousands the field engineers likely derived from measurements or invoices using percent complete, and indirect methods such as expert opinion.

Table 52 The Central Pacific Railroad's 1865 transcontinental railroad project "Progress of the Work" report.

The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date:

Earth excavated—No. of cubic yards	1,465,970	Units complete; formal survey
Rock excavated—No. of cubic yards	821,984	
Stone masonry—No. of cubic yards	21,299	
Culverts, No. 215—length in feet	12,626	Units complete; survey chains
No. of brick in the work	389,894	Units complete; physical count
Timber and lumber in structures, feet B. M.	2,034,106	Units complete; survey chains
No. of ties laid	135,000	Percent complete, and indirect methods, such as opinion
No. of ties contracted for	125,000	
Tons of iron laid	6,000	
Tons of iron purchased and not laid	2,000	
Pounds of iron in bridges	162,700	

[204] $50M in $2009.
[205] $1M in $2009.
[206] Equivalent to 48 acres per mile.

One source found for the Overland Route project is a conference proceedings abstract[207] that gives a per foot production rate for driving tunnels; 0.85 feet per day with black powder and 1.18 feet per day with the more powerful but unstable nitro-glycerin[208] (the Central Pacific Railroad Museum website). To me the two significant figures accuracy indicates the use of surveyor chains. Quantities of material are provided as kegs of black powder and feet of fuse (CPRRa). The accuracy in measurement and description of context indicates the degree of accuracy and the methods used by the contactors to measure quantities. How contractors heuristically measured the mile – they certainly had an inaccurate and quick method – I have not found, speculatively the field crews obtained a quantity by counting the number of rails laid and then later validated with a formal chain survey.

In 1911, fifty years after the Overland Route project, Fredrick Taylor published the ‘push’ project planning and monitoring methods now used in the manufacturing and construction industries (wiki Fredrick Winslow Taylor). The Central Pacific railroad may have operated under a ‘pull’ demand process. In the pull process, the field engineer sends resources as available and production proceeds on resource availability or as applied resources allow: If production is slower than the pace of supply then stockpiles form. If production is higher, then applied resources are idled: a trial and error process. The project engineer sourced the Overland Route labor resources from China. He shipped the equipment and steel materials from the East Coast vendors, down around Cape Horn at the southern tip of South America to land at San Francisco docks. The project engineer sourced wood materials, black powder, and nitro glycerin locally from California manufacturers. It is unclear if the availability of these resources was the driving factor for production.

5.3.4.2 Observed Methods of Quantifying

This section presents my ethnographic observations of the methods used by the ReTRAC field engineers to measure quantities. The field engineers appeared to base the specific method they used on the available resources, and the required accuracy, consistency, detail, reusability, and completeness. In practice deciding on the method to use was ad-hoc and driven by opportunity and paths of least resistance, Figure 39. The four properties of the quantity appear correlated to the applied resources needed. Measurements are obtainable a multitude of ways as actual direct measurement and calculated indirect measurement

[207] Read before the American Society of Engineers, Jan. 5, 1870, and printed in Van Nostrand's Eclectic Engineering Magazine, 1870.
[208] For safety reasons the project decided to use black powder and stopped using nitro-glycerin.

methods, Table 53, Figure 40; specific examples of a method, source, and the operation on the ReTRAC are as follows:

- Percent complete from a visual comparison of ratio completed compared to cognitive visualization of 2D plans as a completed component during sitewalk used to determine the backfill quantity to date[209] as a product of the percentage of completion and the backfill quantity takeoff.
- Equivalent units from the time-cards; the cards provide truck number, material type, dump location and the cycle-count for the number of loads for haul operations[210] The quantity is calculated as the product of the cycle count and an assumed load volume in loose cubic yards, then converted to compacted cubic yards through a shrink factor.
- Units completed based on measured weight sourced from scale tickets provide tonnage by load for haul operations originating at the quarry

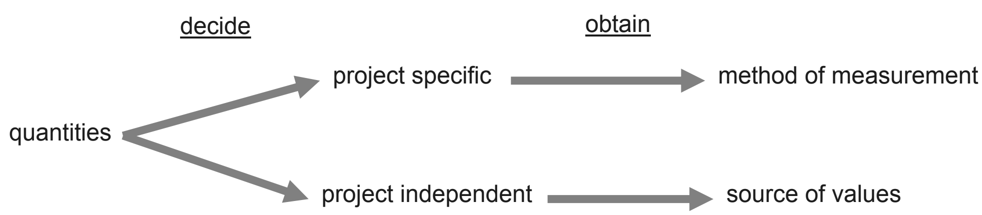


Figure 39 The logic I intuitively utilized on the ReTRAC project to define a method of obtaining quantities and context features. The method depends on the type of quantities. For example, the options are measurement from project independent sources, e.g., cross section height for roadway base or dependent sources, e.g., volume of concrete.

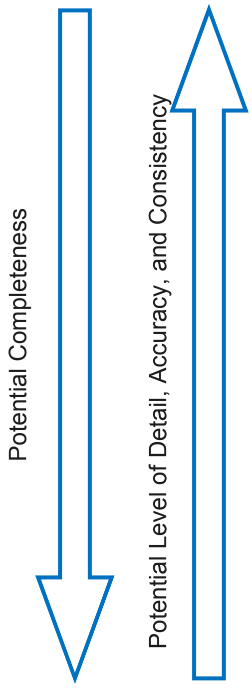
[209] Combined with quantity takeoff with AGTEK digitizer of 2D paper plans (PDF) then exported to spreadsheet for calculations or Takeoff from paper plans (PDF) using triangular scale ruler and key to spreadsheet.
[210] Post-processed with known haul truck volume, or by ton/density = volume.

Table 53 Summary table of the methods presented in the literature sources and expanded to include methods observed on the ReTRAC project and now with the distinction between direct and indirect measurements.

Measurement Methods

Method (listed by level of detail)	Stallard interview	PMBOK guideline	Saidi PhD thesis	Kiziltas case study	Survey of methods	PM 10^{th} ed. Systems	APM guideline	PM 6^{th} ed. managerial	CPM Clough	Ethnographic ReTRAC
Page	88	401	133	142	143	402	404	150	388	238
Direct Measurement										
start / finish date		X			X	0/100				
milestones		X	X		X	X	X			
percent complete		X			X	X	X	subjective numeric rating	X	X
units complete	X		X	X	X			frequency count	X	X
Indirect Measurement										
a priori										BANNED
trust 2^{nd} party										X
fixed-formula		X		calc						
opinion | guess								verbal measure		X
equivalent units	X		X			X	X	indicators		X
level of effort						X	X		X	BANNED
cost formula			X			X				BANNED
apportioned effort						X	X			BANNED
neat-line takeoff										X

Methods of Quantities Measurements



Direct Measurement
1. Field measurement (with or without post processing)
2. Survey 10% (for large volume or area)
3. Count 65%
4. Instrument measurement: Tape measure 56% and Takeoff wheel 42% (for small area linear feet and square feet)
5. Load count 52% (cycle count)
6. Scale ticket 44%
7. Measure from plan-set 69%
8. Percentage of completion estimate 56%

Indirect Calculated Measurement 72% (15% of quantities are estimated)
1. Derive from direct measure with the addition of assumed values for material type and density, and work dimensions, e.g., grader has 12’ blade and 4” cut.
2. Percentage of time
3. Percentage of cost
4. Cost divided by unit cost
5. Supplier invoice 42% (accepted on trust)
6. Guesstimate || opinion

Figure 40 Monitoring completeness decreases absent a change in resources with increased accuracy and repeatability. The methods to collect field production in order of intuitive accuracy and reliability based on experience. The percentages are the survey responses that used each method as a ratio of the total responses (Peterson & Fischer, 2009).

For project specific quantities, the field engineers determined a method of measurement, taking into account the reusability, accuracy, consistency, detail, and completeness’. Selecting an indirect method reduced the applied resources for quantity measurement. The goal of the indirect method is to use the available project independent quantities to reduce the field engineering applied resources without altering the quantities reusability, accuracy, consistency, detail, and completeness’. A direct method of measurement coupled with an indirect source forms an indirect method; the units complete method used the indirect source of the scope plansheets as a quantity takeoff or linear measurement. The indirect measurements were dependent on specification for constants and functions for variables. I observed the properties for constants and variables placed in an electronic database for lookup. Examples of properties placed in the database (project dependent and independent depending on availability) are material type, material density, and assumed dimensions. To integrate the direct measurement and indirect measurement methods, of the five field engineers on the project, if they expected to report an item for several months two would construct a specific database and calculating page in an electronic spreadsheet; the other three field engineers used electronic spreadsheets as a celled word processor.

The organization structure I gave to quantities methods, sources, and post processing while writing a technical report in the year after completing the ReTRAC project represented the calculation of quantities as two categories. The distinction was those quantities measured through calculation and the manipulation of measured quantities to derive additional quantities, termed post processing. As I synthesized the literature review publications, a distinction formed that there were direct and indirect method subcategorizations within the ReTRAC methods of quantifying. The indirect methods include calculations, therefore blurring the distinction between post processing and indirect methods. Also, I considered some sources of quantities as distinct methods rather than a source and method used together. For example, I considered scaling quantities from the planset a method of quantities, rather than the units complete method and planset source. I do not know if the original categories perceived when my mind was fresh from 'the field' or the categories formed by reconciling with the publications are the closest representation to reality; there was a distinct mix of methods, sources, and calculation processes. Those calculations that fit within the published indirect quantification methods are now included in the method subsections, the rest are in the post processing subsections.

5.3.4.2.1 Units Complete Method

For the components the drafters represented on the plans the project engineer expected the field engineers to scale - in addition to other measuring methods - the units completed from the plans for work-in-place. After scaling, the field engineer responsible for that discipline colored in the plans for the zone completed. Coloring prevented scaling the same zone twice and provides a record of work completed by time; each week represented by a new color. There are operations - particularly concrete and earthwork – which the project engineer wanted the reported quantities measured only from the plan-set so to report a *neat line* takeoff quantity of work-in-place, p88. The units complete can be measured using different measuring tools. The neat line takeoff is an example of units complete measured using a takeoff ruler; the same takeoff could have been done using a takeoff wheel, a digitizer, and on-screen takeoff. The common characteristic to units completed is the direct measurement of the work completed without the use of modifying assumptions. The field engineer measures the units completed from differing sources, each with a coupled measuring tool. The field engineer used a scaled ruler to measure the neat line takeoff from the planset. Like the measuring tool, the source of the takeoff has varying formats such as CAD electronic, points spreadsheet, and paper planset. When I used the units complete method to measure quantities on the ReTRAC project 95% of my measurements were from a field source. The field engineer cannot make measurements in the field with a takeoff ruler; measurement tools such as truck scale, tape measure, measuring wheel, and physical counting are used.

5.3.4.2.2 Percent Complete Method

A method I observed to provide measurements with reduced resources is percent complete; the project engineer did not formalized how the field engineers derived percentage, and the field engineers did not have an established practice. Another application of the percent complete method is for dissimilar items and therefore not easily quantified as a distinct unit of measure. If the percent complete is a valid practice, the ReTRAC field engineers debated the use of the method. The field engineers noted inherent issues with the percent complete method and that those using this method must consider the level of detail, accuracy, precision, and completeness needed from the resulting measurements, Figure 41. An extension of the percent complete method is the visual percent complete. Visual percent complete relies on an image of the current project state and a graphical representation of the project. The field engineer cognitively visualizes the 2D plans as a 3D image of the final activity area then observing the actual state of the components intuitively measures the degree of completion as a percentage of the anticipated final state. In the project manager's opinion, not all field engineers possess a 3D cognitive ability and he thought this was a test of a field engineer's value[211]. The result of the visual percent complete method is quantities obtained with minimal applied resources. Four properties limit the visual percent complete method:

- the human ability to discern between degrees of completion, Figure 41
- requires a clear view of the component, Figure 42
- the ability to cognitively visualize the 2D plans as a 3D reality
- optical illusions (p355), Figure 43

Final Quantity Takeoff = 25 EA

Field Measure
Method: percent complete
Measured = 60%

Field Measure
Method: count
Measured = 16 EA

Comparison (60% * 25) = 15 EA

Error = 6.25% (acceptable?)

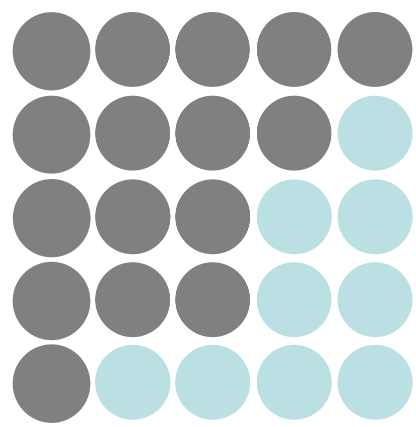


Figure 41 The degree the human eye is capable of discerning is a factor in the visual percent complete method. Note that the percentage of completion correlates with the component breakdown structure level.

[211] Earthwork has a similar cognitive test for the ability to 'see' the grade; as a Laborer I could see the dips and bumps in the grade and was given the task of cutting the bumps with a shovel and filling the dips with an asphalt rake; thye did not want to bring the grader back, the operator could not see the dips and bumps anyways.

Figure 42 Example operation the earthwork field engineer measured as a visual percent complete. The image on the left is the current state and the image on the right is the finished state, what is the current percent complete, 5%?

Figure 43 A second example of an operation measured as a visual percent complete. The image on the left is the current state and the image on the right is the finished state. What is the current percent complete, 25%? Is the table illusion similar to this view, Figure 66 page 356? What if the field engineer measures completion from different vantages for each location and iteration?

5.3.4.2.3 Indirect Methods

In the progress report to congress, the transcontinental railroad project was four years from completion and had been underway for two years. As a calculated value, this is 30% complete by time and at that time 12% of the cost[212] has been expended. This percentage of completion time to cost[213] variance is consistent with the project's slow pace in the early phase activities of tunneling and blasting a ledge through the solid granite Sierra Nevada. The workface is narrow, therefore restricting the workspace and so the labor cost should be low, the material is

[212] Cost is from progress report and total cost is from the CPRR Discussion Group.
[213] A percentage of completion analysis by material quantities was not attempted.

expendable blasting material, and until the ledge is finished, the labor crews cannot place the ties, rails, and ballast, resulting in a low unit cost and low production rate.

5.3.4.2.3.1 Calculations

The calculations the ReTRAC field engineers used for quantities are simple, Table 54. The field engineers considered dividing the measured weight in tons by density, a complicated calculation; the earthwork field engineer used this specific equation to find loose cubic yards (LCY) and then found the product with a coefficient to convert to compacted cubic yards (CCY), Figure 44. The coefficient is a factor of the compressibility of a soil type and the specified compaction density of the soil as a ratio of the loose density of the soil. I calculated the loose density from averaged haul truck weights: the project engineer had requested the superintendent to have a Teamster driver empirically measure loaded and unloaded at the quarry scale. Measurements that require nonstandard conversion between levels of detail or units of measure required a field engineer with experience; once the coefficient was calculated, interns or a program could apply it.

Table 54 Converting between the measured unit of measure to the reported unit. For example, the field engineer measured volumes in the loose cubic yard state by a count of haul truck cycles, trailer capacity, and the assumption that the loader operator had filled it. From this, the field engineer calculated the bank cubic yard with a shrink factor.

Reported Unit			**Unit of Measure**		**Conversion**
Unit	Description	Example	Unit	Description	Recipe Formula
BCY	bank CY	plan takeoff	BCY	bank cy	na
BCY	bank CY	trailer/bucket volume	LCY	loose cy	shrink factor from LCY
BCY	bank CY	measured in-place	CCY	compacted cy	shrink factor from LCY
PC	percent complete	indirect item	$	cost to date	to-date / forecast cost
$	dollars	invoice measure	CY	known CY delivered	CY * unit cost
LF	linear feet	K-Rail	EA	known quantity & length	EA * length of K-Rail
SY	square yard	geofabric	LF	dimension of placed fabric	(length * width) / 9
BF	board feet	misc. dim lumber	LF	length & dimension	width (inch) * height (inch) * length (feet) * (1/12)
LD	Load	demolition	Ton	known tons	ton / trailer weight capacity

Measurement Conversion

Terms:
Bank Cubic Yard (BCY) i.e., in-situ / in the ground
Loose Cubic Yard (LCY) i.e., haul or stockpile
Embank Cubic Yard (CCY / ECY) i.e., compacted fill
Constants:
Material: Screened Decomposed Granite (SDG) Fill
Quarry Density Test: 1.40 ton per LCY
Engineered Fill Density Specification: 1.75 ton per ECY
Example 1:
Measured Units: Ton
Measured Quantity: 337.8
Reported Units: ECY
Reported Quantity: 337.8/1.75 = 193 ECY
Example 2:
Measured Units: LCY
Measured Quantity: 18 (i.e., one end-dump trailer)
Reported Units: ECY
Reported Quantity: (18 * 1.4)/1.75 = 14.4 ECY
Assumptions:
Compacted to specification
Haul truck loaded volume is consistent

Figure 44 The conversion from a measured unit to a reported unit introduces the possibility that assumptions – while increasing repeatability - reduce the accuracy. Examples of assumptions: (1) each haul is exactly 18 LCY, (2) each LCY is the same density, (3) the Teamster places the haul within the fill - versus lost in the stockpile yard - and (4) the fill is not over or under compacted.

5.3.4.2.3.2 Time and Cost Ratios

Periodically I observed that an actual measurement was not obtainable from the default sources, such as the plan set - often due to a lapse in updating the coloring of the plans - a visual percentage of completion - possibly due to lack of vantage point - and the physical measuring of units complete was not practical. At these times a projected quantity can be obtained by two methods; percentage of time and percentage of cost. I observed the field engineers use these methods on the ReTRAC project though the project engineer and project manager did not allow them.

The first method, by time, uses the 5-week lookahead process schedule to calculate a theoretical quantity based on percentage of completion at a given date as a ratio of the duration of work to date and the total expected duration, Equation 4. The field engineer multiplies the expected final quantity - from the plan takeoff - by the percentage of time for a reported quantity to date. Another possible variation is to multiply days of activity duration by planned or empirical production to derive the quantity for the reporting period. For example, after five days of a ten-day activity, infer the activity is 50% complete.

Equation 4 Calculating the quantity to date based on time and assumptions

Quantity by time and takeoff		Inputs
Quantity to date = $Q (d_n / d_0)$	Q	= takeoff quantity
	d_n	= duration at time n
	d_0	= estimated total duration

Quantity by time and production		Inputs
Quantity to date = $d_n p$	d_n	= duration at time n
	p	= production (units per time) estimated or empirical

In the same way as percentage of time, the field engineer can use percentage of cost to estimate the percentage of completion, Equation 5. The risks are similar as using percentage of time. The field engineer derives a quantity from percentage of cost by dividing cost to date by budgeted cost at completion to derive percentage of completion. To derive this periods quantities the process is then the same as used with the percentage of time method.

Equation 5 Calculating quantities based on cost and assumptions

Quantity by cost and takeoff		Inputs
Quantity to date = $Q (c_n / c_0)$	Q	= takeoff quantity
	c_0	= estimated total cost
	c_n	= cost at time n

Quantity by unit cost and period cost		Inputs
Quantity for time period n = $c_n / (c_0 / Q)$	Q	= takeoff quantity
	c_0	= estimated total cost
	c_n	= cost for time period n

5.3.4.2.3.3 Endogenous Assembly

Another method I observed used is an assembly measurement through recipes or ad-hoc formulas or level of detail change[214]. The formal term is the *apportioned effort* method (PM 10th 2009; APM 2002), though the field engineers would not recognize this formal term, they used it intuitively, Figure 45. The method is endogenous because the field engineer calculates a measurement from other measurements. The field engineers used this method to reduce the need to make resource demanding field measurements. As an example, the field engineers derived material measurements from exogenous or endogenous work activities measurements; they did not measure the actual material consumption. The field engineers can query the enterprise resource planning (ERP) [Management Information System (MIS)] system for data such as average (or period) unit cost, production rate, quantities to-date, and cost to-date. These metrics were useful to fill-in values in endogenous calculations.

[214] An example method for calculation of endogenous measurements from exogenous measurements, Figure 45, Table 56, page 163.

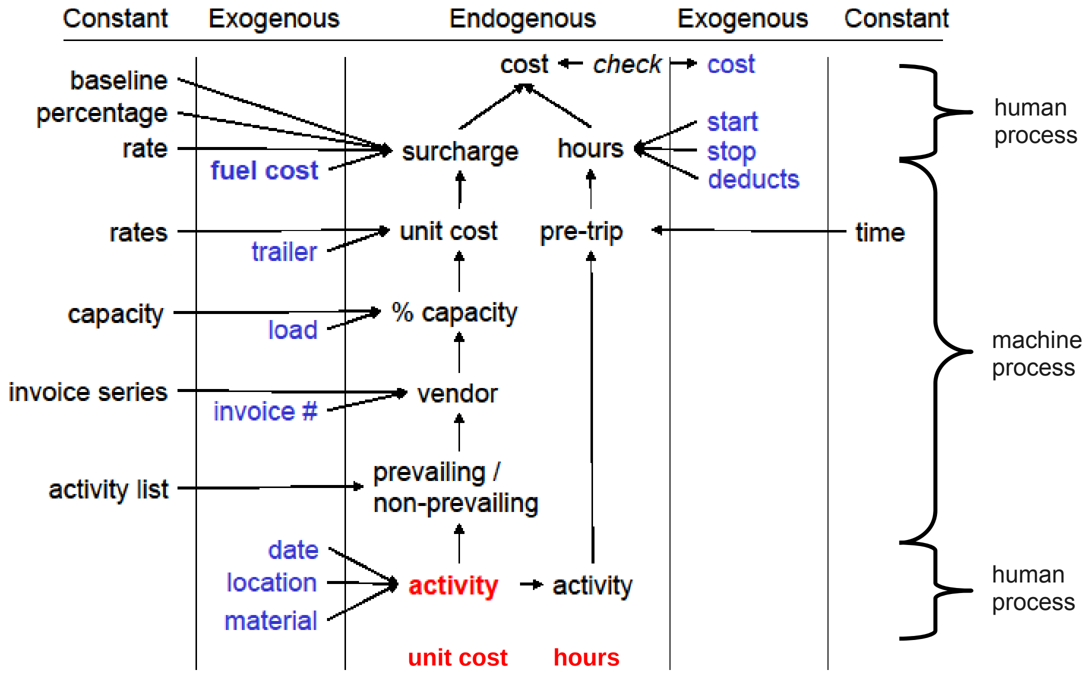


Figure 45 A quantities process; the fields are categorized as constant (database), exogenous (measurement), or endogenous (calculation). The field engineers collect the exogenous quantities each reporting period; initially the field engineer treated all the quantities as exogenous. To reduce the applied resources, two field engineers replaced potentially endogenous quantities with equations and potentially constant quantities with a database.

5.3.4.2.3.4 Unit Cost Method

Another method of projecting a quantity is with past unit cost - either cumulative or for a recent week. The field engineer divides the week's cost - or period to calculate for - by the previous unit cost, thereby generating an estimate of the quantity for the period, Equation 5. A quantity estimated using this method has an unknown degree of accuracy and repeatability; intuitively they are lower. The project manager and project engineer did not allow this method on the ReTRAC project; during audit meetings, as a quality check the project engineer looked for evidence of quantities found by dividing cost by unit cost. The evidence is consistency in the unit cost for several weeks better than from experience what they intuitively expect or unit cost for the week identical to the average unit cost for the operation[215]. The past unit cost method was used by several - possibly all - field engineers on the ReTRAC project. In one case, a field engineer calculated half of their reported quantities by dividing cost by unit cost.

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[215] The smarter field engineers varied the quantifies from the calculated value to achieve a unit cost for the week that varied from the average for the operation.

For a test of the degree of quantities derived this way, each week for a couple months I placed a preliminary cost report on the chair of one field engineer the morning the previous weeks quantities were reported. I did not give the other field engineers a preliminary cost report. The first week I did not give the field engineer a preliminary report they did not provide quantities for the previous week. They had difficulty reporting quantities without a preliminary cost report - evidenced by inconsistencies found during audit reviews - and then after several weeks gained a reporting performance equivalent to the other field engineers. The field engineer later asked for a transfer to another large project[216]. At the next quarterly reporting period during audit review the project manager found a variance between the reported quantities of asphalt and the actual measured by the plant scale. According to the project manager, the variance was unusually large. The variance required a reconciliation of the reported quantities and prompted an inquiry from the project manager for the source and if it was due to error or mistake; I did not determine a source or a reason. The reported quantities may not have been critical, or had a cost significance, and the field engineer may have been utilizing spot-checks based on judgment. Also, the variance could have been due to the degree of accuracy in the takeoff values that resulted in noticeable variances between planned dimensions and actual work-in-place dimensions; I cannot establish causation with the preliminary cost report.

Intuitively a quarter of the quantities provided by the field engineers were derived from unit cost and period cost[217]. Generating a quantity measurement from the previous unit cost has the danger of missing a change in unit cost for that week. I observed activities where the unit cost did not change from week to week. The field engineers assumed that if there were no means or methods changes then they were safe to use the unit cost method. They augmented the projections with sample spot checks to calibrate the specific equation used to project quantities and reconcile past projects with actual production.

5.3.4.2.3.5 Guesstimating

Similar to an endogenous calculation the estimation of quantities endogenously, with no exogenous inputs, the reference texts formally call *opinion*. The opinion method according to the ReTRAC project engineer is the least desirable method of generating a quantity; it is an educated guess also known as a *WAG* or *Wild Ass Guess* ("Wild Ass Guess" Method, Urban dictionary). This method - also known as a guesstimate - had a place in quantities tracking, pages 394. Guesstimating is an estimating method, pages 394, with recognized applications in physics, education, and economics (wiki Guesstimate). At times when the period report was

[216] A field engineer strategy is transfer to a new project during startup to maximize the duration in that location, therefore allowing purchasing a home and maintaining a stable school environment for their kids.

[217] Through informal discussions with a half dozen field engineers from other projects and/or companies, they also recognized this method and its use on projects they had been assigned.

incomplete and there was no quantity available through other methods; then if the project engineer requires 100% completeness in reporting then a placeholder is necessary. I observed on the ReTRAC project that of the five field engineers one had the ability to intuitively guess a number within 10% to 20% of the actual number while the others were within 50% to one order of magnitude.

The guesstimate goes like this: The field engineer infers a measurement from circumstantial and intangible sources where the measured quantity may be too costly or even impossible to obtain. For example, the field engineer may know that an activity has been producing *x* quantities per week. This week due to an influence outside the field engineer's control, the field engineer could not measure this week's progress. The expected final duration and cost is unavailable to derive a percentage of completion based on time or cost. Knowing, the weekly production *x*, and that the workspace was congested this week, the temperature was higher than previous, a key piece of equipment broke down several times, and on two mornings a portion of the crew was diverted to assist with the predecessor activity, then the engineer guesstimates this week's production as *y*. I observed that in addition to field progress measurements, takeoff quantities were guesstimated.

These 'guesses' - to be accepted by the managers - were by a field engineer or estimator (if during the pre-project estimate) with several years of experience in construction and that were familiar with the activity being estimated. The authors of the *Industrial Engineering Text* (p394) assert that for a gusstimate to be accepted the person doing the guessing must be trusted and known as a *truth speaker.* The 'truth speaker' status may explain the observation of perceived experience as actually an observation of trust. The tacit practice was to round guesstimates to one or two significant digits to let the future user of the quantity know the field engineer or estimator guessed the value; the significant digits were applied tacitly or ad-hoc.

5.3.4.2.4 Cross Analysis of Methods

Under cross analysis I present the applied resources effort, the limitation of indirect methods, and the method of guessing.

5.3.4.2.4.1 Applied Resources: Measured Versus Calculated Tradeoff

The field engineers tried to use the indirect measurements infrequently[218]. There is a tradeoff in quantity collection and quantity processing between quantities quality and applied resources, Figure 46. There are quantities from the project that had a greater degree of accuracy. Those

[218] Such as percentage of time, percentage of cost, dividing cost by unit/cost, and opinion or guesstimating (pages: 69, 162, and 179).

measurements made by certified scales, such as the truck scale at the quarry and materials purchased from subcontractors, are subject to the Uniform Commercial Code or similar business laws[219] [220]. The quality of the quantities is determined through the degree of resources applied measuring items in the field and post-processing measurements in the office. At the extremes, or edge conditions, everything is measured in the field and nothing is derived or nothing is measured in the field and everything is derived. A balance between these two extremes intuitively provides the optimum desired characteristic, for example: utilization of resources or quality of reported quantities[221].

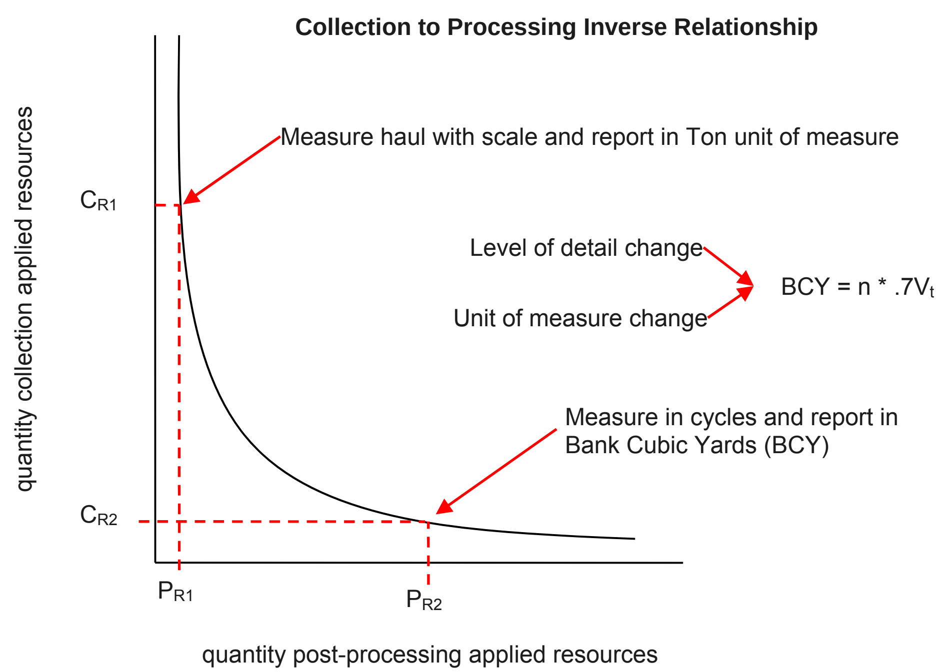

Figure 46 The inverse relation between the resources exerted in quantities collection versus the resources exerted in quantities post-processing.

5.3.4.2.4.2 Limitation of indirect methods

On the ReTRAC project the project engineer did not formalize what a specific quality of quantities an account required; what are critical, what frequency is safe, and how often and how large of sample checks should be conducted, and were left to the field engineer to design as audit controls based on their judgment. Field engineers should use the percentage of time

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219 Such as weights and measure department regulations.

220 Though this is no guarantee there are numerous examples within the construction industry of scale tampering and invoicing errors.

221 An investigation and analysis of this balance is not done here, but is suggested in *Section: Integrated Coding Process* page 232.

and cost methods[222] with caution and infrequently (every fourth reporting period) until researchers pragmatically validate or model these to find the theoretical features. Field engineers should sample at least once a month with actual measurements to test if the reported quantities and quantity takeoff are correct. Field engineers should not use the method of projecting the expected quantity during critical points (assumed as critical path activities) in the project, during times where correct quantities are essential, Table 55, or during periods of non-linear workflow.

Table 55 Some critical times when field engineers should not use indirect methods as a replacement for actual field measurements.

Potentially critical time
Completion of milestones
Short duration activity; less than one month
Regulated material and other regulated materials
Multiple endogenous feeder variables
During startup of project phase
During changes in project methods (startup condition)
Prior to applied resource quantity demand calculation
Prior to forecasting
Prior to long-term (6-month or greater) schedule lookahead planning
Prior to analysis of alternative construction methods
During quantities collection for developing assembly variables' relationship and significance or for deriving constants for repeated use

5.3.4.2.4.3 Guessing

Depending on the managements philosophy they may prefer that if the field engineer does not know a value without the use of opinion then leave the value blank. An engineer's intuitive feel for a value is relevant and based on my observations of the ReTRAC project appeared an acceptable method. The use of intuition reduces the effort and allows a reduced delay in reporting. An example of a scenario where a guess is valuable is forecasting a quantity that is dependent on several variables or constants; rather than go through a lot of effort, the field engineer can guess the values of the component variables or constants.

5.3.4.3 Conserving Resources by Alternating Methods

Through various combinations of the above-mentioned methods, field engineers compile a list of quantities for the indirect and direct operations that they are responsible. Due to alternating the method used, each week there is a variation in the level of reliability of a given quantity. For example, each week of the month the reported quantity may cycle as opinion, projected from unit cost, time progress, and actual measurement, Table 56. Based on the technology

[222] Both these methods are described in *Project Management: A systems Approach to Planning, Scheduling and Controlling* 10th edition, reviewed on page 55, there were no risk metrics or risk mitigating suggestions accompanying these two methods in the text.

available, with the limited resources and time available to them, field engineers use the methods available to give a bundle of quantities that fulfills the risk they are willing to take that the quantities are not to the degree of accuracy, repeatability, latency, resource intensity, and detail specified by the project engineer, Figure 47.

Table 56 Examples of variables influencing the accuracy, repeatability, completeness, and resource intensity of methods for measuring quantities. The values of these five metrics are unknown[223].

Example Operation	Method[224]	Example source(s)	Example measuring tool	Latency (timely)	Completion	Accuracy[225]	Collectable	Consistency	Source (quality)	Level of Detail[226]	Frequency	Reusability	Rotation of Methods	Post Processing Equation	Cost check	Work types	Purpose	Applied Resources
Place type II base	2nd party	delivery ticket	NA	30/hr						M	Day		A	Sum values				1
	2nd party	invoice	NA							L	Month		B	check				1
F/P/S Conc. Curb & Gutter	Percent complete	sitewalk & plans	visual	300ft/hr						M	Month		A	PC * QTO				1
	Unit complete	sitewalk	measuring wheel							H	Month		B					1
	Percent complete	schedule & timecards	NA							L	Month		C	Duration/Total Duration				0
	opinion	field engineer	NA							L	Month		D					0
G/B/F	Percent complete	sitewalk & plans	visual	300ft						M	2-Week			PC * QTO				1
	Unit Complete	sitewalk	measuring wheel							H	2-Week							
Roadway	Unit complete	sitewalk	measuring wheel							H	Month							
	Percent complete	schedule & timecards								M	Month			Duration/Total Duration				
	Level of effort	schedule & timecards								L	Month							
	Opinion	field engineer								L	Month							
Excavate																		
Backfill																		
	Unit complete	drawings	scale & color															
	2nd party	delivery tickets	count | weight															
	Unit complete	sitewalk	physical count															
	[a priori]	estimate	na															
	[a priori]	schedule	na															
	0/100		finished t/f															
	Milestone		finished t/f															
	Percent complete	budget & cost report	calculation															
	Equivalent unit	endogenous formula	exogenous measure															
	Cost formula	cost report	calculation															
	Level of effort	schedule & timecards	na															
	Apportioned effort	endogenous formula	exogenous measure															
	Opinion	supervisor	na															

[223] These observations are recollected from memory several years after the fact.
[224] What work types are associated with each method.
[225] What accuracy is suitable for checking cost?
[226] The level of detail appears a function of method and frequency.

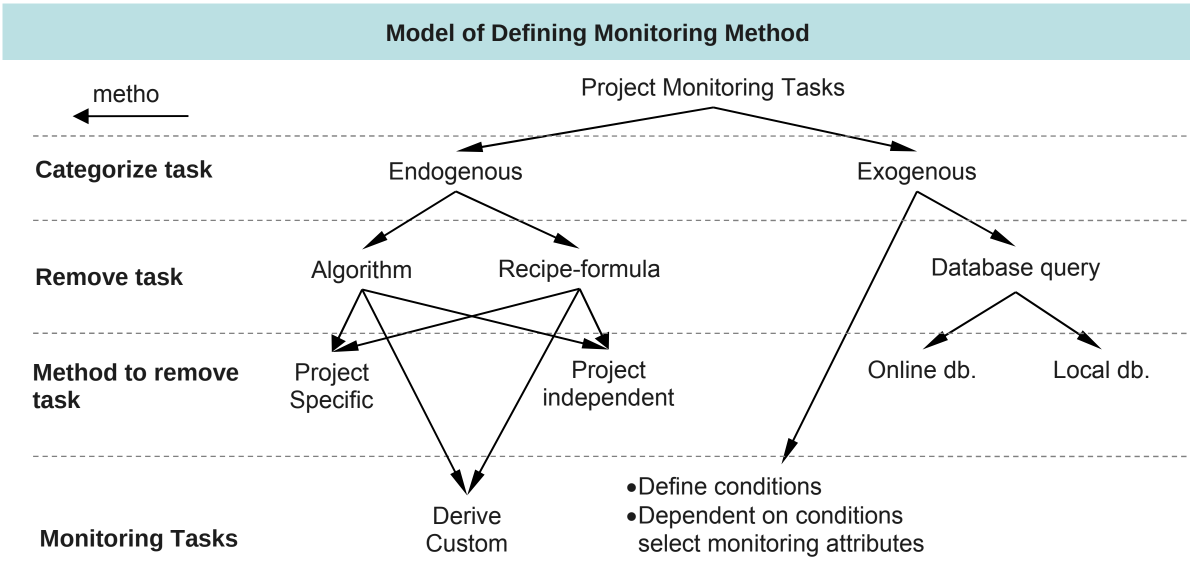


Figure 47 Field engineers base the method of measuring quantities on several variables. The process to select the optimum mix of methods with the available resources for a suitable degree of completeness, accuracy, and repeatability as a bundle of quantities features that provide an acceptable risk is poorly defined, Table 26, Table 29, p133 and 388.

5.3.4.4 Communicating Quantities

I observed the recording of measurements in several forms on the ReTRAC project; these are paper and pencil, printed ticket (scale), memory, electronic spreadsheet (from invoices or radio communication with field), and one field engineer stored measurements on his cellular flip-phone. These methods are ad-hoc and the field engineers did not base their decision for which to use on a formalized decision tree. The Teamster truck drivers recorded load counts and location on the daily invoice in a field specifically for recording purposes. The mason foreman recorded calculations for concrete volumes by location on his timecard. I did not measure the incidence of errors in recording[227]. How field engineers document quantities prior to the clerks, office engineer, or field engineers keying these to the enterprise resource program (ERP) is up to what the individual engineer is comfortable. Several independent variables influence which method to use. First, the skill of the engineer determines the method used, engineers exhibit various preferences and are to varying degrees comfortable with: paper and pencil, software application, spreadsheet functions, or have exceptional memories. Second, the complexity of the activity and the required post-processing can make some methods impractical for tabulations. For example, field engineers often make a simple count on a piece of paper while they calculate a quantities set conversion from loose cubic yards to embank cubic yards with

[227] Post-project analysis for this data has not been developed.

an electronic spreadsheet, Figure 44, page 246. If the field engineer had tracked the quantity as a percentage of completion, the field engineers could recall the value from a visual memory of the percent complete of the component compared to the planned final state and so no method of recording other than memory was necessary.

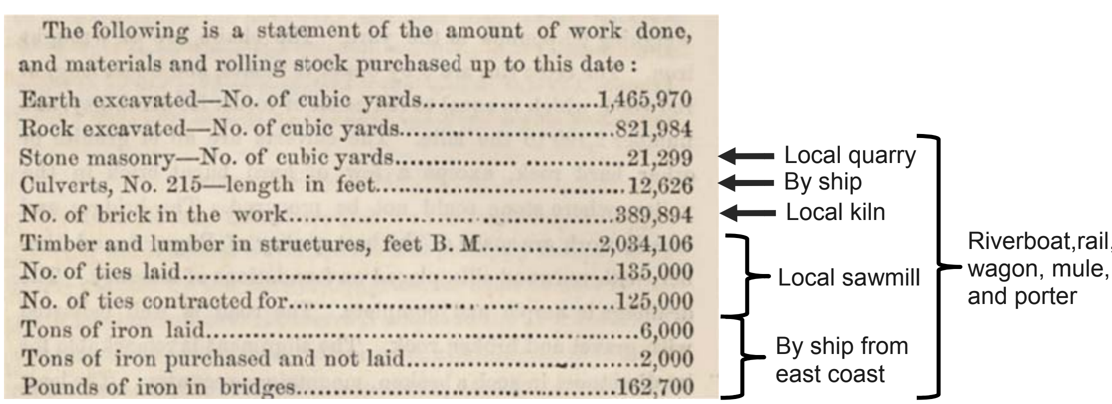
5.3.4.5 Sources

Under sources, I present the sources of quantities I observed on the ReTRAC, the project specific and independent sources, and gathering quantities through a sitewalk.

5.3.4.5.1 Observed Sources

The sources of quantities on the Overland Route project progress report are likely from three or four sources: Each of the following sources continued on to their destination by riverboat, rail, wagon and last by mule train or porter for smaller parts. Some items were clearly shipped from the east coast steel mills, sailors transported these to port by ship. A local mill cut locally sourced logs into lumber and hauled the lumber to site by the above mentions sequence of methods. Similarly, stonemasons quarried stone from a local quarry and laborers locally quarried the clay and fired it as bricks then hauled to site. The haul phase provides a key source of quantities since the items are broken down into transportable chunks and therefore provides the opportunity to reduce the measurement method to counting an assumed load quantity. If mules have a defined load capacity then similar to the ReTRAC project load count could be a source of quantities – in this case a mule count. For the items the field engineer purchases the invoice is a source of quantities. The seller has is an incentive to provide an accurate quantity both for payment and to avoid jail, Table 57.

Table 57 The Central Pacific Railroad's 1865 transcontinental railroad project "Progress of the Work" report. Each transportation "haul" method provides the opportunity to measure the quantity while unloaded and loaded, or counted as a haul unit with a known capacity.



The following is a statement of the amount of work done, and materials and rolling stock purchased up to this date:

Earth excavated—No. of cubic yards	1,465,970
Rock excavated—No. of cubic yards	821,984
Stone masonry—No. of cubic yards	21,299
Culverts, No. 215—length in feet	12,626
No. of brick in the work	389,894
Timber and lumber in structures, feet B. M.	2,034,106
No. of ties laid	135,000
No. of ties contracted for	125,000
Tons of iron laid	6,000
Tons of iron purchased and not laid	2,000
Pounds of iron in bridges	162,700

The sources I observed field engineers use for quantities (perceived percent of cases):

- Labor quantities, in hours, were submitted as a timecard by foremen and verified by field hands (100% of labor hours)
- Equipment quantities hours of operation, are recorded on an hour-meter and may be verified by the fueler (100% of equipment hours)
- Materials quantities often could be collected directly from the suppliers invoice (90% of cases)
- Subcontractors turn in sub-pays with reported quantities (90% of cases)
- Field measurements are made by engineers, foremen, and craft hands (50% of cases)
- Work-in-place measurements are made by engineers from plans (30% of cases, some engineers 80% others 10%)
- Derived from other sources (30% of cases)
- Guesstimate (20% of cases)

Table 58 Summary table of the sources presented in the literature and expanded to include sources observed on the ReTRAC project.

	Input Source																
Method (listed by level of detail)	sitewalk	time card (time log)	equipment meter | OBI	sensor-based	2nd party invoice	delivery ticket	field crew	engineer	meeting	drawings	schedule	estimate sheet	endogenous formula	cost report | budget	production report	project database	public database
Direct Measurement																	
start / finish date											X						
milestones	X	X			X	X	X	X			X						
percent complete	X	X	X	X	X	X	X	X	X	X	X			X			
units complete	X		X							X							
Indirect Measurement																	
a priori										*	X	X					
trust a 2nd party					X	X			X								
fixed-formula										X						*	*
opinion | guess							X	X	X								
equivalent units										X			X		*	*	*
level of effort											X						
cost formula														X	*	*	*
apportioned effort															*	*	*
neat-line takeoff										X							

5.3.4.5.2 Project Specific and Independent Sources

The project field measurements fall into categories, such as: project independent, project specific, scope-time-cost, and plans and specifications, Figure 48. Project independent quantities, such as the diesel fuel cost or the density of the local quarry's crushed rock in tons per cubic yard may be available from a database, either on-line or paper-based. The field engineer can measure reality for the project specific measurements as project scope such as work-in-place, time, such as activity duration, and cost. Cost was the most complete due to U.S. corporate tax and SEC stockholder financial reporting requirements: plus people quickly get upset if paid the wrong amount. Also, the plans and specifications provide a project specific source of quantities. The ReTRAC project engineer required the work-in-place quantities reported as a neat line takeoff from the project plans rather than the actual measured work-in-place, Figure 49.

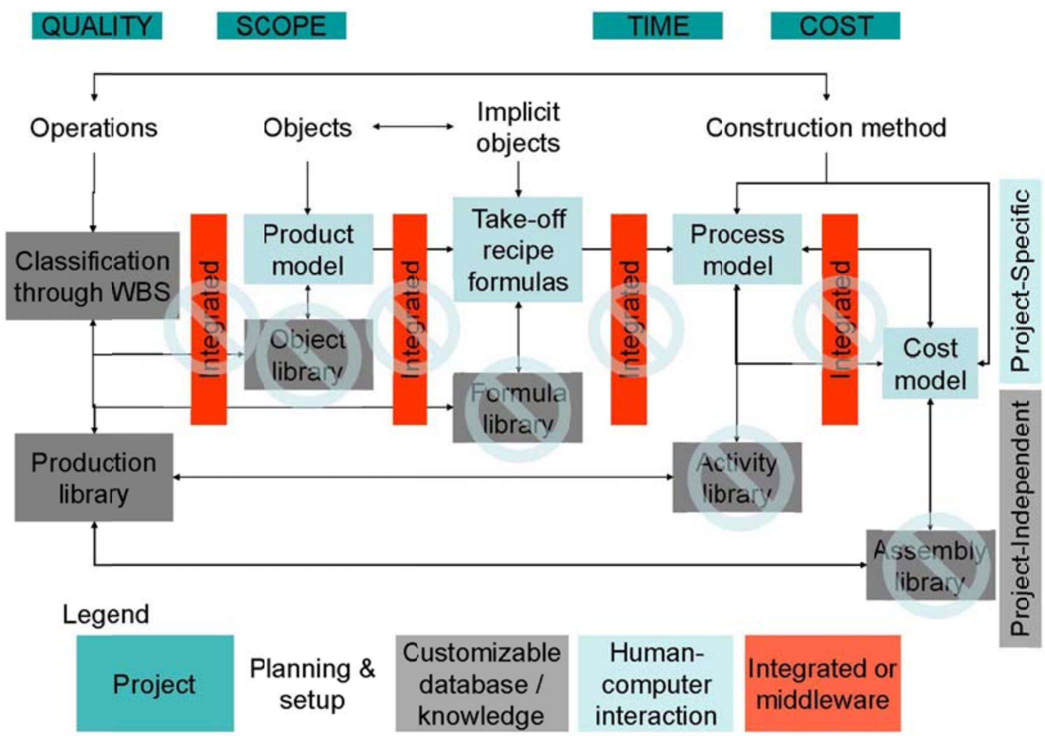


Figure 48 These five sources of field quantity measurements are an attempt to represent the possible sources observed on the ReTRAC project: Production library, Product Model, Quantity Takeoff Recipes, Process model, and Cost model.

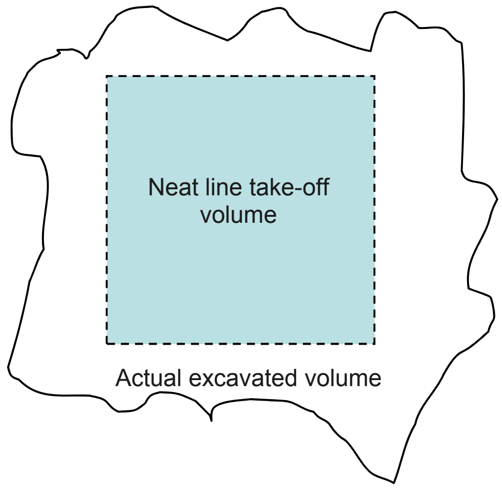


Figure 49 I observed the ReTRAC practice to report quantities as a neat line take-off rather than an actual quantity.

The specifications provide a project independent and a project specific source, Figure 50. A project independent roadway cross section allowed calculating the assumed volume of base material placed as the product of measured roadway area and the assumed constant for base-course depth. Similarly, the plans for project specific backfill material defined by project location allowed calculating the expected neat line volume of material placed by material type, therefore providing a value to compare and validate the invoiced quantities. I observed differing sources used to crosscheck and validate other sources. For example, field engineers make field measurements of the work completed by subcontractors to validate the quantity submitted on a sub-pay application.

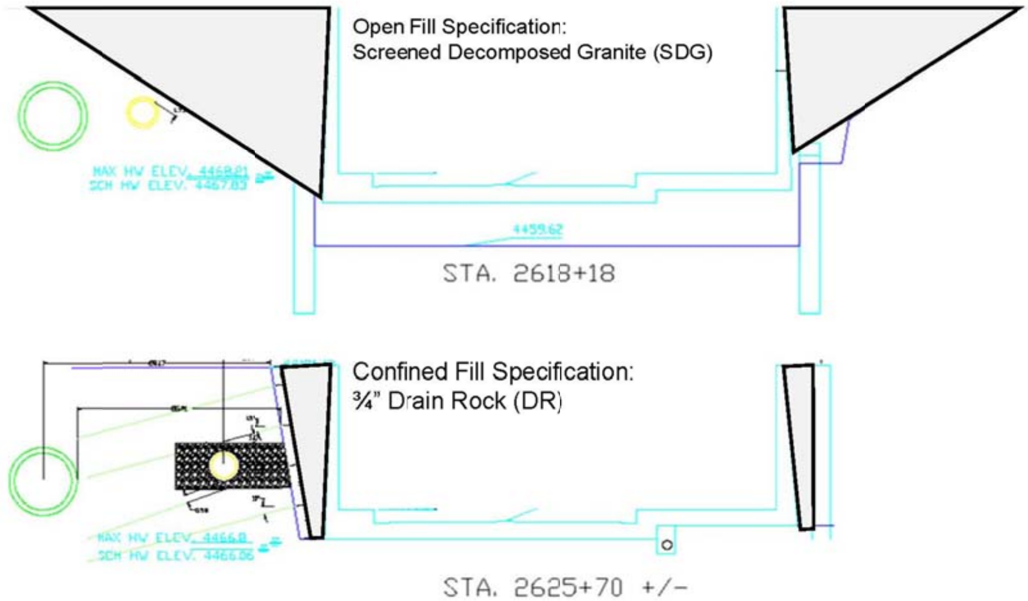


Figure 50 2D Computer Aided Drafting (CAD) cross-section view of the backfill conditions that control the structural fill material used. The specified material for narrow sections is ¾" aggregates and the rest is filled with screened decomposed granite (sand) or bank run (top soil).

5.3.4.5.3 The Sitewalk

A source of field measurements is the *sitewalk.* For sitewalks, once a week I took a tape measure, measuring wheel, notepad, pencil, calculator, digital camera, five-week lookahead schedule, and a spreadsheet printout of work-in-progress and then walked the three-mile jobsite for half a day: a six-mile round trip. I updated the operation start and finish dates on the schedule printout, estimated percent complete and noted these on the cost printout - the cost and time reports (cost and time reports are at differing LoD) were separate documents on the ReTRAC so the field engineers had to measure these separately. If possible, I made measurements by counting items or used a measuring tool, such as a tape measure for measurements less than 30 feet and a measuring wheel for measurements over 30 feet and up to several hundred yards. If I encountered equipment during my sitewalk, I recorded the hour meter reading. If measurements with a measuring device were not reasonable as I discus in page 312, or the work-in-progress precluded safe or nondisruptive access to the workzone then I measured a visual percentage of completion.

5.3.4.6 Conclusion to Methods of Quantifying

In this section, I presented the methods of quantification I observed on the ReTRAC project. The methods are units complete, percent complete, and a range of indirect methods. The indirect methods were for the most part not allowed and the field engineers used these clandestinely to simulate measured quantities. In the Stallard interview it is clear Stallard is aware of these methods and uses audit checks to find field engineers passing of assumed quantities as real quantities. I also present a method of alternating between real field measurements as a spot check of using assumed quants derived using an array of methods with varying degrees of confidence. I then presented the communication of quantities from the field back to the planner, for the most part this was various versions of paper and pencil. Last, I present the sources of quantities – on the ReTRAC this was somewhat confusing since the field engineers were expected to make sitewalks and measure quantities or obtain quantities from a trade supervisor but at the same time the field engineers were instructed to report neat line takeoff quantities as final quantities. I review the neat line takeoff through the interview format and found that the neat line method as it was implemented was incorrectly used on the ReTRAC. The other sources are project specific and independent sources that are mostly relating to deriving assumed quantities.

The tried and true sitewalk method was to take a few measuring devices, a schedule, and a list of feature sets that needed quantities and head out for a day hike across the project. This had the added benefit that if the field crews had a question they could ask in person instead of calling on the radio. Further, it is easier to understand the question if both are standing there looking at the problem instead of verbally communicating a description over the radio from the field to the office - this was before the days of cameras on phones and text.

In the next section, I present the approach to assigning features to the quantity. The assignment of features can be an assignment of features to quantity, usually in the case of invoices, or the assignment of quantity to features, usually in the form of a feature set or ‘cost code’ that has no quantity by the end of a week.

5.3.5 Quantification Features: Features Assignment

In this section, I present the process of assigning context features to a measurement. The context of a quantity measurement is the bundle of features that allows for reuse of that quantity. Without features, the quantity is useless. Having a method to represent features that meets the characteristics wanted is a challenge. Assigning the features to the quantity is another challenge of its own. Features assignment is a tacit process that I observed and practiced on the ReTRAC.

5.3.5.1 Background

A project report to Leland Stanford from James Strobridge, the project superintendent, provided a description of the temperature's effect - the ground was frozen two feet deep - on the production of a crew of 3,000 men and 400 horse and cart teams sent ahead to prepare a large fill (CPRRb). Throughout the work in the Sierra Nevada Mountains, the project engineer made meteorological measurements three times a day of the temperature, barometer, and humidity to provide context for the conditions encountered. He later published the results in a report to the American Society of Engineers (CPRRa). Examples of the types of contextual quantities collected on the ReTRAC are in *Appendix C: Data to Include with Measurement.*

Features aid in quantities identification and future quantities reuse. Examples of contextual features are as follows: climate, shift, previous work-hours, date, location, sub-location, work-zone, activity description, applied resources (crew, equipment, material, and subcontractor), operation, methods, specific resources (labor/equipment/material/subcontractor unique identification), and unit of measure. I observed the inconsistent collection of features on the ReTRAC project. The field engineers collected location features for operations but the project engineer had not represented location in the enterprise resource planning system chart of accounts and so location was not included in reports or the historical record.

On the ReTRAC project, a subcontracted firm inspected for quality. As a field engineer I corrected issues with quality I observed directly during sitewalks or indirectly observed through quantities or cost. For example, the cost and quantity for cure compound was low, indicating the masons did not have their laborers curing the concrete; also the geotextile fabric cost and quantity was low indicating this was only used for roadway over excavations and not to cover the aggregate backfill before placing the topsoil.

In theory an indirect observation of a quality issue can be derived from the schedule due to an increase in productivity or a missing task, this check was not used on the project or I did not perceive it used. An example: On the ReTRAC the trench drain pipe crew installed the 18" plastic pipe without gaskets. They had an incredibly good production rate. Their reasoning for leaving out the gaskets was that the pipe will be encased in concrete so gaskets are not needed. The missing gaskets were not discovered until near the project completion when the trench failed the water leak test: the project had a performance standard for how much groundwater could infiltrate into the trench through cracks and past seals. The field engineers had to figure out where the water was infiltrating – one recalled the missing gaskets. The gaskets had to be installed as an expandable foam through zerk fittings by a 'tunnel rat' crew that shimmied through the drain pipes. The excessive production of the initial utility crew should have raised a flag for further investigation.

In practice, the field crews on the ReTRAC project that I assisted were skilled and diligent in their work and corrections were not necessary. The inspection of work is a property of project monitoring that is in context with the quantities collected; Staub & Fischer identify an example of inspectors fulfilling the quality metric that I provided by the discussion of the roadway sub-grade quantities (1999). For example, reinforcing steel is monitored by tons placed, the monitoring cannot rely solely on this metric since the bar spacing and ties must be to specifications for the activity to progress without the risk of rework in the future. On the ReTRAC project, the inspectors continually monitored quality, therefore the project progress was updated on the assumption that quality was to specifications or the inspectors would have stopped the operation to correct the deficiencies.

Out of variance cannot be found if the quantities are not measured per regular intervals of time. Those quantities must have context features assigned so that the quantity can be compared with the representation in the plan for variance from expectation.

5.3.5.2 Coding Features

The magnitude of an activity during a timeframe is captured by measurements. The context of that activity is represented with a code made of numbers and letters placed in a set of features. These feature sets are called "cost codes" because they are most often used to relate project features back to a budget: they are used for numerous other purposes where the relation of some aspect of the actual project must be related back with the expectation model.

On the ReTRAC project, the field engineers and interns knew that they had corrupted several account codes during the project, possibly, due to a learning curve. These codes were not reliable for forecasting. These codes were *dumping codes*, characterized as high cost, large quantity items, that were active at that time. The field engineers dumped into dump codes miscellaneous items that they should have prorated to multiple accounts and coded. The benefit to the field engineer was reduced resources figuring out what to code too. Because the dumping code has a large cost and cash flow, the dumped component is a fraction of the total and so the project engineer and other field engineers do not notice the variance during the audit meetings. On arrival to the project, an intern quietly pointed out the characteristic for dumping and which specific codes the field engineers, interns, and co-ops used as dumping codes. During slow days, I reviewed these codes, pulled the obviously dumped items out, and recoded to the presumably correct location, I think 75% was undetectable. Intuitively the dumped amount may represent 1% to 5% of the total project – equivalent to $2M to $10M (US2000).

The field engineers found errors in codes during cost review [audit] meetings. Because labor time was often coded by the foreman, another field engineer, or at a different time than the cost and quantities were coded, these three items invariably had different codes if there was an error. The warning signs were:

- labor with no quantities
- a quantity with no cost,
- cost with no quantities,
- quantity or cost with no labor – possibly masked due to presence of other cost components,
- an abnormally high or low unit cost variance, or
- cost or quantity in a code that was not used during that period.

5.3.5.3 Tacit Coding Process

I observed on the ReTRAC project that the field engineers applied codes to expenditures and measured quantities through a tacit and ad-hoc process. I do not know what methods the other field engineers employed, but I do know that the learning experience provided to new engineers was through trial and error. A spreadsheet file of the chart of accounts with short descriptions was available on the project server and the field engineers kept a printout pinned to their cubicle wall, Figure 51. The field engineers understood through consensus how they used each code. As a new field engineer, if I applied an incorrect code, at the cost meeting the project engineer told me it was wrong and then explained what the correct code was. This was the learning process and method of knowledge transfer.

The process of coding is a three-stage process:

- Field engineers use select the feature set from a chart of account using their own methods, Figure 51.
- With the project manager and project engineer, the field engineers audit for code, quantities, and cost each week.
- The project manager and a division analyst (see Interview of Heavy Construction Senior Cost Engineer, page 175) then review the quantities, feature set cost, unit cost, and production on at least a quarterly basis looking for inconsistencies.

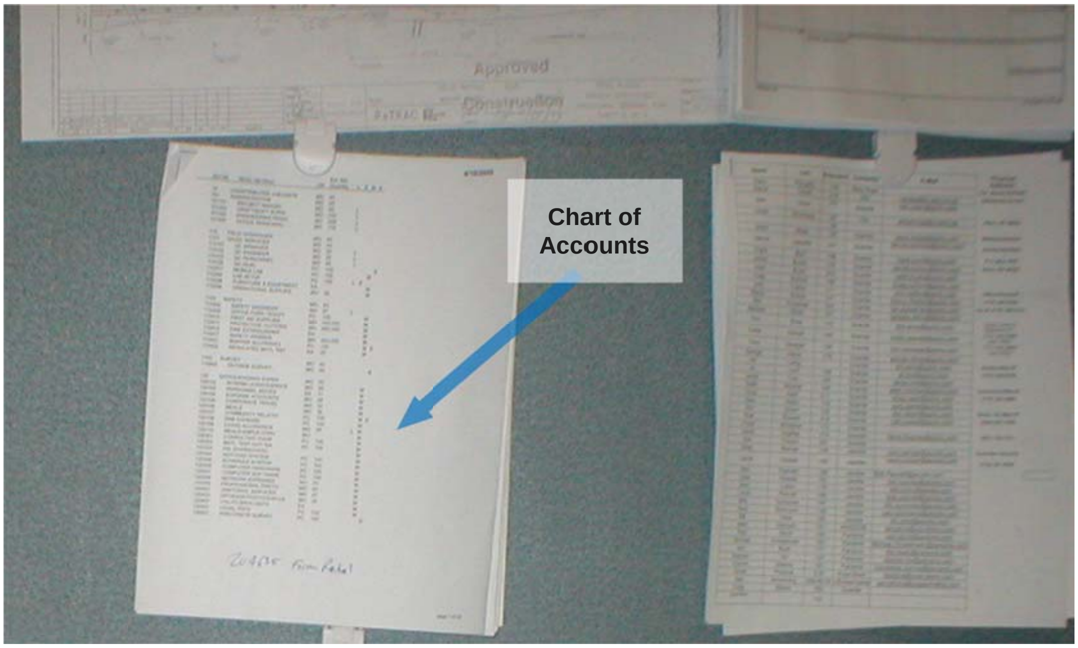


Figure 51 A field engineer's cubicle illustrates the coding process. To reduce miscodes: the chart is short-listed to those applicable during a 3-month period and each account has specific 'open' and 'closed' sub-types[228], note the handwritten unexpected activity. The headers on this sheet are code, description, unit of measure, and open sub-types. Note: at the top of the image is the plan-sheet used to color work-completed and take-off neat line quantities. To the right is the organization contact list with email and phone numbers.

5.3.5.4 Assignment of Codes

The chart of accounts contained two or three word descriptions that were then associated with the activity occurring in the field: I used a process of elimination and deductive logic to match a code with an activity. First, I identified what applied and then eliminate what did not apply, eventually arriving at one account. If several accounts seemed equally correct, I guessed - semi random weighted assignment - possibly consulting with other field engineers. While on the ReTRAC I observed four new accounts created during the project. If a new account or start of a new activity, that is the first use of the account, then I established a description within my mind, and explained to others if needed, what activities applied.

5.3.5.5 Maintaining Tacit Process

Once the project engineer defined a scope of activity for a feature set code then the consistency of applying the informal rule was the definition of quality. If a field engineer coded

[228] labor, equipment, material, and subcontractor

to the account and the project engineer perceived that it did not fit the informal rule then the project engineer corrected the field engineer and provided the account the project engineer thought applied. The tacit ad-hoc learning process continued with sharing of tacit knowledge from field engineer to field engineer. The rule for a code was a source of authority since one field engineer knew what the other field engineers could apply to an account. The rule was not recorded other than in each field engineers memory.

Due to bias, some miscodes were not mistakes they were purposeful. Miscodes were to other projects and to other activities as a form of sand bagging, p133. As a sandbag, the field engineer miscodes cost and or quantity that has reached budget away from the correct code and too an activity with excess budget. There was no formal reason for this practice other than averting the need to understand the cause of the variance and explain this to the project engineer or project manager. There was an annual bonus but the amount of the bonus did not appear correlated with cost performance. Each forecasting period the project manager released unused budget for finished activities. These were then reallocated to future activities that the field engineers had forecasted would require more than forecasted at previous forecasting meetings. The release of excess budget creates an end to sandbagging operations, flushing them out every three to six months, possibly longer for activities crossing multiple years.

5.3.5.6 Conclusion to Quantification Features

Assigning features to quantities was a time consuming and tedious task. The coding of quantities is an essential aspect of project planning and is the last feature that defines the quality of a quantity – a perfectly correct quantity is completely wrong if it has the wrong features. Because the task was tedious and often long lists of small amounts of applied resources took hours to assign to a specific account, the temptation to simply dump these into larger codes was strong. There was minimal incentive to the field engineers and even less for interns and foremen. The practice of a-priori coding (ensuring the cost report appeared as the managers expected it would not representing what it was) was more widespread than even I recognized. That said, there was a considerable effort to maintain accurate coding on a large volume of individual quantities. How coding was done was tacit and learned by each field engineer – likely there were as many approaches to coding as field engineers. Each week an audit review of over an hour with all field engineers and the project engineer demonstrates the resources expended by the project team. I do recall chasing down errors found in the cost audit review, but I do not recall that any of these ever had been masking a variance in the project's applied resources. I can only assume that small corrections each week had a cumulative effect of allowing seeing the variances that were found.

In the next section I present the post quantification of quantities, this is more of a continuation of methods but specialized I included it in a specific section.

5.3.6 Post Quantification

In this section, I present the post processing of quantities, the data entry, and reports of quantities.

5.3.6.1 Post-processing

Under post processing quantities, I first look at the ReTRAC project manger's requirement to complete mathematical calculations cognitively during meetings. I then look at the spreadsheet and associated hardware I used on the ReTRAC for office-based calculations and recording.

5.3.6.1.1 Cognition

One engineer was able to recall, calculate, and present complex quantities; this skill was encouraged by the ReTRAC project manager (p167). The project manager continually encouraged and demanded that the field engineers make calculations cognitively without the aid of a calculating device. During meetings, the project manager expected the field engineers to recall project metrics and calculate quantities. The project manager discouraged the field engineers from using calculating devices during meetings[229]. I assume the project manager's logic is that field engineers assist field crews, calculating and memory tools are not available in the field; therefore, if the field engineers become reliant on calculating devices they would not be as useful or may be dangerous in the field.

5.3.6.1.2 Spreadsheets & Hardware

In theory, a field engineer could utilize electronic spreadsheet functions for quantities. In practice, the project spreadsheets contained simple calculation and cell referencing functions. I looked through the ReTRAC project database and reviewed the spreadsheets used by the project team. Of the spreadsheet files, 95% do not to use the basic functions of electronic spreadsheets, indicating the field engineer did not know how to use spreadsheet functions. Hardware is a limitation for software and places a limit on automating processes. The spreadsheets I observed the field engineers use on the ReTRAC project ranged from simple formats to complex, several megabyte, cross-linked, multi-tab spreadsheets, with lookup database tabs. The field engineers' machines had a network connection with a shared server space, one public to all the engineers[230] and another private to each engineer. As hardware improvements in processors, RAM memory, and network connections appeared in the project office it was possible to work with larger files.

The early limitations in computational hardware defined the limit I could implement spreadsheet programming and the total scope of integrating spreadsheet files; the limit was equivalent to

[229] Ron made this real clear to Galen in one meeting.
[230] They could not simultaneously access the same file.

what could be done with paper and pencil memory, and cognitive computations. The machine I was first assigned (Win 98 OS; 128MB RAM) and the one I finished with (Win 2000 OS; 2GB RAM) demonstrates the relative difference. Initially, the files took a minute or two to load and sometimes the computer became unstable or crashed – the Win98 blue screen of death. The available spreadsheet complexity was limited by processing capacity and memory: on the Win98 machine, I could not complete the tasks I was responsible for within a workday. As a solution I had to salvage the RAM chips from two unused computers (combined 384MB) and lock the hard drive virtual memory to remain on constantly to get another 1G of slow RAM; the hard drive spun at the full 5,400 RPM[231] most of the day. The last computer I had - previously the project engineer's machine before leaving the project - after purchasing and adding 2GB RAM and a second dedicated hard drive for virtual memory - loaded multiple programs and handled multi-megabyte files without the same lag seen in the previous machine. The increase in hardware capacity expanded the scope of spreadsheet programming and the number of interconnected formulas sufficiently to allow a meaningfully complex spreadsheet that resulted in reduced labor demand for quantities post-processing and therefore exogenous measurements.

There is a second limitation: The ReTRAC project presented a unique opportunity to modify the office machines since as a separate company division the field engineers made decisions on the project's information technology (IT) and the project management was supportive of innovation from the field engineers. When I contacted the company's local branch for technical support with machine modifications, the local IT technician was upset, "you opened the computer case and changed the RAM?" – I figured he did not want to admit he had no idea what I was doing - and thought I should be fired immediately. I did not request technical support again and figured out how to modify the machines with parts sourced from online vendors and auction sites.

At first, I made the modifications and testing before and after work hours until sufficient validation was available to show the improvements. With a second field engineer as expert support to interpret the results (he had been on the project for a year and knew the managers better – I was just new), I then presented to several key managers who then approved funds for parts and my time for modification of a machine.

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[231] At that time hard drives used a rotating platter with magnetized sectors to store data – unused hard drive space could be used as a form of RAM. To get the most performance the RAM had to be set as a predefined reserved space ready for use - the relatively continuous ready state of these sectors resulted in the hardrive continually spun to full RPM. Anyone in the office walking by my cubicle could hear the harddrive.

Written here the process sounds simple but it was incredibly confusing, political, bureaucratic, and overly complicated at the time. From this experience, I recommend that companies provide a dedicated account for modifications, fund the account with relatively unlimited resources[232], and allow their field engineers to modify their machines or purchase different ones as the engineers think necessary; the field engineers are the ones using the machine and therefore they know best what is needed. Also, do not give the new machines to the managers who use them to review reports and read email, and give the oldest machines to the field engineers that are making the reports and generating the work that the emails are describing; machines are tools not status symbols.

5.3.6.2 Data Entry

In this section, I present the data entry process and the job cost planning system (MIS/ERP). I include a discussion about allowing the field engineers to directly enter their quantities to the job cost system and by-pass the office engineer – my suggestion was not adopted on the ReTRAC project. I also present the process of guesstimating quantities as part of the reporting process to cover missing quantities.

5.3.6.2.1 Observed Process

I observed on the ReTRAC that the field engineer or trade foreman recorded each week's measurements to paper. Then the paper record was keyed to an electronic spreadsheet and post-processing calculations made. The electronic spreadsheet of quantities and each quantity's associated identifying code were then printed and given to a designated office engineer. The office engineer then compiled the quantities from the field engineers, calculated added quantities from assemblies derived through indirects, keyed these quantities, and associated identifying codes to an electronic spreadsheet. This spreadsheet was then printed and the quantities keyed to an enterprise resource planning (ERP) system [Management Information System (MIS)]. The office engineer placed the final spreadsheet in a 'quantities binder' as a paper-based historical document of the weeks reported quantities, Saidi's (2002) graphical representation Figure 23 on page 140 is similar to what I observed and present here.

The field engineer's involvement in the quantities process is for the quantities only, there were five clerical office staff dedicated to the *job cost accounting* called the *business department* and managed by a *business manager*.

[232] Relatively unlimited means the field engineers could not buy enough parts to exhaust the account, the equivalent of several machines per engineer per year.

A quantity followed the longest possible path of the quantities process for 50% of all instances. The other 50% followed a shorter path where the field engineers submitted handwritten quantities measurements, the office engineer keyed these to the accounting system, and then placed the handwritten notes in the quantities binder as a historical record. The shortest path is double data entry and the longest path is four entries. I observed the average actual number of data reentries was three.

5.3.6.2.2 Management Information System (MIS) Redundancy

On the ReTRAC project, the project engineer designated the office engineer as the sole user of the ERP system. This was formally a decision made for quantities integrity and allocation of blame for problems. For access to the ERP system quantities the field engineers and managers had to make a request to the office engineer to customize and print them a report using the ERP weekly reports function - these are cost and production.

Learning the ERP system required the new office engineer to continually sit next to the previous office engineer for one month. For the month, the previous office engineer helped the new office engineer learn the ERP system. It took several months to become proficient with the ERP; it takes one financial quarter to cycle through the various reports and associated processes. Knowledge continued to accumulate after 18 months, though at a slower pace and for edge scenarios and uncommonly used functions of the ERP system.

If multiple users were modifying the ERP and did not exercise disciple in correcting errors, it may be difficult to maintain system integrity. The previous cost engineers that had moved to full field engineers retained access to the ERP system and often maintained their account audits; they entered their own quantities and generated reports as needed. Each office engineer held this position for one year before being considered a field engineer. Amongst the three field engineers that had been office engineers - a particularly shunned and sometimes demeaning task – the field engineers discussed the advantage our knowledge of the ERP system provided and the disadvantage this was to field engineers and managers that had shunned this task or those the project manager had hired above this position from another company. The field engineers discussed that the established ReTRAC data entry process was unnecessarily redundant - triple data entry - and that field engineers could key their weekly quantities directly to the enterprise resource planning (ERP) system [Management Information System] that is single data entry therefore doing away with the office engineer role. The prevailing argument against the field engineers keying to the MIS was that the project engineer had not provided the field engineers an education in accounting. The project manager and business manager agreed that without an accounting education the field engineers would corrupt the MIS system with errors. The project engineer did not accept the field engineers’ suggestion to open the system to the field engineers with one field engineer given the responsibility to provide ERP support and auditing; I do not known what the results would have been.

The core feature of the Granite ERP system [MIS] (JD Edwards AS 400) that makes it difficult to learn is it did not have an undo function - possibly a core feature of ERP systems [MIS] for transparency reasons or just a database feature - changes were permanent. The process for changes is a reversing entry and then the new entry[233]. Entries that cancel each other out indicate to other field engineers that it was incorrect[234].

The project and business managers assumed the reversing entry concept basic to accounting was a sufficiently abstract concept that the field engineers would require resources in education greater than the perceived return.

The project maintained a business office for payroll and expenses. The five locally hired clerks were able to use the ERP system [MIS] without issues. The difference between the clerks and field engineers was time dedicated with the ERP system [MIS]. The clerks operated in the system >80% of their time while the field engineers are in the system <10% of their time. The office engineer, given the dual role of field engineer and office (cost) engineer was in the system 25% of the time.

As a mitigation of the need for the field engineers to modify the quantities and their inability to access the MIS, the ReTRAC project engineer had the office engineer build and maintain a parallel accounting system with electronic spreadsheets, see Stallard interview page 175. Because the ERP and spreadsheet quantities are independent the project engineer's mandate created a continual task of checking that they were consistent with each other; doubling that task's workload for the office engineer. The spreadsheet quantities system had the benefit that custom spreadsheet functions could be written to endogenously compile quantities therefore reducing the office engineers' indirect quantities workload. The ERP system did not allow or the field engineers could not modify JD Edwards with custom equations to assemble linking relationships between accounts like spreadsheets can. Therefore, if the ERP system had been

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[233] There are cheats to this process, for example, the field engineer can maintain a cognitive running total and alter the value of entries to mask an incorrect entry. For example, entries can be bundled to a abstract level of detail both to save time and to mask the subcomponents that aggregate to the total sum. To break the aggregated sums into their components at a later date is time consuming, difficult without writing a program, and requires pulling the backup documents for a specific period. In the same way a subsequent entry can be increased or decreased both to save time or mask an incorrect entry. For example rather than take the time to back out and reenter the next entry is simply altered by an equal amount as the mistake. Finding and correcting these was for me a trial and error process that required an electronic spreadsheet and an afternoon of trying various combinations of sums until a match was made to the penny.

[234] It would not be too difficult to program this function as part of the undo function.

integrated with the spreadsheets then the dual systems would have been superior to either individually.

Overall, nobody on the ReTRAC that had much experience with the job costing system was particularly impressed with the performance or usability.

5.3.6.3 Reports

Like the quantities collected on the Overland Route project, quantities aggregated into information and presented as reports is for those responsible for the project but not sufficiently involved to understand what is happening. Reports are a managerial accounting topic and this study is concerned with quantities; the specific detail is a topic that is beyond this studies scope. The inclusion of a report section in this thesis is to provide an example of the human interface with quantities. Quantity collection does not need reports; the process is endogenous.

The office engineer derives the reports from the measured project quantities, Table 59. Because the report is dependent on the quantities, then the cost engineer compiles the report with both field measurements made with a tape measure and then post-processed with formal recipe-formulas and plug quantities based on opinions. Alternatively, the field engineer could have derived the quantities from a guesstimate and the post-processing also could continue with additional guesstimates.

Specific examples of formal and guesstimate follow: The monthly cost report contained directly measured quantities of the work-in-place and indirect overhead quantities. Guesstimating often was used to fill-in for missing quantities so that the report was complete. This was not done fraudulently or with malice, it was simply out of necessity.

In contrast, the five-week schedule activity durations were determined in an ad-hoc way that was not observable. The field engineers and superintendents gave the durations during the schedule meeting with no calculations. However, it is possible the engineers were multiplying the production rate from the production report by the takeoff quantity for that activity to derive the duration; unlikely since if the case, I would have observed evidence of this process.

Table 59 I observed the following internal (cost and production) and external (invoice and billing) reports used on the ReTRAC project

Scope takeoff (AGTEK software and triangular scale ruler):
- bidding takeoff represented in estimate
- baseline takeoff represented in budget
- takeoff updates represented in cost report

Process model[235]:
- baseline project schedule with major milestones
- six-month lookahead
- three-month lookahead
- weekly draft two-month lookahead schedule (pre schedule meeting), used to update actual operation start and finish dates; percentage of completion was not used for scheduling.
- weekly preliminary five-week lookahead schedule (post schedule meeting) updated with actual start and finish dates established at scheduling meeting

Cost model[236]:
- project estimate (proprietary detailed nonintegrated estimating software)
- baseline budget
- weekly cost meetings: increasing emphasis placed on monthly, quarterly, and annual (ERP[237] report)
- weekly cost meeting, audit cost report, correct errors, and solve issues
- monthly cost report provides the 3-month, monthly, and to-date unit cost (ERP report)
- monthly production report (ERP report)
- monthly project billing
- monthly subcontractor payment
- monthly accrual (potentially prorated by quantities)
- quarterly forecast meeting, increased emphasis on yearly forecast (every fourth quarter)

Management report (electronic & ERP):
- project monthly report (PMR)
- quarterly forecast report
- partnering survey report
- project final report

Once the preliminary report is ready, I then printed a copy and then made photocopies for the rest of the engineers. The engineering team then sat down and audited the report. After updating the job cost system with the audit changes O then printed the report and made photocopies for the managers. What the mangers did with the report I do not know – some did through checks and used the values for profit forecasting.

5.3.6.4 Conclusion to Post Quantification

The processing of quantities and data entry for reports is a process that has room for improvement. The large spreadsheets I used on the ReTRAC overwhelmed the computing

[235] Primavera P3 software; 5-week lookahead done in electronic spreadsheet prior to June 2005.
[236] For example, estimate, budget, and forecast (electronic files).
[237] Enterprise resource Planning (ERP) in this case referring to the JD Edwards (JDE) https://en.wikipedia.org/wiki/JD_Edwards and the IBM AS400 https://en.wikipedia.org/wiki/IBM_System_i

resources we were provided as field engineers. The solution was to build my own computer out of parts. The other field engineers that used complex spreadsheets had been there from the start of the project so had acquired better computers for themselves as something of a status symbol. The data entry process is truly horrendous; the manual keying of quantities and features through a keyboard was the only method to enter quantities into the planning system. Even at that it required compiling and recompiling the same quantities and then keying the quantities into each separate component of the planning system: a mind numbing experience. To sidestep this approach I suggested that the project allow the field engineers to key their quantities directly to the job costing system. The managers had seen this fail in the past due to the inability to know who had made errors in the system. The quantities submitted by the field engineers often had gaps and the field engineers gave their guestimates.

In the next section I will present the method of quantities controls through ght cross checks for internal consistency, reconciliations to date for clearly wrong quantities, and auditing for errors.

5.3.7 Quantities Controls

In this section, I present crosschecking for errors, reconciling quantities to date, and auditing quantities. Crosschecking for errors is the process of checking the job costing system for internal consistency. For example, if an account has x cubic yards and another account representing the same component has a different quantity, then there is an internal inconsistency. Reconciling quantities is the process of adjusting the values to obtain a known and reliable value. For example, the cost of concrete is constant, if the unit cost in the job costing system does not match this value - then there is an error. The audit is a more complex process of looking through the detailed transactions for errors or looking at patterns that look inconsistent. For the most part the audit was based on personal intuition and skill at finding errors.

5.3.7.1 Cross-checks for Errors

A control implemented on the ReTRAC to increase the confidence in reported quantities was independently checking each quantity three times. For example, a haul vendor submits an invoice for payment, the clerical office checks that the vendor is associated with the project and then hands the invoice to the field engineer to check that the charge is consistent with project activities - not placing landscaping boulders in the superintendent's yard. The field engineer then verifies that the check by clerical is valid, assigns a code to identify the activity, and checks that the specific charge is correct – including for the negotiated rate and looks for the above mentioned fraud. Last, the project manager checked each month the aggregated payment of invoices to each vendor.

The project manager implemented a similar sequence of checks for self-performed operations. The use of multiple samples with multiple observers provided for increased confidence. I did not observe the use of multiple observers on the ReTRAC project for quantities, except for the initial takeoff from the plans. Therefore, the number of independent observations for each measurement on the ReTRAC project is assumed limited to one. For quantities takeoff, the project engineer once instructed two field engineers to do the same takeoff and then compared the results, reconciling variances in an ad-hoc process. A similar approach to quantities, that is duplicating the field engineers' tasks, should increase confidence in the project monitoring.

5.3.7.2 Reconciling Quantities To-Date

Reconciling quantities to date to produce the expected actual value was a practice on the ReTRAC; possibly accounted for 10% of reported quantities. For long interval items, such as those reported quarterly, 25% needed reconciliation to-date. Reconciliations were for those items that had been continuously or intermittently reported as estimated measurements rather than actual measurements, as an effort to reduce the resources necessary to collect measurements. Although the field engineers recreated corrupted quantities from available sources, they had to reconcile to what the quantities should be according to the takeoff, unit cost, or as an assembly derivative of other items. On a quarterly basis, the project team would validate these items against available and perceivably reliable source, often vendor unit cost for materials, and derive a presumed measure of quantities. Each quarter the project manager audited the reported quantities. The project manager expected the field engineers to have independently audited the quantities with the project engineer's guidance. Concrete is an example that has a known unit cost, the concrete vendor gives the concrete cost per cubic yard, if the concrete material account does not reflect the same unit cost when the total reported cost is divided by the total reported volume placed, then cost or volume has not been reported. At the end of the ReTRAC project the concrete unit cost to-date was not the actual unit cost indicating that quantities were missing while the recorded cost was likely correct due to its being a reliably sourced value from the invoice. As a check for if it is cost or volume that is incorrect; if the calculated volume of concrete placed, derived from a takeoff, has a large variance from the volume delivered then the error is probably in the volume. The second example contains more assumptions held constant than the previous example. The reason of putting greater effort into quantities reconciliation on a quarterly basis is the forecasting process and its impact on the revenue reporting of a publicly traded company[238]. Prior to closing out the year, an additional effort was made to finalize the quarterly reconciliations (for most), and monthly and weekly quantities. Adjusting records from previous years, while not impossible was difficult without documentation due to the perceived duration of time to have passed and the reduced reliability of memory. These quantities are now unreliable due to a reduced accuracy and repeatability and only act as placeholders for future uses. An estimator could use them for estimating a future project without knowing that the project engineer backed into these values from other sources.

5.3.7.3 Audited Quantities

With an effort to achieve the highest degree of accuracy, repeatability, and completion in measuring field production, on a bi-annual basis the project received a list of several hundred items that did not pass an auditing process used by the heavy division senior project control engineer, see Stallard page 175. The project team corrected these items prior to the end of the year. The project control engineers' checks appeared to focus on completeness, ratios, crosschecks, checks with suppliers' unit cost, and checks against averaged quantities from previous projects. The details of these checks were not shared, I only know the type of checks and nothing more.

[238] Granite Construction Company is a publicly traded as GVA on the New York Stock Exchange.

The audit appeared able to detect seemingly small variations in reported quantities, for example, indirect material; small variations were a result of the imbalance between suppliers invoice periods, the field engineers' quantities schedule, and the reporting period. The overlap was one week.

The solution was micro-accruals for the cost and/or quantities to reflect cost or quantity from a later reporting period, which is one week of next month, and/or cost or quantities from the last week of this month,

Figure 52. The issue with accruals is they consume engineering and clerical resources to derive initially and need discipline to back-out after the period report close out.

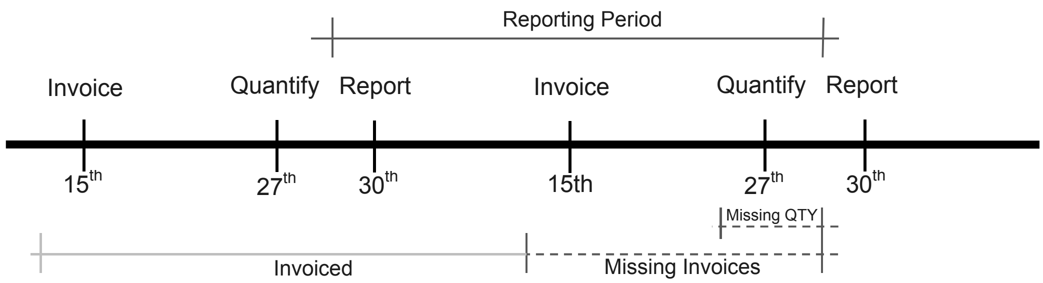

Figure 52 The overlap between vendor invoices, quantities measurement, and the reporting closing results in the need to reflect items that are not documented but are expected to be documented for a period. For example, the invoice submitted on the 15th reflects cost incurred prior to the 30th therefore, the field engineer must temporarily represent an estimate of this cost for 15 days with the related quantities until the project receives the invoice, because the unit cost and production rate will be incorrect.

The importance of this issue and the purpose for inclusion here is that the auditing process was an automated system of checks, therefore requiring inputs with a greater degree of accuracy, consistency, and completeness than prudent to the layperson. This degree was a cognitive hurdle for new engineers to overcome - possibly a characteristic of automation - therefore a potential lesson in future automated systems.

5.3.7.4 Conclusion to Quantities Controls

In this section, I presented the control for quantities through internal checks, reconciliations, and audits.

The check is made through an independent crosscheck of features of some quantity by three different people: on the ReTRAC this was usually the foreman, field engineer, an office clerk, and a fourth for audit review, the project engineer or project manager. Each of the first three added a different aspect of the feature codes, the foreman adds what were called cost codes (context features encoded in a nomenclature) – these are usually component-action-method, the field engineer adds the applied resource feature, and the office clerk adds the unique identifying feature for the applied resource and a workmans comp feature for risk. Another approach to crosscheck that I saw for takeoff quantities, but just as easily could work for field quantities is independently measuring a quantity by two field engineers. For example, field engineer A could track asphalt quantity by invoices, and field engineer B tracks asphalt by calculating volume from measured area and a project independent specification for asphalt thickness. For some quantities, I used duplicate measuring approaches to derive a quantity from two sources – if there was a gap then I would look closer. Part of that practice was to verify invoice quantities – such as backfill delivered.

The reconciliation is a check against expected and/or known values. Often a known unit cost from a vendor is used as the check. In general, in reconciliation if the unit cost (unit cost equals cost divided by quantity) does not match the known unit cost, then the assumed incorrect value is the quantity, not the cost. The reason for reliance on cost is that there are multiple parties verifying cost because of the business aspects. One aspect that could cause the cost to be wrong is miscoding – so the coding of cost to accounts must be accurate. The quantities could also be miscoded as well as simply measured wrong – or missing measurements. On the ReTRAC, 10% of the quantities measured on a short frequency required a reconciliation during the quarterly audit review. The quantities measured at a long frequency, such as cell phones on the project, a quarter of these had to be reconciled. The items that had a longer frequency were probably measured less accurately or intermittently ignored and that was the reason for the larger error – these were also less important to project controls. The reconciliations at the financial quarter was necessary for financial reporting for a publicly traded company.

The last of the three controls is the audit. On the ReTRAC I saw a bi-annual audit by the a team lead by a senior project controls engineer that resided at a home office. This controls engineer looked at three aspects of the job cost accounting. They looked for internal inconsistency – known account relationships were compared to equivalent quantities. For example the volume of aggregates delivered should match the purchased aggregates. The second check is through ratios based on historical patterns. For example, the ratio of small tools to project labor or the ratio of labor to total cost for that project type. The last check is the comparison of unit cost to known unit costs, for example the cost per cubic yard of concrete should be equal to the job cost account for concrete cost. The last aspect of the audit is the accrual process. An accrual is an estimated value entered for actual cost that has not been recorded, usually because it is within a billing cycle and the project had not received the invoice. The audit, the values must be stable at a point in time. I neglected to place an accrual on a somewhat obscure indirect material account, for two weeks I knew the value would be wrong – one the invoice arrived I would update it. The project controls engineer detected this discrepancy during his audit review. The hazard of the accrual entries is they must be backed out after the audit is completed. On the ReTRAC the field engineers entered accruals at the end of each month and then backed them back out.

The three quantity controls I observed on the ReTRAC provided a measure of the quality of our job cost accounting. The out pout from that system drove the forecasting process and provided a check for process deviation. As project planning systems become further integrated and more closely tied in with the feedback loop, the quantities control process will be increasingly critical and itself need to become a process of automated checks.

Next I will provide the conclusion to my ethnographic observations.

5.3.8 Conclusion to Ethnographic Observations

My observations of the ReTRAC project provide a snapshot of the quantification process used on large civil projects. The first topic is the purpose of quantities on the ReTRAC project. This is followed by the breakdown of my observations into the quantification process and the process of assignment of features to the quantities. Within quantification, I will discuss the performance features, the methods, the sources, and the audit check. Within context, I will discuss the purpose of features as a mapping tool, the breakdown structure and nomenclature, and the process of assigning features. There are key insights on kickback from the project team against an overly tedious quantification process and suggestions to resolve this risk. Last, I will discuss the power and generality of these observations as well as the limits.

On the ReTRAC quantities were for the forecasting process – there was no other purpose. Similar civil projects are required to provide quantities as part of the contractual reimbursement process – that becomes a gamed system. A nice aspect of the ReTRAC is that as a design-build lump-sum percent complete progress payment contract – there was no reason to game the quantities for outside parties, any gaming that occurred was purely between the project team and with themselves. That by itself reduced the gamed aspects. As a pure forecasting tool – the accuracy of the quantities must match the forecasting accuracy. Forecasting let the project team know how aggressive they needed to be about maintaining their profit margin. If the forecast profit dropped or showed there was the opportunity for large profits – then the team could be aggressive in pushing the crews into less safe conditions, reducing the environmental protections, and impacting the community, as well as increasing the risk in the previous three aspects. These are in addition to the normal construction measures of reducing the quality of labor, equipment, material, and overhead support, or just good old overbilling on change accounts and pushing cost onto subcontractors through unfair backcharges. There are innovations and advanced construction methods that provide a higher profit margin - these are the hallmark of what field engineers strive for - but these are experimental and risky and that is why they are not standard practices, when they work it is terrific and celebrated but when they fail it is often to the detriment of safety and the environment. Sometimes innovations are simply nice covers for the implementation of harsh methods. The ReTRAC had a positive forecast showing profit margins in unheard of territory, these undesirable practices could be dropped as long as the margin remained constant. For that reason the forecast in incredibly important - without the forecast the project supervisors would continually assume either they are not making enough profit or their profit is in danger and continue with harsh construction methods to the last day of the project – despite having an acceptable profit margin.

The quantification process on the ReTRAC includes the performance features, the methods, the sources, and the audit check. The performance features that control the quality of the quantities and also the effort exerted are the level of detail, the frequency, and the completeness of the measurements. For example, quantities made at the component level of detail, each month, for a third of the accounts is not difficult nor requires much effort to maintain. The ReTRAC required quantities at the method level of detail, each week, for 95% of the accounts – this required a commitment of 10% of the overhead resources by the project. For the ten field engineers and their supervisors employed on the ReTRAC project, without the quantification plan, one field engineer could have been removed from the engineering staff. Intuitively, I think this estimate is conservative – probably half the field engineers could have been released if not for the quantities. At the start of the project the project manager and the project engineer held a meeting with the field engineers where they established the level of detail, the frequency, and the completeness of the quantification process. These properties became fixed constants that the field engineers could not modify. In addition to the performance factors there is the degree of accuracy expectation – on the ReTRAC the expectation was for perfection, this increased the effort considerably. There are two additional performance features that have less of an impact on the effort of the quantification process. An individual field engineer can change the effort they exert towards quantities. These are the method of quantification and the source of quantities. The method and source of quantities can change the quality of the quantity, for this reason ranges of methods and sources were banned by the project manager – presumably based on instructions from the projects controls engineer. This raises a core problem in maintaining the quality of quantities since the frequency, level of detail, and completeness of quantities are easily inspected: the method and source used to collect the quantities is pragmatically impossible to determine. This is where audit checks come into play. From the interview with Bob Stallard and Ron Dukeshier it is clear that as supervisors they spend a large amount of their time looking for evidence of the use of methods and sources that are banned. The problem is the banned methods are habitually employed by field engineers as relief from the tedious and time consuming quantification tasks. As a solution Stallard has implemented a new quantification process that is relaxed where he has not found the effort justifies the benefits of quantification – for example direct materials. On the ReTRAC he had implemented the elimination of direct materials and has since then implemented further targeted reductions. Stallard has found that without reducing the intensity of the quantification process he continually finds the quantities is corrupted from the field engineers gaming the quantities with a priori values – essentially they turn in values that will pass an audit but are incorrect, therefore losing project controls. Stallard's experience is consistent with my observations on the ReTRAC. Between the level of detail, the frequency, the full completion, and perfection requirements – the field engineers turned to sources and methods that reduced the effort and then ensured the quantities are a priori, meaning they removed outlier quantities. To further complicate this process there was a quiet disagreement between the project manager and the project engineer about the source the field engineers should use for quantities. The project manager wanted the quantities measured from sitewalks. The project engineer wanted quantities measured from a neat line plan takeoff. Why the project engineer wanted the neat line is unresolved, it was incorrect for the ReTRAC percent complete progress report but correct for the project engineer's previous project's units completed progress reporting. Possibly the project engineer understood that the quantification plan on the ReTRAC was impossible and rather than have completley invented quantities reported that simply provided the expected unit cost he preferred neat line quantities that would at least show a variance in the unit cost. Most of the project engineers passed the task of collecting quantities from the sitewalk to the foremen and therefore satisfied the requirement that the quantities are measured from the field and then they reported neat line quantities. The field engineers used field supervisors or whoever was best situated to collect quantities with the least effort. The field engineers use of field supervisors is specifically addressed in the literature – this practice is widespread and the consensus is it will be a source of errors. As a field engineer, I devised a method that mixed both sitewalks with other methods of quantification. During the four weeks of a month, I made a sitewalk one week, then used a product of percentage of time and production for the next week, followed by an a priori cost calculation, and the last week I used a derived calculation based on direct and indirect sources such as specified thickness and neat line area takeoff. For the weeks I estimated the quantities I used two methods of estimating the quantity that each relied on a separate source – this redundancy provided me a check for consistency. If there was a higher risk or I found inconsistencies, I then increased the number of sitewalks and made direct measurements. This was the only feasible method I could find that allowed me to pay the required attention to safety and the community in planning while still maintaining the quantities. After the quantities had been measured there was a post-processing process to derive related quantities from the known quantities. The quantities were measured in the field and written on a notepad then taken back to the office. In the office the quantities derived from office sources such as invoices and neat line takeoff were then added. From this list the remaining quantities were inferred or in some cases duplicated. For example, the product of the surface area of graded roadway and the specified depth of the aggregate base provides the volume – the product of the volume with the specified compacted density provides the weight in tons. The post processing of quantities was allowed but the rules were vague. For some items it was ok and for others it was not – the distinction was informal and loosely based on the criticality of an item for forecasting. A specific example is the bundle of tasks for earthwork excavation, there is the support labor, the haul truck, and the excavating equipment – the same quantity was reported for all three. From the field collection to entry to the job cost system the quantities would be entered and reentered three separate times – this redundancy is common, Saidi (2002) documented a similar process used on the project he observed, p140 Figure 23. The redundant keying of the same quantities multiple times was mind-numbing. With the consensus of all the former office engineers, I recommended to the project management that the field engineers simply key our own quantities to the AS400 EDJ – therefore eliminating the redundancy. The managers were concerned with the project planning system becoming corrupted and if only one person was entering quantities than they would know who corrupted it and could instruct them to make corrections. Therefore, the redundancy stayed to the end of the project. The field engineer usually entered their quantities to their own quantities spreadsheet , then printed this spreadsheet and handed it to the office engineer. Some of the spreadsheets were large and the old computers the field engineers had could not open them – I had to pull RAM and second harddrives from unused computers to make one that would work. With a working computer, the office engineer then entered the quantities into a spreadsheet that tracked all the field engineers quantities – this was then printed and placed in a binder as a physical backup. The quantities were then entered to the AS400 EDJ project planning system and the material quantities were also entered to a spreadsheet. The material quantities were then printed from the material spreadsheet and keyed to the AS400 EDJ – the printout was placed in a binder as a backup record, occasionally the field engineers used these and it was good to have a weekly record of what had been done. The purpose of the duplicated quantities in both spreadsheet and the AS400 EDJ was a by-product of Stallard's removal of direct material in the AS400 EDJ. If the project team wanted to monitor quantities then they could do this in excel. The last aspect of the quantification process is the audit check. I discussed the audits done by Dukeshier and Stallard and the purpose. They made three checks, they looked for reconciliations through first internal consistency and second against known values, and third they used multiple independent sources. A further security measure was that every item had to be reviewed by three people on the project team, usually one person each from engineering, business, and construction supervision.

In the quantification process there is a parallel process of features assignment to quantities. I will discuss the purpose of features, the breakdown structure and nomenclature used on the ReTRAC project, and the process of assigning that feature to quantities.

The assignment of features is parallel to measuring quantities. This means the quantities can be measured first and then the features are assigned to the quantity or with a null quantity as a placeholder the features are assigned first and then the quantity measured. On the ReTRAC project, the labor and invoice cost were quantified first and then assigned features: the progress quantities were usually assigned features first and then quantified. The quantification process is slightly different depending if the features are assigned to the quantities or if the quantity is assigned to the features. The measurement effort is similar, though when quantities are measured without the features then they must be narrowly defined – for example, measuring labor hours for an individual, there is certainly a context for this but the boundaries of the labor context will be blurred. By blurred I mean that labor hours submitted without assigning features first to a null value will be subdivided into groups of activities based on the foreman's perception of the activity features. If the foreman's concept of activity features has the same boundaries or even the same grouping into the feature sets of the activities in the project chart of account – is not certain. Therefore, mapping a foreman's activity feature sets on a timecard to the chart of account is not a neat process. Some of the foreman's feature sets are contained in one account – meaning the timecard will have two entries with the same features. The opposite scenario is the foreman's feature set does not exist and two or more accounts represent that group of features. The labor hours for the foreman's feature set must be somehow distributed amonst the three accounts. When quantities are collected without first assigning features then it is the person collecting the quantity that defines the feature boundaries. Assigning features after measuring the quantity raises the problem with mismatched features and feature boundaries. When the features are defined first and then the quantity is measured – the mistake can be made that the wrong feature set is measured. Then mapping of quantity to features is a problem.

Now that I have explained the mapping of quantity to features and features to quantity – I will explain the purpose of mapping. In general, the need to map a concept to a class is universal. First a comparison between animal behavior and fiend engineer behavior: I am no expert, but from personal experience, I believe the dog I had years ago had a feature hierarchy to represent concepts. I think all dogs have this feature hierarchy system. For example, my dog knew the difference between a bag of clothes and a bag of groceries. He instinctively categorized one as food and the other as non-food. Possibly his entire world had two feature groups, food and everything else. One set of features he cared about and the other he did not. He seemed to have a concept of quantity. If he had a lot of food he ate less of it and if he had only a small amount of food he ate much more. He saw that if there was a large bag of food he had no reason to worry about the future – he ate what he wanted and shared the rest with the other dogs. If he had only a bowl of food he was then concerned there would not be another bowl and ate everything to ensure another dog would eat his food. We as field engineers are not so different from my dog. We need feature sets of construction context, some we care about and others we do not. We quantify these things according to our feature hierarchy system. When we have a surplus we are comfortable and when we have a shortage we consumed all the project project resources available to ensure we would have the things we care about. In construction, we have a word for consuming excess resource – it is sand bagging. The difference between my dog and project managers, my dog did not hide that he had eaten extra food just in case, while project managers hide when they do this. The behavior of my dog essentially captures the behavior of project managers so I think this behavior is universal.

The system on a construction project to group things into quantifiable boundaries of feature sets for those we care about is a formal process. The process of quantifying these feature sets is also formal, as I have shown in the previous paragraphs of concluding remarks. There are three aspects of the features. First, there is defining the features into sets and providing some way of describing the boundaries of that feature set. Next, is the representation of that feature set in a form that is easily communicated. Using my dog as an example, I could claim he cared about the molecular structures that formed protein – maybe diagramming the structure and counting the valence electrons, maybe a stoichiometric balance, all the things necessary to recreate or find this thing my dog cared about. Or, I can use the simple form to convey that my dog liked dog food. In the same way, in construction we care about how much time humans need to twist steel threads around long slender rods of steel. Or, we simply say 051.550.01, that is my nomenclature for tie rebar. It is simple and concise, 051.560.01 can be drive a truck and 051.540.01 is mix concrete. There is no mistaking that 051.550.01 is tie rebar. I can add detail and distinguish between black rebar and epoxy coated rebar with an index increment of 051.551.01 and 051.552.01, so there is no mistake that when I say tie rebar that I mean tie epoxy coated rebar. There is a breakdown structure to this nomenclature, there are features in the breakdown structure. There are five features; these are discipline, resource, operation, modification, and applied resource. These are 051 is the ironwork discipline, 5 is the rebar discipline, 5 is tie wire rebar, 2 is rebar with the epoxy modification, and 01 is the labor applied resource. The features define the context. The breakdown structure defines the nomenclature list in what is called a chart of account. This chart lists the accounts created from the breakdown structure in the nomenclature. The chart of account can have two forms, these are indexical and non-indexical. Indexical means that concepts are equally spaced from each other in the nomenclature. For example, I have three components varying in size, they are A, B, and C. If A is equally smaller than B as C is bigger than B, then B less A is equal to C less B, they are equally indexically distanced. In the nomenclature if these are three types of rebar each a different steel strength and they are steel strengths A, B, and C: A is equally less then B as C is greater. Using our previous nomenclature but now using an indexical nomenclature for features, A is 051.552.01, B is 051.554.01, and C is 051.556.01. This leaves room for adding additional strengths of steel between A, B, and C, as well as stronger and weaker steels. The

ReTRAC project chart of account had indexicality but it was more of a folkcality, it was not purposeful but done intuitively. Most chart of accounts are also sequential, the first tasks of the project given lower nomenclature than each successive task. The ReTRAC chart of account had sequence and again it was intuitive not necessarily purposeful. Because of this, all aspects of the ReTRAC chart of account had exceptions to the rule and was internally inconsistent. Given these shortfalls, the ReTRAC chart of account contained the basic components of conditional boundaries, breakdown structure features, nomenclature, sequenticality, and indexicality.

The purpose of assigning features to quantities on the ReTRAC project was specifically to map between the facets of reality and expectation. This was both from reality to expectation and from expectation to reality. The components of the expectation are scope, schedule, and cost. On the ReTRAC these expectation components were known as the Quantity Takeoff, the cost was known as the Job Cost and the Forecast, the Schedule was known simply by that term. Mapping between quantity takeoff and Jobcost was allowed by the features. Though mapping from schedule to either quantity takeoff or jobcost was not done by features, nor was it pragmatically feasible. The schedule used a natural language descriptions and a mix of work breakdown and location breakdown structures. The reason for not mapping with the features was inability to map across level of detail. This was due to both a lack of function in the software and simply a lack of theory overall on how to cross level of detail on the scale of the job cost and schedule. Mapping between expectation aspects provided the ability to plan a consistent quantity, production, and cost expectation and in this indirectly provided the foundation for the schedule. The last aspect of the expectation to update those expectations with what actually happens – I call that reality. Mapping from reality to the expectation requires features. The flow from expectation to reality moved through the natural language schedule, the flow from reality back to expectation mapped through the features codes. The level of detail of each of these aspects varies – the most is the jump to the schedule with the 2D dimensional plans in a close second. Neither the schedule or the dimensional plans used the context features codes. From the plans the quantity takeoff was derived, the takeoff used the codes and is the only place where the level of detail was converted from the component level to the applied resource level. For the most part the plan takeoff was completed at the start of the project and only if there was a design change or a more accurate quantity was needed was a new takeoff completed. The schedule, the dimensional plan, the quantity takeoff (in spreadsheet form) and the quantities feedback shared a context feature set that was not included in the job cost breakdown structure, this is the location breakdown structure. With location the quantities were known for a subset of the project and provided a convenient means to estimate quantity completed based on viewing parts of the project. The job cost contained a breakdown structure shared with the quantities feedback in the applied resource breakdown structure. The quantity feedback was the only aspect that shared the location breakdown, work breakdown, and resource breakdown, though not strictly and not in every case.

Now that I have explained the forming of a feature hierarchy of construction and then encoding the resulting breakdown structure with a nomenclature and listing the feature set leafs (accounts) in a nomenclature list called the chart of accounts, I can now describe the process of assigning (coding) those accounts to quantities. First, the coding process is a tacit process – on the ReTRAC there was no instruction manual. Through my literature review, survey, and interviews I have not found a description of the coding process beyond a few sentences along the lines of “accurate coding is important.“ The effort exerted on coding is 10% of the project overhead resources – each morning most of the field engineers coded for nearly an hour. The project engineer and then the project manager audited the codes for several hours each week. The coding and auditing process for everyone involved is tedious. The coding starts with handwritten notes on invoices and paper notes with field quantities. These notes and invoices are then passed through the engineering and clerical offices until they are keyed to the job costing system – they then are printed as a time period report and audited. This long, tedious, and repetitive process that while producing accurate quantities (what looks like 97% correct of total) also produces apathy in those involved in the process. At the core no one quantity and code pair is important, each represents a small fraction of the total project applied resources. Split into the constituent parts, the quantity or codes is even less of a contributing factor. Of course the code is slightly more imprortant than the quantity since a miscoded quantity places not just a zero value in the correct account but also adds an incorrect value into another account – doubling the error. An incorrect quantity at worst corrupts only that account – and invariably the quantity is wrong within one order of magnitude - limiting the corruption. Each field engineer coded using their own approach, some were clearly better than others. At the core no one error in coding is critical to the project though the sum of errors is critical. The question then is how much error is acceptable and when does it become critical. This lost importance of each quantity and code results in the apathy of tediousdom. It is the discipline of diligence that offsets this apathy and one of the reasons for the project engineer and project manager to also endure the tedious task of auditing the quantities. Through the combined efforts of the field engineers and the project supervisors - in coding and auditing the project - the project achieves discipline in the quantities process.

The power of the ethnographic observation is the depth and richness of context. Through first hand situated active participant observations I gained an understanding of both the nuanced details of dumping quantities into convenient accounts as well as the difficulty in determining the context of a quantity that I neither measured nor was present for – both circumstances have an equal chance of having the correct features assigned. The depth of observations allowed learning about dumping codes from other field engineers, something they likely would have never said to an outside observer. When situated as a field engineer the advice was offered more as condolences. With this depth of understanding it is my responsibility to capture these observations.

The generality of these observations is found in the scope of the ReTRAC project – 0.5% of all 2005 U.S. civil work is represented by the ReTRAC. The ReTRAC project team came from a diverse background of other large heavy construction contractors – each bringing with them a rich experience in quantification. My ethnographic observations covered earthwork, structures, underground utilities, and streets. My observations are general to this domain.

The ReTRAC had quantities requirements that were seemingly infinite. In retrospect it seems understandable that field engineers augmented their quantities with randomized features assignment for quantities such as labor hours and provided dummy *a-priori*[239] values to achieve reporting completness. These shortcomings exposed, this is not the full story, this is the ethnography knowledge of reality and what are known as war stories. The ReTRAC project team maintained the quantities and assigned the features to those quantities for the most part accurately and to the best of their ability. Does it matter which account a field engineer coded a $100 invoice? It does if that happens ten-thousand times over the course of a five-year project – but there probably aren't even that many invoices on the entire project. If each of five field engineers dumped two $100 invoices per week they would have dumped $250,000 over the course of a five year $200M project: that is one-tenth of one percent of the total project – just due to inherent human errors alone coding will have a five percent error rate. The effort exerted to correctly code those two obscure and uncertain invoices each week just cannot be justified. The project engineers that provided pure dummy quantities or dumped every invoice into a semi-randomized account were the exception to the rule. A huge effort was placed on measuring quantities, coding these with features, and auditing the resulting reports.

[239] What is expected rather than measured.

5.4 Conclusion to Observations

The power of my observations is through the six methods of observation: literature review of three categories of publications - reference, practice, and research publications, survey through both context rich pre-survey and broad questionnaire survey, open interviews, and ethnographic observations. These observations are then followed by lab-based case study investigations into niche questions.

Even with the most advanced statistical approaches to project planning – methods that are seen for the most part only in project planning in industries such as aircraft manufacturing, the output of these methods is still a quantity represented in context. If I ignore the method used to derive the quantity, project planning and control becomes a simple loop of prediction of expectation and feedback of reality. The core of this loop remains the quantity and the context of that quantity.

A good product design is no good if the field engineers cannot enact it. For example, the US20 project in Oregon had this problem. This project had an adequate erosion control plan (Cite Stallard) and most likely had a quantity takeoff for the erosion material. On the project site there was likely a large pile of the erosion control materials, more than enough for the entire project. The quantities are not just about material. There are labor, equipment, haul, and workspace quantities. These have a different unit of measure than material; the labor and equipment have a quantity measured in time. The time measure is further modified to become a quantity measured in dollars after the quantity supply and quantity demand equilibrium defines the unit rate of cost. On the US20 project it appears that they were aware of the time they had available to install the erosion control – from published records this sounds like several weeks. What I presume they did not do on the US20 project was to determine the labor and equipment quantity needed to install the material quantity within the quantity of time they had available. Maybe they did and were simply being aggressive in pursuit of profit and had a comfort with a high degree of risk. Either way, they lost. The rains came and the erosion control material installation activity was not completed. They first two days of rain must have been hectic and the entire project labor and equipment resources were shifted to the erosion control activity – but it was too late. Securing hillsides of recently disturbed soil devoid of vegetation during a heavy rain is difficult – large gullies must have formed nearly instantly. The quantities must be integrated and balanced, the labor, material, equipment, and haul quantities must align with the quantity of time available and the quantity of workspace available.

Throughout this thesis I ignore the *detailed process analysis* approach to deriving the expectation for the project. For the most part I do this because with the existing technology field engineers cannot measure the actual for feedback. For example, the limiting factor for excavation is the excavator. Regardless of the shoring material, the labor, the haul truck, and the workspace – I cannot achieve a higher production that a single excavator can produce. Of course, if shoring material, labor, haul trucks, and workspace are limited, then even one excavator cannot achieve capacity. In practice, these other factors are usually achievable – for planning purposes field engineers can assume the *driving production factor* will be the actual production rate. The challenge then is to find an expected production rate for the excavator. In the detailed process analysis the motions of the exactor are decomposed. The excavator steps are A) swing-fore, B) dig (curl), C) swing-back, D) dump then repeat. Each of these four steps cannot move faster than the hydraulic controls allow. The rate of swing for any given excavator is a known constant. The time to dig varies based on soil type so this is an uncertain variable – the soil should have been previously loosened to aid digging, if this is the case the dig time becomes nearly constant. The time to dump is usually a constant. Assuming a proficient operator performing at 100% of the excavators capacity then I should know the cycle time of the excavator give or take the variance due to digging different soils. The next variable is the volume of material moved with each swing cycle. The excavator bucket defines the maximum volume. A one cubic yard bucket – assuming a struck versus heaped volume - will hold one cubic yard. Combined, I can assume that if the excavator cycle time is six seconds and the bucket is one cubic yard, then my production is ten cubic yards per minute. Under the detailed process analysis I then apply the resources for shoring, labor, haul, and workspace to accommodate ten cubic yards per minute. Next, I need to consider my time constraint, if I have 60,000 cubic yards to excavate and five days to complete this with ten-hour workdays, then one excavator will not work, I need ten days to excavate 60,000 cubic yards. The bundle of excavator and supporting applied resources is a *crew*. Everything I have presented in this thesis applies to the detailed process analysis approach I simply do not present the material at that level of detail. Once it is possible to measure the actual swing rate of an excavator and feed this back to the project plan to modify the expectation, then knowing only that this exactor is moving 30,000 cubic yards per week is sufficient to verify that the reality matches the expectation. Why exactly is not necessarily know.

The factors for quantities performance are well established and published in the reference and research publications. The factors are frequency of measurement, level of detail of measurement, completeness' of measurements, and then less clearly delineated delivery factors of latency of measurement, method of measurement, and source of measurement. I found these factors applied through the survey and ethnographic observations. The new factor that previously was not understood is fraud on the part of the field engineers. Fraud on the part of the field supervisors was understood to be as a result of an intuitive desire to meet expectations. The field supervisors simply shuffle the quantities to make it appear they are meeting expectation both overall and on each individual task. The fraud on the part of the field engineers was not understood. By fraud I do not mean fraud for personal financial gain, but fraud as in any misrepresentation of the truth as best it can be known. In the interview with Stallard I found an explanation in his findings. Through Stallard I can see that if the quantities system is designed for the optimal performance then it is a tedious process for the field engineers. As a result the field engineers either pass off the task to field supervisors or they misrepresent the quantities. The first response – passing off to field supervisors is known through the literature review. The second response, falsifying quantities themselves is new. Stallard's observations are consistent with my own in the ReTRAC project. The performance factors known for quantities have an additional factor for tediousness. How to measure tedious and at what level has process become too tedious is not known. The ReTRAC system clearly was too tedious. Once a process become too tedious the performance will decline. The solution Stallard uses is he underdesigns a basic quantities system then lets the project team on each specific project to them extend the quantities system to a level they feel comfortable with.

The counter catchall to the quantities is the abstracted stakeholder meeting. This is the condition were quantities are optional. The human ability to abstract and work with concepts removes the need for quantities – from what I have seen quantities are detrimental in this process and abstraction is preferred. The core of the stakeholder meeting is founded on a simple premise – field engineers cannot manage the details, they will consume the project, manage the issues, and manage the people. The stakeholder meeting sequence is based on providing a forum where an established process is maintained so that when the project planning process cannot accommodate an exception then that exertion is passed to the stakeholder meeting for resolution. Examples of issues are boundary objects, often these are not clearly part or not part of the project scope. The solution is to bring the boundary object - some scope of activity - to the stakeholders and resolve it through discussion and agreement. I thinkt he stakeholder process is an incredibly important component. There will never be a perfect project planning theory that never produces an exception. For this reason alone, the stakeholder process must exist. Second, the stakeholder process is the nucleus of the ability to fall back on in the event that the project planning process fails. For example, what if the database becomes corrupted due to non-diligence on the part of the project team with their quantities. Another example is if the project suffers a large change in expected conditions, setback, or design change, the current planning systems are cumbersome and do not adapt to change – the stakeholder system is a bridge that allows for a temporary patch until the planning system has been updated and recalibrated. The project planning system and the stakeholder meeting are the two components of a complete project planning system.

Next are the core topics I covered through the observations – there are interesting findings in these and follow on the foundation I have provided in my previous discussion about the core role of quantities in planning. In these discussions I will review the process of quantities, the 'how' for enacting the process.

The first aspect of the quantification process is the tacit nature of learning quantification. Outside of a few textbooks the quantification process is ignored. Even when it is in the textbook the quantification chapters are not necessarily part of construction course assigned reading material. The chance anyone will read an unassigned chapter in a textbook, let alone read it outside the class is nearly zero. As field engineers we all had a shelf of textbooks in our office cubicle and occasionally pulled one for reference, they were mostly decoration. The courses on estimating and quantities use quantities but these are set piece toy case examples, the exercise is limited to teach just the basics of estimating and scheduling. The quantification process is learned by doing. As a new field engineer the first step is to find your desk, and receive a hardhat and safety vest. The next step is to learn which quantities you are responsible for and the feature sets. From that time until forty years later when you retire, quantities and feature sets will be a part of your world. The methods of quantification you know are those you see and sometimes those you or fellow field engineers 'invent.' The more experienced project engineer and the project manager informally define the methods that are acceptable and those that are not. They do not define these methods through a formal algorithm or table, they do this through instinct gained from experience. Later, in the future when the quantification process is completed with sensors and cost coding algorithms, at that time the method the automated system implements will also be derived through an algorithm. Until then, the system is tacit.

There is a culture for good quantities. Quality quantities require diligence and discipline – finding field engineers with these two attributes is difficult enough. On top of this there must be a culture for quantities. First, field engineers cannot be punished for telling the truth. When some unappreciated truth about the quantities or the planning is made public, these must be done without fear. In the same way, the field engineer that hides errors or other unappreciated aspects of the quantities must be disciplined immediately. If a culture of punishment for telling the truth and leniency for hiding the truth prevails the quantities might as well not be done.

Now is the core of the quantification process. The process consists of two core components, these are the quantity and the representation of the features of that quantity.

The method of obtaining the quantity is related to the project features, for example neat line takeoff is used for billing with unit cost contracts. There are methods that are direct and those that are indirect. The direct methods essentially mean to walk outside and make a measurement, or rely on quantities from someone else that did. The indirect methods rely on some form of estimating – these are usually done during post processing of the direct quantities. For example, the roadway area is measured but I need to know the volume of base material placed on the roadway: I indirectly estimate the volume based on the area and the assumed depth. This relies on project specific and project independent quantities. In the previous example the field sourced area of roadway is the project specific quantities – the assumed depth of the roadway is project independent since it is a universal standard for base depth that applies to all projects. With direct and indirect quantities and specific and independent sources I can use a multiture of variations to create varying degrees of quality.

Assigning the features of a quantity is the other half of quantification. At this time the features assignment is thought of as ‘cost coding.’ In this thesis, I present a broader use of features to include all features attached to a quantity. For example – I have two. The question is two of what. That is a request for a feature. I have two cubic yards. Followed by I have two cubic yards of concrete for the bridge abutment on the northbound bridge. The features of the context allow mapping the quantity to a concept and then reuse. The quantities are divided into indirect quantities and direct quantities. Indirects cannot be traced to a specific activity directs can. In theory all indirect can be associated to a direct. For example the support provided by the project manager for the tasks during a day could be recorded in fifteen minute interval then distributed. Pragmatically if the shared applied resources on the project were distributed it would far exceed the benefit. For this reason there is the indirect account. As technology improves in sensing, features assignment, and planning tools – the use of indirects should decrease with time until eventually there will be no indirects.

With the quantity and the features of that quantity the next step is assignment of the features to quantity. This topic has the least knowledge available and is therefore a tacit process. In the conclusion to the ethnographic observations I present my concluding thoughts. Because the process has no standard approach ther is not much in the literature review and the survey and interviews did not provide much. They key point I gained from the survey was the advice that management directs most miscodes. This opens the discussion to auditing - the last step in quantification. For me the auditing process on the ReTRAC was the most interesting aspect of quantification. For the most part the audit process is tacit and is not in the reference or research literature. My thoughts on the audit are also in the ethnographic observation conclusion.

The theory that project planning and control involves quantities and features that then a built into a sequence of activities that form the expectation is not universal. There is a counterview that there is no need to measure anything. The reasoning falls into two categories, these are A) the effort does not merit the return, and B) that is just now how field engineers do things. Based on the literature review and interviews the idea that the effort does not justify the benefit is supported by Stallard and by Motwani's (1995) survey. The 1995 survey predates the widespread introduction of computerized project planning but it is supported by Stallard's experience and that means it is possible the opinions in the Motwani survey are still valid. The larger projects seem to benefit from the use of the quantification process – where the returns no longer support the effort is unknown. Stallard's projects are for the most part in the $50M to $200M range: across that entire range he has reduced the degree of quantification. On the upper end in at $200M the interview with Ron showed that Stallard's cuts were unnecessary. Based on that the breaking point for where to begin reducing quantification is in the $150M range. Even Stallard uses the quantification process down to $50M and simply does not have project smaller than that. From this it seems that the Motwani survey covers smaller projects in the $1M to $20M range. In that range there are projects that do not use quantification. On the ReTRAC project the field engineers found as a rule of thumb that there should be one field engineer for every $8M in project scope. It is possible that a $20M dollar project staffed with three competent field supervisors can handle that project without a quantification system. A similar project with average supervisors would need the quantification. There is one more piece to the puzzle: nobody builds a schedule with quantities and production anyways – in the ten years I have been watching it has not changed.

That concludes my observations of the quantification process through literature, survey, interview, and ethnographic observation. In the next chapter I look at series of six topics where I took a closer look and expanded the discussion beyond my observations.

6 Selected Discussions

In the next sections is a cross analysis of the literature review, questionnaire survey, and the ethnographic observations. The results of both the literature review and the survey show that the methods I ethnographically observed on the ReTRAC project are representative of the methods used throughout the construction industry: the literature and survey are my validation for my ethnographic observations.

There are methods used by the ReTRAC field engineers that are not documented in publications nor could I find through the survey. Also, there are methods I found in the publications and survey that the ReTRAC field engineers did not use.

Where these three sources do not overlap, that is the focus of my discussion in this chapter. To show this I will cover six areas, these are (1) quantification effort, (2) indirect applied resources, (3) applying features to quantity, (4) sensor-based measurements, (5) quantification methods, (6) endogenous relationships, and (7) sources of errors and mistakes.

The sections in this chapter replicate earlier sections and for this reason there is some overlap as I need to reintroduce the topics here. In the previous sections I present these topics as neutral observations, in this chapter I take a more active role and provide my opinion and cross analyze between the separate handling of these topics in the literature, survey, and thhnographic sections of the previous chapter.

In the first section, I will cover the effort required for the typical quantification on a civil works project. With this foundation to establish the scope and applied resources I will next provide a common approach to reduce the complexity and effort. In the second section, I introduce the breakdown structure used to represent the features of measured quantities. The breakdown structure represents the features. The next section presents the application of the feature breakdown structure to the quantity. I then introduce an attempt I made on the ReTRAC project to reduce the effort needed to apply the breakdown structure to the quantity through the use of sensors. I then will review the complete methods list I found through literature, survey, and ethnography. I then follow-up with an approach I used on the ReTRAC to reduce the effort exerted on measuring quantities through the use of endogenous relationships. Last, I cover errors, mistakes, and bias in both measured quantities and the assignment of feature context in quantification.

6.1 Quantification Effort

Estimating the resources needed to collect a measurement at a specified level of detail, accuracy, repeatability, and completeness was not observed on the ReTRAC. Halpin (1985) and Saidi[240] (2002) believe there is a correlation between the resources needed to collect a field measurement and the method of collection, Table 60. This begs the question, are there methods inherently more resource intensive? Next is the modification of this question to address resource intensity depending on the conditions. Halpin and Saidi do not elaborate on what methods and what resources they are addressing, they only propose the correlation. Saidi continues with his dissertation to propose the use of hand-held computers, possibly indicating his conclusion to existing collection methods.

Table 60 Relation of method of measurement from low level of detail to high level of detail and measured units, measurement, resource intensity, and post processing. The potential utility of each method is defined, this is the reuse of the quantities for future uses. See Figure 40 for a list of methods.

Method Level of Detail	Unit of Measure	Report use	Measurement	Resource Intensity	Post-processing (level of detail)	Fieldcrew Utility
Discipline	milestone	billing	T/F	lowest	highest	none
Activity	start / finish	schedule	date	low	high	low
Resource	n/a	n/a	n/a	n/a	n/a	n/a
Component	percentage	takeoff (scope)	percent complete	medium	medium	medium
Operation	units dimension	budget	L/E/M/H/S	high	Low	high
Method	units dimension by resource[241]	estimate	specific L/E/M/H/S	highest	Low	highest

In the literature review, I found that Kiziltas (2006) reviewed six sources for resource intensity, accuracy, and sources of quality quantities (p142). Kiziltas found that field supervisors dedicate 30-50% of their time to measuring, recording, and analyzing field quantities (McCullouch, 1997). What type of supervisor, quantities, and project type was not documented nor the breakdown between measuring and analyzing. The overhead resources expended to monitor and record project progress is 2% of sitework total resources (NISTIR 6457, 2000) – I assume this is labor, material, and equipment combined as total resources. Knowing that 50% of the superintendent's time represents 2% of site resources, then the total supervisor labor is equivalent to 4% of sitework resources. This varies depending on the judgment and writing skills of the person collecting the quantities (Liu et al., 1995). As a reality check, in my experience, 4% is within the realm of reality though lower than the average of 10%. My conclusion is based on an analysis of historical overhead resources I completed while I was a

[240] Refer back to Field Observation, page 80.
[241] Improvement afforded by sensor-based methods.

project engineer at the Granite Construction Bay Area Branch[242] after completing my time at the ReTRAC project.

For a second reality check, I observed on the ReTRAC project that the percent of time the various people spend on tracking and working with quantities varies with the field engineer, consistent with the finding of Liu (1995). The time dedicated to collecting quantities varied from 1hr per week (2%) to 40 hours per week (70%), depending on the difficulty in obtaining measurements, often dependent on activity frequency, duration, and accessibility of the task. Post-processing involved spreadsheets, if the spreadsheets were already setup it took a couple hours each week to process the quantities; 1 hour per week collecting quantities plus 2 hours per week post processing for 3hour per week is 3hr/60hr = 5%; this is lower than the 30%to 50% found by Kiziltas (2006). The preparation time to setup a spreadsheets could take several weeks to format the user interface, define inputs and outputs, derive functions, program, and debug. Without the spreadsheets the time necessary for quantities is considerably more.

The overhead resources required for project quantification are between 1% and 7% of the total project resources – on average it should be 5%[243]. This is by definition the non-productive overhead. Further, as I have shown in the observations in the previous chapter, the quality of the replans produced by this effort is nearly unusable at the workface and even at the executive level provides a blurry picture. For the most part it appears to be a for-show effort that shows due diligence exercised for billing and in the event of a lawsuit.

Next, I present the representation of features and the abstraction of features to reduce the effort needed to assign features to a quantity.

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[242] Completed under the supervision of Dan Elshire, the former branch construction manager

[243] As a percentage of labor, supervisory labor is 20% to 50% of total labor and averages 30% - this seems like a large percentage but this contractor has a high foreman to worker ratio and much of that is related to how they categorize a foreman, most are working foreman and are simply responsible workers. Further, this contractor has does earthwork and so the number of operators on some projects may be low, a high percentage of these could be categorized as foremen.

6.2 Indirect Bulk and Temporary Applied Material

Now that I have presented the effort quantification requires I will now look at an approach used to reduce the effort. The basic principle is that some items on a project are more critical or informative than others. To reduce the quantification effort, a two or more tiered feature set allows representing quantities at multiple degrees of context.

Through the example of direct and indirect material, this section details the relation the chart of accounts breakdown structure has on defining how quantities are measured[244], post-processed, the reporting format, and re-use. One of the core divisions in representation is between the degree of features that are represented.

In a perfect world everything would be represented using an equal number of features. The practice I observed on the ReTRAC and I backed-up through the literature and interviews is that most projects use two feature set breakdown structures. One is abstracted and does not include enough features to relate a specific quantity to a specific finished product. The other does include the features to map a quantity to a specific product. These are called indirects and directs.

Many of the chart of accounts used in construction have a ‘warehouse’ branch that allows holding applied resources without the features that define the activity aspects since the work process has not begun and the material is simply stored. The warehouse is not necessarily a physical entity, it describes the concept.

Some chart of accounts have removed one or more of the applied resource distributions and therefore keep that applied resource as an indirect in the warehouse. The reason is to reduce the effort needed for quantification by reducing the degree of features necessary to define. On the ReTRAC the material was held as an indirect and during an informal discussion I found that Bechtel[245] hold equipment as an indirect. CII published the results of a questionnaire survey with a population of vertical construction general contractors. The discussion I provide here, while form a different methodology – parallels and is consistent with the CII findings[246].

In a perfect world, indirects are a temporary holding warehouse – when they are used as the end-all holding account then that is an indicator of an open problem to solve.

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[244] Geoffrey Bowker and Susan Star “Sorting things out: Classification and its consequences” The MIT Press, Cambridge Massechusetts, 1999.

[245] Discussion with Guy Skillett, Bechtel project engineer – August 4th 2015

[246] Jaselskis, E., Becker, T., El-Gafy, M., Du, J., Liu, L., and Salanki, P. “Improving Project Performance by Estimating, Controlling, and Managing Indirect Construction Costs,” Construction Industry Institute (CII) Research Report 282-11, April 2003. https://www.construction-institute.org/scriptcontent/rts2.cfm?section=res&RT=282

For example, representing permanent and temporary material is a critical component of the quantities and there are several methods of resolving this issue. The field engineers tracked the all the materials including permanent materials on the ReTRAC project as an *undistributed job* quantity, an accounting term for indirects. Undistributed job accounts are in theory those items that are not associated directly with an activity.

On the ReTRAC project, the undistributed permanent material accounts were associated with one or several activities. These implicit unmapped associations resulted in problems with assigning materials to the activities so to make an analysis (compare and contrast to historical records or reuse for future estimates) of the bill of materials and resources needed for the operation. During the project, several discussions addressed this issue and several potential solutions were discussed based on practices at other companies and perceived logical functions.

Similar to the permanent material and with the same proposed solution, the field crews reuse the same temporary materials for multiple operations and the same material is repeatedly counted and reported as a quantity for each use, leaving no record of the quantity purchased originally. This is an issue because if there is no record of the temporary material purchased then a portion of the project record is missing. Therefore, without this knowledge, estimators must make assumptions when forecasting future activities or during analysis of past operations. For example, purchased formwork - as opposed to pre-owned formwork - if tracked as a distributed material, then measured for the operation *form walls*, will result in a quantity at completion of the total square feet of contact area (SFCA) of the walls. The field engineer therefore will capture the cost of the form material within the wall forming operation. The originally purchased square footage is lost and so the formwork material cost per unit is unknown; this is a problem because the field engineers use the material unit cost to forecast future purchase cost or salvage value.

The solution I observed on the ReTRAC project created a problem for reuse of the project quantities. The temporary material cost and quantities were held in an indirect account and a separate ledger was maintained in the field engineers’ memories of the distribution to direct operations; sometimes for several years. During the project the engineers responsible for that scope of activity knew the relationships between direct and indirect accounts – so there was not a problem. The field engineers added the material cost into the forecast from the secondary spreadsheet. The problem arose at the project completion. On the project there was a spreadsheet with the ledgers as recited by the field engineers. The office engineer created a logical assembly to distribute to cover for gaps and included it as part of a technical report draft called the Project Final Report (PFR). A short aside on the PFR: In theory, the field engineers under the project engineer's guidance produce the project final report for each large project. There were no Granite HCD project reports for the previous ten years,[247] and there was not a report for each project. It was clear that if the field engineers had completed the PFR we would have been the exception to the rule. Back to the spreadsheets: The spreadsheet documented the associations between direct and indirect accounts, though the field engineers did not know the distribution percentages: they relied on intuition. Without a record of the connection between the indirect material and direct activity accounts, recreating these links from the remaining field engineers, several years after the fact, by someone unfamiliar with the specific activity, resulted in what may or may not have been an arbitrary *a-priori* distribution.

As quantities change for the direct accounts forecasting cost to completion based on quantities and unit cost needs to vary and is a reason why it is important to put material in the direct costs and not carry material in overhead (Teicholz Interview).

The question of direct and indirect was raised by Ron on the ReTRAC project – he had seen materials accounted for using the indirect warehouse and direct activity at Atkinson – this was Paul Teicholz's method. At Granite Ron saw the material grouped as indirects across the board – this was Bob Stallard's method. The question is why the difference. By the ReTRAC project the knowledge of charging the material from indirect warehouse accounts to direct activities had been lost. The field engineers compared and contrasted but could not understand why Granite's accounts did not accommodate the direct material. This rendered the material accounts useless.

The ReTRAC planning system still allowed for a material production quantity but this was an abstracted quantity that did not have a matching material applied resource.

The questions I have:

- Why on the ReTRAC there is no applied material resource in direct activities?
- One of the relationships I would like to understand is the role of indirect and direct materials. Where is the line between direct and indirect?
- Formwork lumber is purchased by the project but is consumed by numerous concrete activities. Which activities reflect the use? How is the material resource applied to those activities?

[247] This is a strong argument for collaboration with research groups such as CIFE who provide researchers as interns or junior field engineers and in return as part of research provide documentation oversight and produce the final technical reports [PM4D citation]; similar to this document - though with pervious literature to depart from – in a reduced from.

I have eight independent discussions of the indirect and direct quantity issue:

- The second Construction Project Management Special Cost Accounting Problem example (CPM 4th, Ch10.23, 2000),
- Bartholomew's Heavy Civil Estimating book
- American Association of Cost Engineering (AACE) 20R-98, 2003
- discussed by Stallard (p167) during his interview
- discussed by Dukeshier (p167) during his interview
- discussed by Goodson
- discussed by Teicholz (p163) during his interview
- my ethnographic experience

As part of this study I distributed a questionnaire survey (p159) – the survey missed representation of material as a direct or indirect in both the pre-survey and the questionnaire. My literature review (p88) found a few texts that address indirect and direct but the topic was presented flatly without giving the why it was done that way. My most prominent sources are my ethnography (p196) and interviews (p167).

As a field engineer, I tracked the quantities for the earthwork discipline. The earthwork scope during that project timeframe included 400 indirect accounts and 120 direct activities. These counts are prior to adding the applied resource suffix – the direct accounts on average had six applied resources in addition to the production activity and the indirect accounts had one applied resource. With the applied resource suffix, my earthwork scope was represented by 840 direct applied resource activities and 400 indirect accounts. The direct activities I planned, supported, and monitored totals to $10 million, the indirect accounts were less. The project engineer divided the project quantities into indirect and direct. From the survey interviews, I now know that the indirect quantity is a warehouse quantity – at the time of the ethnography this distinction was not fully understood by anyone on the project.

On the ReTRAC project, the managers used four practices to broadly reduce the effort needed for quantification: these solutions created numerous problems with accounting for the use of resources.

- First, they carried the material applied resource as an indirect.
- Second, they dismissed associating indirect applied resources with direct activities.
- Third, they had the field engineers code actual equipment cost directly to the activity. This meant there was no record of the equipment hours used on each activity.
- Fourth, they provided a weekly series of stakeholder meetings to negotiate solutions to exceptions the planning system could not accommodate – this was the Goodson system

On the ReTRAC project, temporary material, permanent material, cranes, and overhead supplies were tracked as indirects: I observed that removed material and modified material was tracked as a direct quantity. While the modified material was monitored as a direct material, it was given a separate ‘quarry’ activity division and then treated like an indirect material. The earthwork field engineer had the trench spoils hauled to an on-site stockpile where a subcontractor processed the material to remove cobbles over 3” (contained up to 3’ boulders), they then hauled the material back as backfill for the structural retaining walls. The material in this case was not identified as an applied resource material, it was a production quantity.

There are features common to indirect quantities such as consistent values, low risk to project success, and can be tracked on a long interval such as monthly or quarterly. For example, the indirect non-material quantities such as overhead labor, equipment, heavy equipment hour meters, project truck odometers, and cell phone count; the field engineers tracked these on a monthly basis. Presumably, the project engineer specified the monthly interval due to the consistency of the quantities.

On the ReTRAC, the Project Manager (Ron) could see problems with applying material quantities to direct accounts. Material that will be used by one activity is purchased and the quantity applied to that activity – bypassing the warehouse indirect account. Later, the same material such as forms are reused and each use is recoded as a quantity, so there is no record of the original quantity. He then saw the counter problem: If the material is applied as an indirect, there is no record of how much input material was used by an activity – only the production output.

The solutions I observed – they apply to any of the applied resources and in these examples applies to material and equipment:

- Indirect: carry as an indirect (method used at Granite HCD)
- Direct
  - Direct: When applied resource is procured charge it directly to the activity that used it – the problem is if the purchase was for more than one activity or will be reused on subsequent activities.
  - Distribution: Apply applied resource to activities using methods such as percentage, level of effort, or cost ratio. There are problems with this split. First, individual estimators inconsistently group items as an indirect or direct. Second, the estimators estimate the indirect items after the direct items are finished.
- Warehouse:
  - The answer from both Teicholz and the CPM (2000) is to purchase bulk material for large projects – and account for the material purchase in a *warehouse* or *clearing* indirect account. Then, as the material is used, sell to the direct activity. Pragmatically, Stallard found there is an insufficient benefit from knowing the material quantity and cost for each direct activity: all material can be an indirect.
  - The problem with traditional warehousing is that once the project is done, there is no record of the original material purpose – this was relayed by Ron. For example temporary material, each time the material is used the quantity of is recoded with the direct activity, if the material is used five times than the sum of direct activities material will be five times the original purchase – a single indirect account resolves this problem. The counter problem with maintaining one indirect account – there is no record of what was used for each activity. A solution is to redundantly maintain the applied resource in the distributed activity and maintain the sum in an undistributed account.
- Direct Asset: Assign an asset number and rent (not observed or found used) to the direct activity to cover the applied resource cost with the apportioned effort method as the product of a predefined rental rate and a measurable unit, for example operating hours or quantity of material worked (Bartholomew, 2000). The rent solution is the most complex and requires the field crews to record their use.

To investigate the practices on the ReTRAC I interviewed the designers of the constituent parts of the ReTRAC system, these are Stallard, Goodson, and Teicholz. The Stallard planner is based in pragmatics. This means that Stallard has evaluated the benefit of the Teicholz and Goodson systems then retained those aspects that are providing a return on the effort. For the most part the Goodson system is used – this system fills the gaps left by exceptions in the Teicholz planner theory. The Stallard system replicates most of the Teicholz system with the exception of the applied material. Stallard maintains the indirect accounting of the warehouse but does not record the handoff of material from the warehouse to the activity. Stallard found the benefit of A) knowing the quantity and cost of material on each activity and B) the calculation of cost to completion including material cost, as insufficient to justify the effort.

Stallard makes some core arguments for his pragmatics – I have to agree with Stallard since I saw these issues first hand on the ReTRAC. First, Stallard saw an inverse relation between the level of detail in the quantification plan and the accuracy of those quantities. The reason is the highly detailed quantities - while in theory good - was pragmatically a tedious system to maintain and the field engineers do not have the patience of accountants, so they simply start entering dummy numbers to the system that they think will pass audit checks. The planner becomes a huge gamed system.

Backing up Stallard: In the survey there are indications that bias takes the form of everything from taking a shortcut with quantities and reporting something easy though incorrect, to purposefully misrepresentation for a financial gain. This echoes the findings by Saidi (20002) and Kiziltas (2006). Bias in reporting can mean quantities that are misrepresented and/or misrepresenting the features of those quantities. Several senior administrators from well respected companies - though anonymous - indicated in their questionnaire that bias in reporting is usually directed with the purpose of fraudulently obtaining a greater financial return than otherwise possible. Often this was accomplished by misrepresenting the cost code and therefore misrepresenting the context of the quantity. For this reason, cost codes are an important focus of a construction audit.

I agree with Stallard that with the current theories the material is overly tedious to include as a direct applied resource. Stallard's planner allows the field engineers buy-in – Stallard purposefully leaves out the lower breakdown structure levels and lets the field engineers fill in this detail throughout the project as needed to reach measurable sources of quantities.

As a solution, the project engineer has several options.

If the project engineer categorizes the temporary materials as an indirect material then the field engineers can capture the cost in this account. The field engineers can then recover the cost through a rent fee – estimated by dividing initial cost and maintenance cost by expected use, therefore zeroing the account – charged to the direct activity operations therefore capturing the distribution of use. This is similar to the process of capturing equipment used by mutiple operations; a core benefit is that the field engineers apply the maintenance cost to the equipment rather than an unlucky operation. The downside is that the zeroing of the indirect account is dependent on the field engineers' degree of accuracy in forecasting expected use, maintenance cost, and trusting that the responsible field engineer will not create a 'sandbagging' account to hide losses. The process of renting the material to operations adds an additional level of detail to the records and allows in-depth analysis offsetting the added cost of documentation. Renting those materials that will be used repeatedly allows for an indirect account to record the initial cost of the material as well as use of that material on a distribution of direct accounts. If the project team would have the patience to apply the quantity of use and apply the cost to the material asset account and charge rent to the activity is probably low. With improved electronic monitoring and more intelligent enterprise cost accounting systems it might work. The argument successfully used on the ReTRAC project against using ‘rent’ distributions is as follows: Actual cost will differ from the expected cost. But the field engineer has already distributed the cost through a rent. Therefore, the cost associated to each account for a distributed cost will be wrong. The mitigation to this argument is to distribute cost through a rent and then as actual costs are found, adjust the rent distribution to reflect the actuals. In this way, the rent is only a temporary placeholder that should be close to actual and therefore smooths the cost curve. For a simplified example, a compaction roller has a maintenance and repair cost of $400 per month, if it has no loan payment then this is the rent. After ten months the compactor account has accrued $4,000 in the maintenance account but the compactor did not need repairs and the maintenance has cost only $400 during that time. There is a $3,600 surplus, most equipment departments will keep this and pay themselves a bonus. On the ReTRAC they associated the $400 directly to the activity using the roller when it was maintained. The alternative is to return the $3,600 and distribute it equally to the accounts that used the roller. For reuse of the quantities, this provides a more exact record of how hard the activity is on the equipment.

The planners given by Goodson, Teicholz, and Stallard, combined into a hybrid system provides for a robust and pragmatic planner. The indirect subaccount modification Ron identified is the missing component.

For the indirect accounts, there needs to be an additional level of detail showing the distribution from indirect to direct accounts – and probably some breakdown in purpose of distribution, maybe by material types: permanent (concrete), temporary (forms), and modification (lime). I need to see the distribution of the material at a sub-distribution level for the indirect accounts with sub accounts for sources of inputs and the outputs. For example, purchases from material suppliers (or purchased from another project) versus material returned from other activities are two separate inputs. For outputs, each use of the material is a unique line item.

With advances in automation the inclusion of materials as a direct applied resource should be feasible at a reduced effort. For the direct accounts – the tedious task of quantification and assigning features will be automated with sensors and feature assignment algorithms. The technology for automated sensing is not far off – the use of RFID tags is becoming common. These sensing technologies will remove the quantification task and leaves the automated features assignment. Again, sensing will resolve some aspects of features assignment and the remaining aspects will be resolved through model-based features assignment algorithms.

The use of indirects should decrease with time until eventually there will be no indirects.

The project engineer can define the specific method of representing the project material and how the field engineers will distribute the materials’ quantities and costs to the direct activity accounts, but it is not certain that the process will be free of errors or mistakes.

Now that I have addressed the core approach to slimming the project quantities effort with two breakdown structures using differing abstractions of activity and the related concerns, I will next present the relation of context features to the quantities.

6.3 Applying the Context Features

As suggested in the AACE review (p409), I have found that encoding the context features to create specific accounts is a useful tool to not only integrate field to planner quantities but also to integrate scope, time, and cost, as scope-time, scope-cost, and time-cost (Peterson & Fischer, 2009a). The encoding topic does not stop at just the features but also the accuracy - The ReTRAC project team used significant figure rounding in the quantity to represent the accuracy.

6.3.1 Scope of Miscoding

On the ReTRAC project under the trench excavation activity there are applied resource feature sets for labor support, excavation equipment, haul trucks, and supervision. These categories are intended to hold all the resources applied to the excavation activities (with the exception of material since ReTRAC held those as indirects). The problem is the as-built record represents that the laborers consumed 250,000 gallons of diesel fuel – presumably they drank this during work instead of water and eating lunch.

This example miscode likely occurred due to a perceived lack of benefit to the project (by project staff) from reporting diesel consumption at an equipment level of detail rather than the project level of detail, Table 61. A weekly task on the project is that quantities and cost in the enterprise resource planning system (ERP) suspected of being miscoded, or applied to the wrong account are investigated and verified. If the quantity or cost is found to be applied to the wrong account then a Job Cost Adjustment (JCA) is prepared.

Table 61 In this example miscode, the project team was tasked with figuring out after the fact what combination of codes were short 250,000 gallons of diesel fuel. An effect of this error is faulty scheduled resource allocation for the remainder of this project and the next project baseline. The values are changed to protect company estimating data.

Context Description	Quantity BCY	Charge		var.	CY/MH		var.
		budgeted	actual 1-year		planned	actual	
Excavation Support	92,000	$150,000	$700,000	+366%	20.0	17.0	-15%

The following three examples provide a potential effect of miscodes on project scope and schedule, and how this could affect the owner or contractor, subcontractors, and regulatory agencies, therefore indicating why they should care:

- Change Order quantities misplaced therefore resulting in an over/under record of scope, time, and/or cost, especially in *time and material* (T&M) invoicing.
- Billings quantities misplaced resulting in over/under and therefore the owner incorrectly billed. Potentially resulting in a loss of time value of money or the contractor being incorrectly paid, possibly resulting in contractor solvency issues.
- Quantity and cost miscode results in a forecast to completion error, therefore resulting in misappropriated resources and therefore an opportunity cost.

For an idea of what sort of miscoding occurs on a project, the following is a small sample analysis of job cost adjustments (JCA), Figure 53, as I participated in the process on the ReTRAC project. I use percentages to protect company estimating data. Coding was from a predefined chart of accounts by individual field engineers based on their own methods of associating features. Each week a cost meeting was held with a manager (project engineer) to review the weeks' quantities (including cost as a quantity) and find errors. The project manager and a division cost analyst then reviewed the unit cost and cost on a quarterly basis looking for obvious inconsistencies. For example local concrete was $65/CY, the cost report had $75/CY, indicating the quantity reported was low or the cost applied to the account was high, requiring further investigation and correction.

For this project the project scope is represented by a contract value at completion of $190M (US2005). The maximum man-hours for one month are 45,000. This project was recorded using 1,200 unique feature sets; six unique feature sets represent the cost type feature - each have two feature sub-types - and no location feature breakdown. Each cost code averaged three cost types, resulting in 3,600 individual cost accounts. If location breakdown was added, then the thirteen project locations, three sublocations (elevation zones) and two work zones equals 168 locations. The three sublocations are not certain to be used and half the cost codes are indirect so would not be assigned a location feature. The resulting permutations results in 40,000 cost codes, including the 1,500 indirect cost accounts. This project used a lump-sum contract with the contractor carrying the risk of cost over-runs; the significance of these issues is not known for unit cost, time and material, and cost plus contracts.

Taking no specific months' job cost adjustments, I randomly selected one several months past the projects maximum man-hour recording. For this four-week period the project billing is a third of the project average and the man-hours are 40% of the maximum but are average for the entire project, indicating material costs are low, consistent with a project winding down. The project duration is 1,300 days, so this review covers 2.5% of the project time. The project population sample, that is, billings, sample size is one-third to one-fourth of what would be expected to present results that are scientific: twelve weeks of Job Cost Adjustments would provide this population. The confidence interval in this sample at a 95% confidence level is 40%. The total number of coded items for the period is not available so the miscode rate is not available.

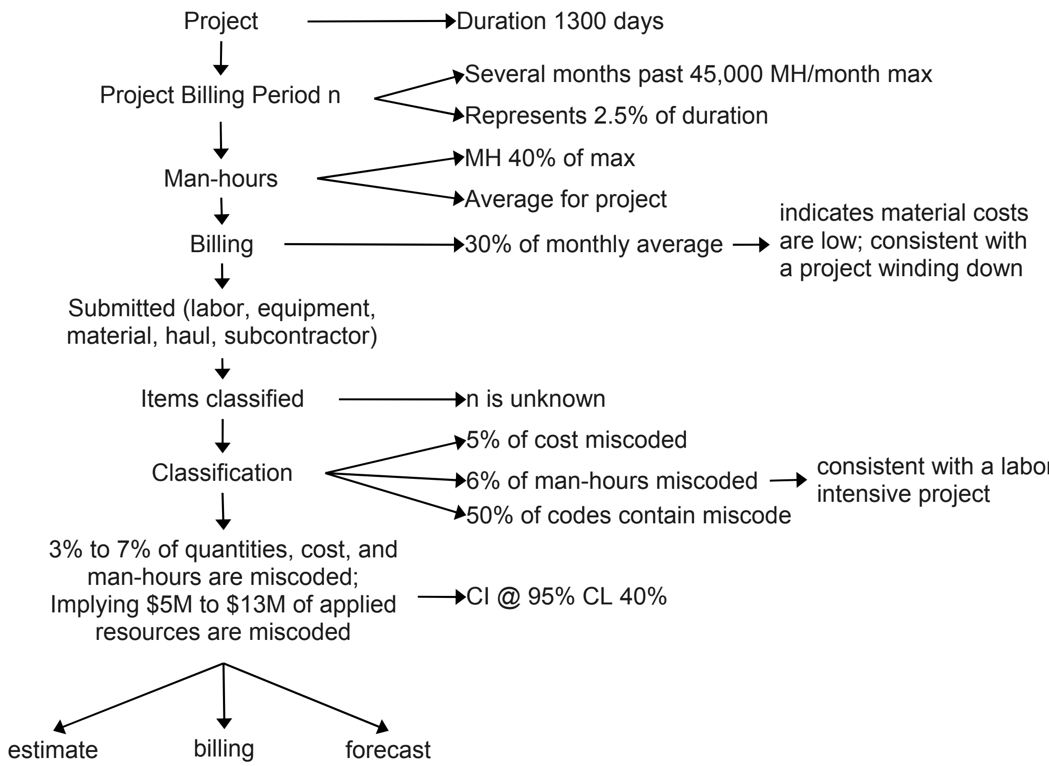

Figure 53 An analysis of job cost adjustments history on the observed project provides insight into the scope of miscodes for a reporting period. A small sample comparison of the reported quantities and subsequent correction for the reporting period. This graphical representation illustrates the properties of the quantities set sample.

Of the codes - labor/equipment/material/haul/sub - submitted, 5% were later determined to be miscodes. This represents 6% of the sample months man-hours, consistent with a labor intensive project. Of the individual codes submitted for the month, half were later found during audit to contain miscoded cost. This is consistent with the human errors at a magnitude of 10x of the minimum expected, *Human Error* on page 341. Miscodes represent 3% to 7% of job cost and man-hours; it can be concluded that from $5M to $13M of the project cost is miscoded. Similarly, project forecast estimating for this project and subsequent projects could be affected 3% to 7% by miscoding. Project billing and subcontractor billings are also possibly over or under billed. For a comparison of expectations, a CIFE 2015 measurable goal is a 2% actual cost variance from the project estimate (CIFE Mission).

The rework to correct miscodes is 200% of the work it originally took to code. The added work is due to double entry accounting[248] for each cost type when making a correction, whereas original entries are a single entry. Miscodes contributed to specific cost forecast variances that affected decision-making and resulted in overages and underage, and if reused as a historical library for future estimating gave similar results. Similar to cost forecasts, miscoding affects the degree of schedule update accuracy and consistency. A schedule that does not consistently represent the real events within a degree of accuracy can lead to recurrent accidents (Belke, 1998; Leveson, 2003; Mitropoulos et al., 2005). These appear resource related and due to either their modification of productivity that should result in a reduced expectation of production or are the result of the failure to increase resources to meet these expectations:

- awareness of surrounding
- fatigue
- environment conditions
- rushing
- misequipped for work task

} Appears resource related

6.3.2 Integrated Coding Process

On the ReTRAC project, I used the following process for coding from plans and schedule. This process allowed me to reduce the effort I exerted on coding – intuitively by half. The tradeoff I made is in the quality of my coding – I relied on the schedule and plans with the assumption they were correct. Further, my perception of the plans and schedule in relation to the activity feedback I coded controlled the quality of coding meaning that misperception on my part resulted in miscodes.

[248] An entry to back out the charge by adding a second equal but negative entry and then a new entry with the correct code.

Find the timestamp for when the observation or measurement was completed, if there is not a timestamp then make an educated estimate knowing it must be prior to the present.

1. Observed features or make an educated estimate
   - o Look for a location and sublocation
   - o Identify the project
   - o Identify the location
   - o Identify sublocation
   - o Identify grade or elevation
   - o Identify workzone
2. Look at the project schedule: default is chart of accounts or fragnet: Identify what activity and operation is expected in that location at that time
3. Record the code
4. Checks:
   - o Look at the plans, verify that a similar component is on the plan at that location
   - o Check that the observable features are consistent for that code; if not sure pick the closest match.
   - o Discipline – timecard union payscale
   - o Resource – temp material
   - o Activity – *
   - o Method – look at equipment to identify
5. Apply the code
6. Audit to verify the labor, equipment, material, and haul quantities, progress, and cost agree

6.3.3 Summary

Applying the feature context to a quantity is an important aspect of the quality of the quantification process. Without the ability to represent the features correctly then the quantity is useless or worse corrupts the feedback quantities. In this section, I present the scope of miscoding on the ReTRAC project and the process I used to apply context features with less effort. Despite the quantitfication quality control process on the ReTRAC there were sufficient miscodes to affect the quality of the project forecasting - though due to the non-integrated nature of this forecasting the miscodes had a limited impact. In the next section, I will present an experiment on the ReTRAC to reduce the effort needed to apply context features. The experiment relied on the use of laminated cards with a barcode that represented the project.

6.4 Assign Context Feature by Sensor

There are changes in the works for the construction industry. The technology revolution is making inroads and I have seen some technology out in the field. In-line with the innovation theory taught by Professor Tatum, the ReTRAC project had the roles necessary for innovation and the field engineers tried innovating during the project – aspects of that is throughout this thesis, Table 62. On the ReTRAC project, one of the repetitive operations was hauling demolished material to the regional waste management facility; several trucks a day to several a week were loaded-out. The dump fee for each truck was calculated by a measured quantity with a unit of measure of load; the minimum unit was one and was rounded to the next load – 18 cubic yards. For this reason, the volume of material disposed was not known. The hauls were sometimes partial loads and the material was often a mixed load of concrete rubble, asphalt, and aggregate sub-grade. Behind one casino it included a large cache of old poker chips long ago used as subgrade when the sidewalk was placed.

At the end of each monthly billing cycle an invoice with the combined charges for the project and a local company branch – the waste facility did not differentiate between the two – was mailed to the project office. A sublist of charges for the project was then denoted by making a pencil mark next to each charge. The field engineer verified these charges by comparison of the ticket numbers of dump tickets given to the haul truck Teamster drivers at the waste management facility - submitted to the field supervisors at the end of each day - and then submitted to the field engineer responsible for that specific operation. The portion of the invoice incurred by the project was paid and the remaining invoice items returned to the local branch for their payment. Although the drivers were a mix of company, subcontracted, and independent, they were greater than 99% consistent at returning the ticket to the earthwork foreman - a long standing practice that probably has existed for several generations of Teamster drivers - and there were no missing tickets.

Table 62 I adapted Tatum's (1989) innovation literature to the ReTRAC project. The names provided in the table are the individuals that appear to have fulfilled these roles on the ReTRAC.

Character		Role
Visionary	Dukeshier	Broad grasp of bigger conceptual issues driving change and change that present potential opportunities for a competitive advantage over the 5-year horizon.
Iconoclast	Forest	Driving force for change in pursuit of improvement independent of need for improvement or even not warranted, i.e., boat-rocking. Stereotypical of the phrase "there must be a better way"
Champion	Burk	The facilitator of resources to implement opportunities; a member of senior management. In addition to resources, facilitates buy-in from multiple stakeholders.
Gatekeeper	Galen	Knowledgeable in technology external to the organization and potential application.

6.4.1 Technology

In an effort to reduce the cycle time of the haul I formed a collaborative effort with the engineer at the waste management facility. The engineer at the waste facility had implemented a barcode scanning system that allowed the Teamster driver to bypass the ticket office and hence the queue of trucks waiting. He was having trouble finding customers to implement his new system: during one of our discussion I mentioned to him I was thinking about looking for technology to monitor haul trucks and he asked if I'd like to try the barcodes. The waste management engineer provided the project with a half-dozen laminated cards containing barcodes identifying them as ReTRAC project trucks. These cards were given to the driver in the morning by the earthwork foreman and then returned to the foreman at the end of the day. The barcode cards were tagged in the system as ReTRAC project and the invoice would then be subcategorized as project and branch loads. This removed the need to search the invoice for matching ticket numbers and then prorating the invoice between two cost centers.

6.4.2 Results

The system failed to work for two reasons. First, the drivers sometimes [10% of drivers] did not return the cards and if the haul vendor did not dispatch them to the project again the card was lost. As a solution to this anticipated issue, I asked for several more cards than needed expecting half to be lost and the other half to float around the drivers sufficiently to be available. The second and primary reason the system failed was the waste management office staff did not (or would not) understand the load sensing and recording system was integrated with the billing system. They printed out the barcode-derived record then with the manually ticketed loads keyed (data entry) each day's loads to the system, again resulting in a combined invoice for the project and local branch. The result was the same invoicing verification process as previously described.

6.4.3 Further Inquiry

After the system had obviously failed to produce the results expected – several invoicing cycles – I asked the earthwork foreman for feedback. He noted that the drivers did not see a benefit from the cards since they did not have a large queue at the facility and customarily stopped at the ticket booth. It is possible the drivers liked talking with the people at the booth and it was customary in the region for small talk between friends, acquaintances, and likely extended family[249]. They felt the cards were an unnecessary item to keep track of and something to misplace in their truck cab. The foreman also had similar misgivings with distributing cards in the morning and retrieving them in the evening since it was necessary to receive the card after

[249] After several weeks in the Reno region I learned to pick-up this custom so to allow getting anything done.

their last load. It is a practice to sign-out the truck at an anticipated later time and receive the invoice as the truck leaves so the truck does not need to return to the jobsite after their last haul to the dump to sign-out. The card was needed for the last haul and so did not allow this practice or likely the card was returned the next morning or lost.

A discussion with the waste management engineer produced a description of an office that was not accustomed to technology and resistant to change. His attempt at introducing an innovative technology was not able to overcome established office practices of data entry. He planned to next trouble-shoot the system and address the issues he perceived prevented an automated invoicing system – likely in the form of a workaround in the billing system that would bypass the office staff. Recent attempts to contact the waste management engineer for an update have been unsuccessful[250].

6.4.4 Discussion

The introduction of an innovative technology introduces a potentially destructive re-creative process change in an organization. I documented the resistance to this change and I suggest using Tatum's (1989) process of introducing innovation and structuring an organization to be adaptive for innovative methods. Tatum proposes establishing or encouraging character roles in the organization to help provide this organization structure, Table 62. An innovative organization with these roles will facilitate the adoption of innovative methods and technology. The ReTRAC had this organization and the roles and likely this explains the innovations the field engineers attempted.

New technology introduces new problems. What I have documented throughout this thesis is pragmatic – it is known to work – it is not necessarily the best practices it is the robust practices. The barcode cards are an example of technology that is not robust and failed the site test. Much of what I present in this thesis is anticipated to be replaced with technology – though this has been anticipated for the past ten years and most likely will be another ten years before it is replaced. Even once technology in sensors, algorithms, and communication have been implemented, this thesis is a guide for the processes those technologies must fulfill. Further, this thesis provides the fall back system that must be ready in the event the technology fails.

Next, I present the methods of quantifying as I found through literature, survey, and ethnography.

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[250] Bill Carr, bcarr@wm.com, (775) 342-0401, Lockwood Landfill, Reno Nevada.

6.5 Quantification Methods

The approach to capturing the quantity is not in any one source: I used my ethnographic experience validated as a confidence interval based on revenue, a literature review of reference and research publications validated through scope of search, a questionnaire survey I distributed to a broad cross section of project based industries, and several interviews I did with heavy civil industry professionals. The methods I observed on the ReTRAC project are represented in the broader study – I have found variances but nothing out of line with my experience. Through the literature review, I found quantification methods that were specifically banned by the ReTRAC project engineer. These methods relate with prorating quantities based on time or cost, and were deemed to produce results unacceptable for project monitoring on this project type. These methods were used on the ReTRAC anyways. The logic of why these were banned was not explained and therefore presents a gap in the knowledge I have presented. From the Stallard interview, his theory of precision variance, predicts these prorating methods will fail.

Controllable | Uncontrollable

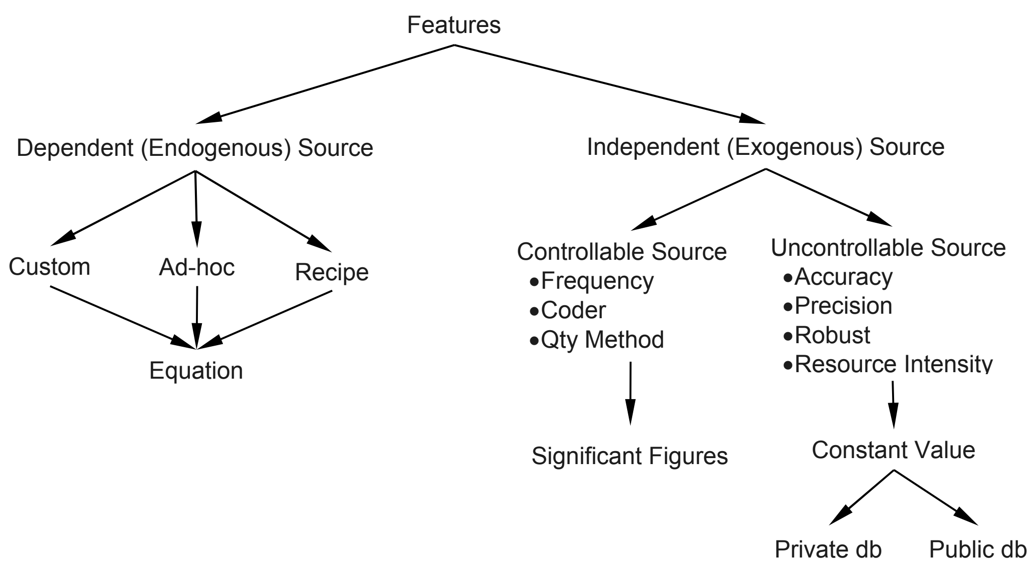

Figure 54 Attributed breakdown structure – controllable and uncontrollable sources as defined by Akinci and Fischer (1998). Controllable sources are those that the field engineer has access to and can control the method the quantity is measured. Uncontrollable sources are those the field engineer has no control over the measurement such as weather reports. The independent and dependent sources – for example y = mx+c has both, m, x, and c are independent and y is dependent on these.

As a laborer, prior to my employment as a field engineer, I observed that field supervisors and project engineers periodically queried field hands for the project progress and the expected project progress. The measurements they received were ad-hoc and based on my opinion.

Occasionally, if requested I measured and recorded length or count (similar to observations by Kiziltas, 2006), though not often enough to keep recording devices as part of my tool belt equipment. The field hand that actually measured the quantity could be field oversight personnel such as the superintendent or the foreman though they often reassigned the task to journeymen. These could be journeymen from the various building trades: on civil projects like the ReTRAC these were the[251] Operators, Cement Masons, Ironworkers, Carpenters, Teamster truck drivers, and Laborers - or their lowercase equivalents on non-union projects - or anyone on the jobsite able to recall the day's activities such as the apprentices.

The specific features that make each method suited to a specific scenario requires further investigation. The following four tables present my cumulative literature, survey, interview, and ethnography observation. The importance of these tables is they allow having the conversation on a project. As a field engineer because the methods I wanted to discuss were not in a textbook and I had simply reasoned them as logical was insufficient to allow for discussing their application. These tables provide the methods, the sources I found the method, and the features of the method.

[251] Capitalized as these are trade unions.

Table 63 Summary table of the methods presented in the literature sources and expanded to include methods observed on the ReTRAC project and the distinction between direct and indirect measurements.

Measurement Methods											
	Sources										
Method (listed by level of detail)	Stallard interview	PMBOK guideline	Saidi Dissertation	Kiziltas case study	Survey of methods	PM 10th ed. Systems	APM guideline	PM 6th ed. managerial	CPM Clough & Sears	Ethnographic ReTRAC	
page	88	401	133	142	143	402	404	150	388	238	n
Direct Measurement											
start / finish date		X			X	0/100					3
milestones		X	X		X	X	X				5
percent complete		X			X	X	X	subjective numeric rating	X	X	7
units complete	X		X	X	X			frequency count	X	X	7
Indirect Measurement											
a priori										BANNED	0
trust 2nd party										X	1
fixed-formula		X		calc							2
opinion | guess								verbal measure		X	2
equivalent units	X		X			X	X	indicators		X	6
level of effort						X	X		X	BANNED	3
cost formula			X			X				BANNED	2
apportioned effort						X	X			BANNED	2
neat-line takeoff										X	1

Table 64 Examples of features influencing the accuracy, repeatability, completeness, and effort intensity of quantification methods. The values of these metrics are unknown[252].

Example activity	Example method[253]	Example source(s)	Example measuring tool	Method Features: Latency (timely)	Completeness	Accuracy[254]	Precision	Source Quality	Level of Detail[255]	Frequency	Reusability	Rotation of Methods	Post Proc. Equation	Purpose: Cost Check	Activity Type	Effort
Place type II base	2nd party	delivery ticket	n/a	30sf/hr					M	1-day		A	sum values			1
	2nd party	invoice	n/a						L	1-month		B	check			1
F/P/S[256] Conc. Curb & Gutter	percent complete	sitewalk & plans	visual	300ft/hr					M	1-month		A	PC*QTO			1
	units complete	sitewalk	measuring wheel						H	1-month		B	none			1
	percent complete	schedule & timecards	n/a						L	1-month		C	duration/total duration			0
	opinion	field engineer	n/a						L	1-month		D	none			0
G/B/F[257]	percent complete	sitewalk & plans	visual	300ft/hr					M	2-week			PC*QTO			1
	unit complete	sitewalk	measuring wheel						H	2-week						
Roadway	unit complete	sitewalk	measuring wheel						H	1-month						
	percent complete	schedule & timecards							M	1-month			duration/total duration			
	level of effort	schedule & timecards							L	1-month						
	opinion	field engineer							L	1-month						
Excavate																
Backfill																
	unit complete	drawings	scale & color													
	2nd party	delivery tickets	count | weight													
	unit complete	sitewalk	physical count													
	[a priori]	estimate	n/a													
	[a priori]	schedule	n/a													
	0/100		finished T/F													
	milestone		finished T/F													
	percent complete	budget & cost report	calculation													
	equivalent units	endogenous formula	exogenous measure													
	cost formula	cost report	calculation													
	level of effort	schedule & timecards	n/a													
	apportioned effort	endogenous formula	exogenous measure													
	opinion	supervisor	n/a													

[252] These observations are recollected from memory several years after the fact.
[253] What work types are associated with each method.
[254] What accuracy is suitable for checking cost?
[255] The level of detail appears a function of method and frequency.
[256] F/P/S form, place, strip concrete forms
[257] G/B/F grade, base, finish roadway subgrade

Table 65 Features to decide on a method to monitor project progress

	Purpose Index*	Latency	Freq.	Reuse	Effort	Post Process	Level of Detail	Source Quality	Minimum Accuracy	Minimum Precision	Robust	Simple	Complete	Units	Quantity Magnitude
sig															
Method(s)															

*index value must be >= 1 to use[258]

Table 66 Summary table of the field quantities feedback sources I found in the literature and observed on the ReTRAC project. Some methods have a preference for sources and this table reflects this preference. The '*' denotes relationships I observed during my ReTRAC ethnography.

	Input Source																
Method (by level of detail)	sitewalk	time card (time log)	equipment meter | OBI	sensor-based	2nd party invoice	delivery ticket	field crew	engineer	meeting	drawings	schedule	estimate sheet	endogenous formula	cost report | budget	production report	project database	public database
Direct Measurement																	
start / finish date											X						
milestones	X	X			X	X	X	X			X						
percent complete	X	X	X	X	X	X	X	X	X	X	X			X			
units complete	X		X							X							
Indirect Measurement																	
a priori										*	X	X					
trust a 2nd party					X	X			X								
fixed-formula										X						*	*
opinion | guess							X	X	X								
equivalent units										X			X		*	*	*
level of effort											X						
cost formula														X	*	*	*
apportioned effort															*	*	*
neat-line takeoff										X							

I present the quantification methods I found in the literature and through ethnographic observations. Through the ethnography I found that some methods are in practice banned. Though I never saw anyone's employment terminated for their use I also never saw anyone

[258] See Attribute Value System http://en.wikipedia.org/wiki/Attribute-value_system

more than suspected to have used one of the banned methods. The banned methods are the statistical style methods. The problem with banning some methods is they are still used by the field engineers and without oversight or guidance. On the ReTRAC the field engineers tried to communicate the quality of the quantity through significant figures, the better the method the more significant figures.

A part of the quality of quantities is the source of the quantity. The literature near unanimously discourages the use of field supervisors as a source of quantities. On the ReTRAC this was a common practice and for some field engineers their sole source of quantities. While some methods of quantification were banned – the use of field supervisors as a source of quantities was not. The key importance of providing the methods of quantities is to provide a platform for the discussion of quantities.

On the ReTRAC I wanted to explore methods of quantification that required less effort but without documentation about the different methods the discussion was dismissed as undiscussable. From what I have found, the discussion about quantification methods should focus on the features of each method. For example the activity Form/Place/Strip Concrete Curb and Gutter. The quantity of both input and output quantitates can be be measured using a range of methods such as percent complete, units complete, and opinion. These methods can rely of different sources such as site walk, schedule, and the field engineer’s idea. For input quantities that have stakeholders interested in an accurate quantity then units measured by sitewalk is the method used on the ReTRAC. For example, payroll hours – the workers wanted to be payed correctly, so their hours of work was measured by a foreman that was physically there on the jobsite. The output quantity did not have a stakeholder as interested in the exact amount of curb and gutter forms so these could be measured using less accurate methods such as the field engineer’s opinion or guess. The decision on what method to use rests on the features of that method and the purpose of the quantity. A guess is quick but inaccurate while a sitewalk is time consuming and accurate.

As automation is usable for quantification then the selection of method through an algorithm will be useful. Automation will have a range of methods available and need to decide on which method to use in a given situation – knowing the features and weighting of these features towards a measured expected quality and the needs for quality allows for selecting a method.

Next, I will introduce the use of endogenous relationships to derive quantities. The endogenous relationship is an indirect method of quantification.

6.6 Endogenous Relationship Method: Indirect Monitoring and Post-Processing

After completing the ReTRAC and several change order extensions to the project, I reflected on the lessons I learned on the project, this led me to a lab experiment to test my ideas relating to the limitations of spreadsheet functions, macros, and collecting data through the internet. The benefit of these was clear to me as the keyboard was my limiting constraint, bypassing our only known method - keying data to the spreadsheet file - would remove a bottleneck (Peterson & Fischer, 2009b). In that investigation, what started as an experiment in macros became an investigation of quantities post-processing strategy, and then a driver for the need to expand programming integration in construction engineering education. Prior to these lab tests, while I was a field engineer an earlier idea was to automate in spreadsheet software simple but time-consuming field engineering calculations, logical decisions, and data lookup. These tasks were characterized as being repetitive, consistent for the project duration, and simple.

6.6.1 Case Study: Verification Process

There are repetitive tasks to which field engineers use discretion in allocating their scarce resources in an attempt to maximize their impact. One of these tasks is verifying invoices. In this process, field engineers check the invoices for unintentional and intentional over-billing by vendors. If an under-billing is discovered it is ethical to notify the vendor. Because this task was time-consuming, I observed a practice for field engineers - during training, an experienced field engineer specifically instructed me - to focus on the larger cost items as spot checks. The problem is the bulk of errors occur in small increments. Therefore, the larger errors represent a small portion of the total errors in the invoices and likely are also a focus of spot checks or added scrutiny by the vendors. Increasing labor resources to find the smaller and numerous errors cancels out gains in preventing over-billing.

6.6.2 Discussion: Programming Solution

Intuitively, invoice verification - similar to other repetitive tasks - could be automated using software programming. This could result in fewer endogenous tasks and allow for an emphasis on exogenous tasks[259] Figure 56 and Figure 45. Spreadsheet functions are simplified software programming methods that are predefined for functions – for example finding the sum or average - and can be combined to form more complex programs; this makes them suited for those without programming knowledge. Engineers utilized spreadsheets, as reviewed in

[259] Endogenous tasks are those consisting of calculating values within a system and exogenous tasks are those collecting measurements from outside a system.

Spreadsheets page 268, and their limited use[260] was gaining widespread acceptance on the project, Figure 55.

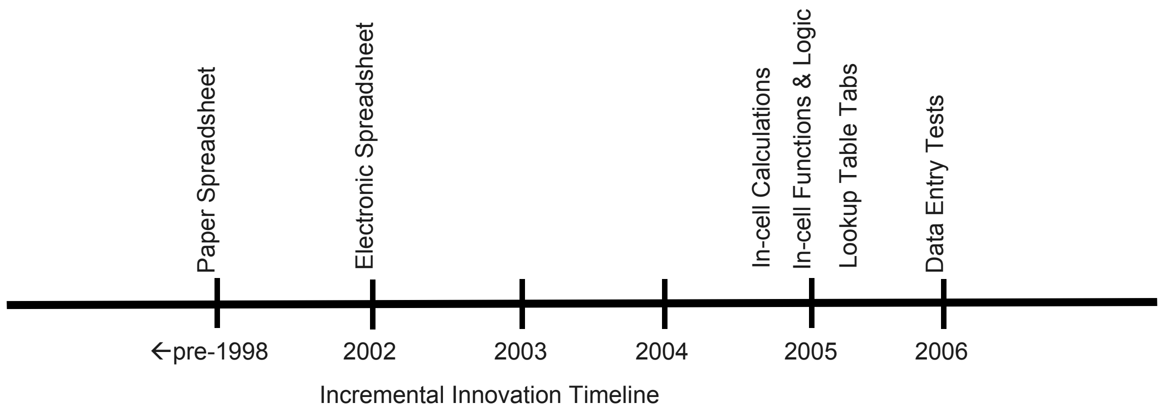

Figure 55 This time-line represents the ReTRAC project technology infiltration. Observations prior to 2005 are derived from informal conversations and review of project documents. There are few spreadsheets and - with exceptions - contain few cell references or equations, p268. Near the end of 2005 and into 2006 some processes had been automated.

For the most part field engineers are not programming literate; the Construction Engineering and Management (CEM) program at Stanford University does not require programming coursework (at the time of this thesis – as of 2015 they do) nor did my undergraduate program at California State University Chico[261]. From informal discussions with my graduate student peers I found that one or two of the 50 Stanford CEM students take courses in the computer science department. Spreadsheet functions are an entry step to programming languages such as *Java or C++* from hand calculations. On the ReTRAC project, during undergraduate studies and graduate studies, field engineers - both recent graduates and those with professional experience - did not use electronic functions. On the project, two of the field engineers used the electronic functions and one of the managers used in cell calculations; collaboration and sharing of knowledge within this small group helped advance the sophistication of the functions the field engineers built. The uses of macros were discussed but due to a lack of understanding what these were, no attempts were made to build a macro function. Without

[260] There were concerns with reliance on electronic programming due to perceived issues with robustness and transfer of knowledge.
[261] A summary review of coursework requirements indicates a minority of universities require programming coursework for undergraduate engineering degrees.

coursework, training, or time provided by managers[262] to learn this knowledge, there was not an opportunity to explore and test these tools on the ReTRAC project.

6.6.3 Baseline: Spreadsheet Analysis

For a spreadsheet analysis, I performed a search of the files in an archived subset of the project database. For a search, I simply opened a sample of filed to categorize the file type. Then I counted the files for type and repetition.

A sample of the ReTRAC database representing half the field engineers employed on the project contains 3,780 electronic spreadsheets (@1.5 GB). Of these 2,780 are duplicates in 30 batches of 30 to 200, due to archiving and instances of re-use. The duplicated formats are forms for the: 5-week lookahead schedule (later 5-week scheduling done with Primavera P3), monthly subcontractor payment, monthly billing, quarterly partnering meeting, and the job cost adjustment. The remaining 1,000 spreadsheets are duplicated from 2 to 10 times, averaging to an ad-hoc: high of 6, low of 3 and medium of 4.5 duplications. There are possibly 330 to 160 individual spreadsheets in the represented database and the entire project likely used twice this, possibly 440 unique spreadsheets.

For an indication of the spreadsheet complexity, I used the file size as a metric. If given more time to test for complexity I would have defined metrics and opened each spreadsheet type to measure the complexity. I assumed that the larger file size indicates a greater complexity: complexity being the number of cell referencing, lookup tables, equations, specialized tabs, and rows and columns of data. It is possible that a large file simply contains many rows of data. The few spreadsheet files that I opened and reviewed indicated to me that complexity correlates with file size.

The spreadsheets range in size from 14KB to four >30MB spreadsheet reports containing photos. There are eight spreadsheets between 3MB and 16MB dedicated to quantities tracking. With the exception of the several reports with photos, the spreadsheets greater then 3MB (90 each, 860MB total) are quantities tracking spreadsheets. The files between 1MB and 3MB (140 each, 225MB total) are a mix of quantities tracking, monthly report (contain photos) and design-phase timecard calculators. The files from 100KB to 1MB (1015 each, 310MB total) are a mix of forms for: monthly billing, subcontractor, and the partnering meeting. The spreadsheets <100KB (2,625 each, 130MB total) are a mix of job cost adjustment forms, quarterly forecasts, and the 5-week lookahead schedules. The smaller files between 20KB and

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[262] Requested spreadsheet programming training from project division human resource managers and was not granted.

100KB are calculators for specific cases, for example calculating tons of asphalt for a given area, density, and thickness.

Table 67 Example of a quantities tracking spreadsheet from the ReTRAC. The indented columns to the right are locations, the percent complete column to the left sums the percent complete for each location, the to-date value is then reported for the activity. This format is likely adapted from an older paper format that was photocopied and reused. The benefit of this format is that the field engineer can print then *walk the site* and update quantities. Notice the different significant figures in the takeoff column.

Description	Account	UM	Take-off	%	To-Date	Qty	Period Qty	%	3rd.- 4th.Lt	To-Date	%	2nd.- com. Rt	To-Date	%	Plaza - 4th. Rt	To-Date
Grade C&G	285101	LF	2,170	28%	609	0	609	85%	390	332	42%	450	190	25%	350	88
Backfill Curb	285102	LF	390	0%	0	0	0		390	0		0	0	0%	0	0
I/P/F C&G	285103	SF	22,220	5%	1,185	0	1,185	85%	1,170	995	42%	450	190	0%	7700	0
Grade SW	285201	SF	94,976	8%	7,459	0	7,459	85%	8,775	7,459	0%	1	0	0%	8050	0
Grade CW	285202	SF	1,095	0%	0	0	0	0%	0	0	0%	1	0	0%	263	0
I/P/F SW/CW	285204	SF	105,519	16%	17,399	3,667	13,732	85%	8,775	7,459	70%	9,450	6,615	40%	8313	3,325
Cross Str	430211	SY	0		0	0	0		0	0	0%	0	0		0	0
Park Lots	430241	SY	32,000	0%	0	0	0		0	0		0	0		0	0
Base Course	700421	SY	32,000	0%	0	0	0		0	0	0%	0	0		0	0
AC Pave	720130	TN	9,072	0%	0	0	0		0	0	0%	0	0		0	0
C&G 36"	285112	LF	2,170	24%	522	190	332	85%	390	332	42%	450	190		350	0
Med Curb	285113	LF	0		0	0	0		0	0		0	0	0%	0	0
Valley Gutter	285115	SF	0		0	0	0		0	0		0	0		0	0

At least three of the spreadsheets out of 400 used on the ReTRAC project migrated with engineers from other projects or companies; I found this by reviewing the files' owner attribute field. One was from Kiewit Pacific, a large heavy civil contractor. Only two spreadsheets collected from the project appear to have migrated from a previous project the company constructing the ReTRAC project constructed. One spreadsheet, the oldest, for daily cost calculations, appears to be from a regional operation and was not used on the ReTRAC project. This spreadsheet, while the oldest, contains functions, cell references, and a database lookup table. Four spreadsheets appear to predate the project, originating between 1998 and 2002, there are no spreadsheets older than 1998.

This seems like a low re-use rate for spreadsheets. Possibly this was one of the first projects to make widespread use of electronic files, Figure 55 page 324, indicating the electronic file has an innovative attribute. The spreadsheets likely had also originated from outside the project but I found no evidence of this during the review of project spreadsheets. The distribution in the creation date of the spreadsheets appears even across the project from 2002 to 2005. The spreadsheets are likely characteristic to the ReTRAC project due to special tracking requirements or other features of the project. The widespread use of electronic spreadsheets is not universal and some engineers calculated their weekly quantities on paper and pencil for even complicated items.

Two spreadsheets contained macro functions, these are the subcontractor payment form and a 3MB quantities tracking spreadsheet for the trench activities. The spreadsheets contained conditional logic and look-up tables. One spreadsheet used multiple nested logical statements and lookup tables to automate the field engineers post-processing tasks and made endogenous some of the factors previously obtained through data entry.

6.6.4 Define Task: Endogenous or Exogenous

A task can be categorized as either endogenous (within a system) or exogenous (outside a system), Figure 56 and Figure 57. The following are examples of each and the method utilized.

Endogenous formulas were used to calculate project quantities from measured exogenous quantities. Exogenous measured quantities can be either variable or constant, for example, haul truckload counts are variable each day, while the volumetric capacities of the trailers are constant.

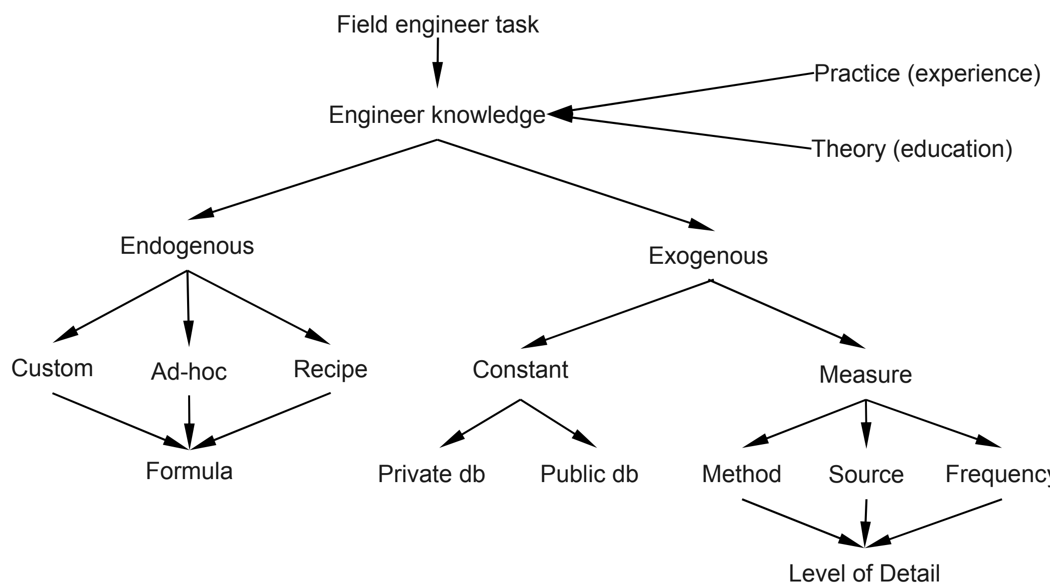


Figure 56 Initially several ReTRAC spreadsheets contained macros for simple functions, such as print and sum. The project team discussed writing additional macros to automate field engineer tasks but implementation was delayed due to project priorities. Field engineer knowledge was the actual roadblock to the application of macros; a lack of programming knowledge removed the macro tool as an option.

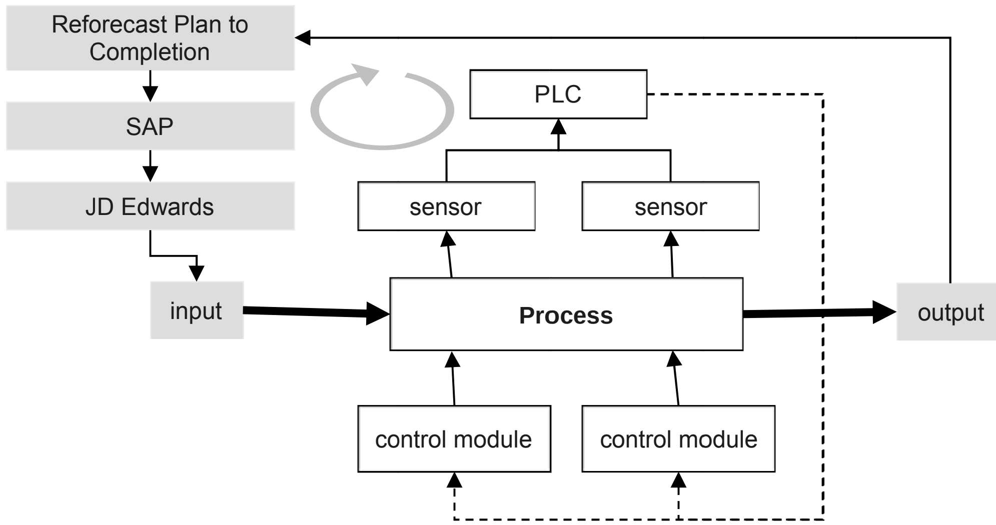


Figure 57 An example of an endogenous system with exogenous inputs. The Programmable Logic Controller (PLC) integrates a feedback loop that allows self-corrections for variations in production. The inputs to the process are resources and the output is the product. The construction activity should be viewed as a similar loop. Graphic from Peterson et al., 2009c.

On the ReTRAC project, an engineer with at least five years of experience determined the complicated non-repetitive tasks. I assume that this practice is based on the belief that from previous experience these engineers have developed knowledge of what has worked in past situations. Once the process has been developed, first and second year engineers act as data entry technicians with the assumed educational background to use critical thinking if necessary. Once the quantities are formatted into an electronic state the remaining analysis tasks such as changing unit of measure, applying assembly relationships, and calculating production variance are often repetitive.

A specific field task that was a nuisance on the ReTRAC project is the need to lookup fuel cost and then calculate a percentage surcharge to allow verifying haul subcontractor invoices. Due to fuel cost fluctuations, a surcharge was assessed to the hourly rate based on weekly fuel cost within a given region. The field engineer must calculate the surcharge every week prior to verifying invoices, or if the invoices have accumulated for several weeks, then a surcharge for each week must be calculated and applied. The automation of the surcharge lookup results in reduced potential for error and eliminates one task from an engineer's list of things to do each week. I observed that on the ReTRAC project - with several dozens of haul trucks operating - the invoice verification could require up to half my workweek, Table 68.

Table 68 Scope of haul production on the ReTRAC project; on average each day there were 20 distinct task-types done by six haul trucks. For reporting, the responsible field engineer aggregated the record into one or two operation codes.

Haul	Date	Max	Mean	Med.	Mode	Stdev
External vendor (subcontractor)	8/13/04	71 +17=88	12	10	2	8.7
Internal vendor (project trucks)	7/24/04	26 +11=37	8	8	6	4.2
distinct haul types per day by location-operation-material			20	18	8	
External vendor	8/13/04	36 +13 = 49	2	2	2	1.2
Internal vendor	11/10/04	34 +14 = 48	4	2	2	2.9
equipment or invoice count, i.e., haul trucks per day			6	4	4	

6.6.4.1 Setup of Variables

The weekly fuel cost is posted on a government website (Energy Information Administration) with cost broken down by region and fuel type. Each week it is necessary to retrieve the new fuel cost, calculate the week's surcharge, and update the invoice verification spreadsheet or if using manual calculations note the new rate on a piece of paper or rely on memory. Verification software is simply a spreadsheet replication of the subcontractors invoicing software[263]. Reported Teamster labor hours from the invoice are entered with deductions for lunch, mechanical breakdowns, and then additions for truck startup and commute driving time from where the truck is stored when not used. The trailer type is entered since each trailer combination has a differing cost rate. The load weight is entered since this may affect the rate. An under loaded truck is billed at a lower rate than a loaded truck. The importance of this is that under loading results in a faster cycle time[264], potentially used to hide a stop for lunch or mechanical breakdown and results in a faulty volume derived from load count.

6.6.4.2 Define Exogenous and Endogenous

The task of checking invoices is tedious and simplifying the process allows checking each invoice rather than conducting semi-random spot checks or acting from gut feelings. The exogenous variables are hours, adds, deducts, trailer type, load tonnage, load count, and surcharge, refer to Figure 45. From these exogenous variables, the field engineer can calculate the endogenous variables. The field engineer then compares cost with the invoice submitted; these should be equal to the penny, a variance requires an explanation. Each month a list of

[263] One subcontractor called into the project office to help explain changes they had made unannounced to their billing rates and was surprised to see their billing system reverse engineered in spreadsheet.

[264] The time to load a truck is a function of the number of loads placed in the truck by loading equipment, for example a front loader. Each cycle of the loader requires a minute and so shorting the load saves several minutes.

invoices with discrepancies was sent to the haul subcontractors. Using the spreadsheet with lookup tables and maximizing the use of endogenous calculations, for a small 40-week haul of 150,000 cubic yards, I found some months with $10,000 billed in error, an amount too small to perceive with spot checks or gut feeling, Table 70. Without screening, the project would have paid this cost.

The exogenous variables, except for surcharge and tax rate, are non-repeating. There are limitations to macros and what the current web data is configured to provide – even the functionality I present here is pragmatically outside the scope of macros. I wanted to also write a macro to search online for the local tax rate. The surcharge rate is the main variable that is exogenous and can be determined in a repetitive manner and being required at a regular subproject interval. Removing the surcharge task from the exogenous tasks as a macro function endogenous task was tested and published by Peterson and Fischer (2009b).

6.6.4.3 Endogenous Formulas

The exogenous and endogenous variables for the haul invoice verification were implemented in a spreadsheet. In this spreadsheet, each row represented a specific task and specific haul truck identified by equipment number or invoice number. To arrive at a task, the breakdown structure is as follows: there is a project location, a sub-location, an activity at the location, and a material transported, these features sums the activity context. For example, task *A* is a 10-wheeler, hauling aggregates for roadway base course to location *A*, sub-location North, for half a day. If the same truck then was loaded with soil for several loads to the same location, then this is a new task. During the course of a day, a truck can be involved in anywhere from one to a dozen tasks.

The columns in the spreadsheet contain each of the exogenous quantities and the related feature context and then progresses to endogenous data. The first column is date (feature), the second truck number (feature) and so on. The final columns are endogenous and so are calculated through recipe-formulas from the exogenous columns. Those exogenous columns that are constant values such as trailer capacity (feature) and unit cost are placed in a database tab within the same file. Through endogenous formulas, there is no longer the need to calculate each column using a hand calculator or the simple in-cell calculating ability of the spreadsheet. This seems strange to think the functions in software are not used but the older spreadsheets on this project contained individual calculations in each cell and the use of linked cells and lookup tables was not used by the field engineers.

6.6.5 Implementation Impact

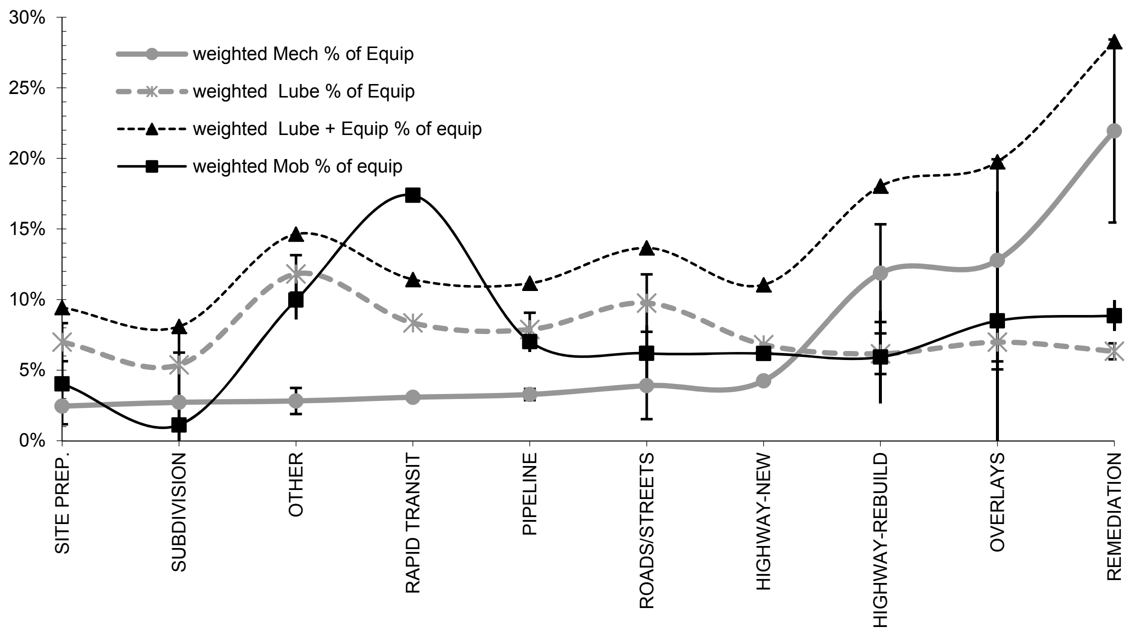
What sets the spreadsheet described above apart is the use of a database and recipe formulas. Rather than enter the data for each column as an exogenous value, leveraging constants and recipe-formulas reduces the exogenous values from 28 to 11. The reduced labor resources for data entry, re-work, and errors is obvious. Not as obvious, the improved application of project resources and the higher degree of project record accuracy that therefore allows a higher degree of project forecasting accuracy. A difficult task converted to an endogenous value was the equipment unit cost. Since each of nine vendors had two different rates for up to 15 trailer combinations, a simple lookup table was not sufficient for the resulting 270 specific rates. Two 2x2 matrixes were used with a lookup function to represent the two rate categories for the nine vendors' 15 trailer combinations. In pseudo code the equation is: if prevailing - labor union rate - then use table A else use table B, lookup vertical axis for trailer type then lookup horizontal axis for vendor, return cell value. As simple and obvious as this equation appears in this text, it was a revolutionary innovation in the field and caused the expected organizational issues associated with such an innovation. A fellow field engineer was so troubled by my use of spreadsheets that he made a plea to the project manager that I was somehow cheating and should not be allowed to use spreadsheets like that. Essentially, they wanted me to type it in and use a hand calculator like everyone else. For this reason, it is evident that possibly this knowledge should be a greater focus in both undergraduate training and profession retraining in companies continuing education programs.

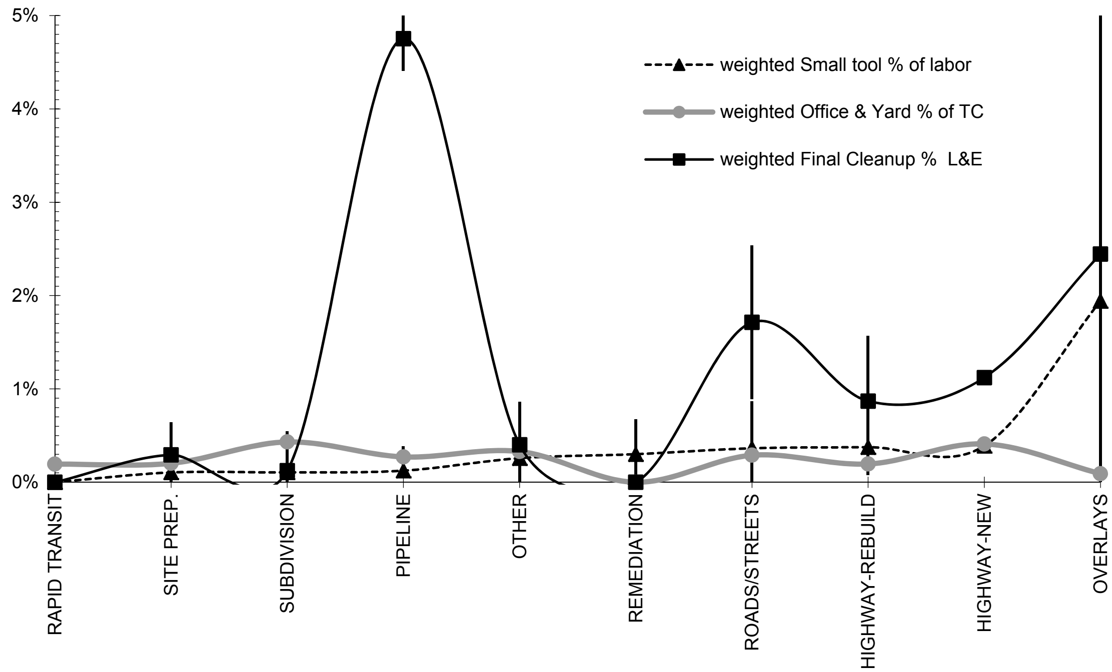
6.6.6 Suggestion: Ratios as Endogenous Values or Checks

I developed an indirect forecast approach at a local branch office. The estimators calculated the quantities as the product of an associated operation that is quantifiable and a ratio derived from historical data analysis. The data analysis produced functions that would have allowed field engineers to extrapolate quantities-to-date based on measured metrics – this is an apportioned effort type method.

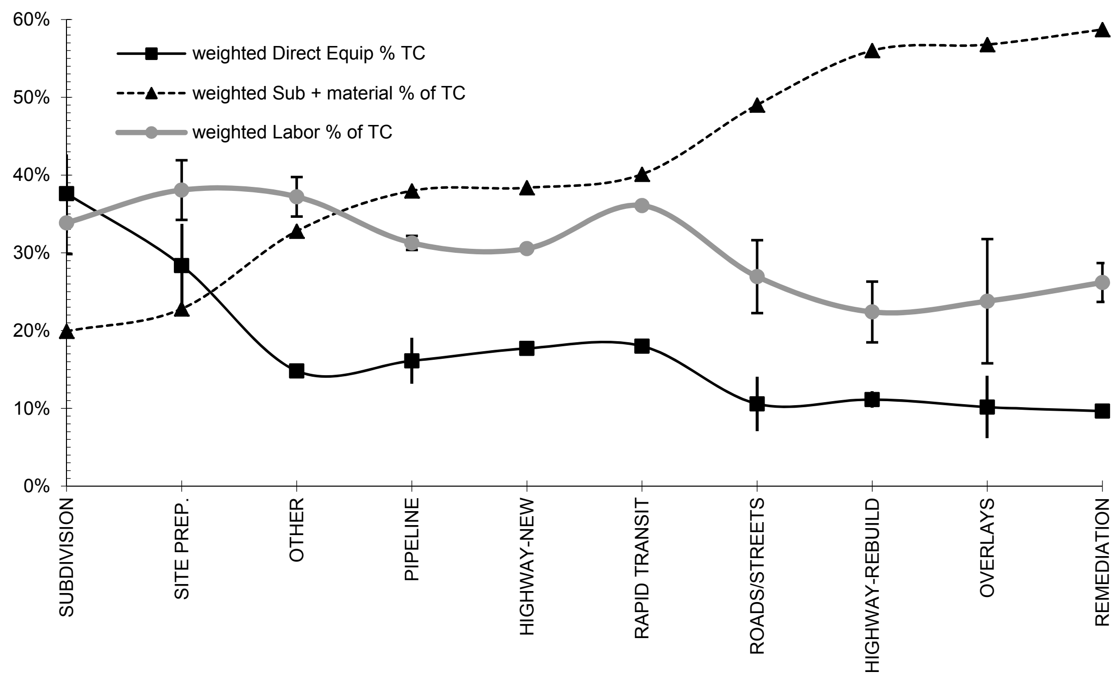
Table 69 The ratio is a solution to balance the return on investment problem: the ratio reduces the effort. For example, the effort to monitor undistributed quantities could be more than the benefit. As a ratio, the indirect is dependent on an independent variable that is easier or already measured. One estimator and one field engineer thought this is not a valid method; they argued that estimating and field engineering is an art that cannot be duplicated with formulas and ratios.

	Potentially monitored as a ratio of		
Indirect Overhead Items	Total Cost	Labor	Equipment
Mobilization			7%
Small Tools		0.2%	
Office and Yard	0.2%		
Lube (fuel, oil, grease)			8%
Supervision		15%	
Mechanic			5%
Final Clean-up		1%	

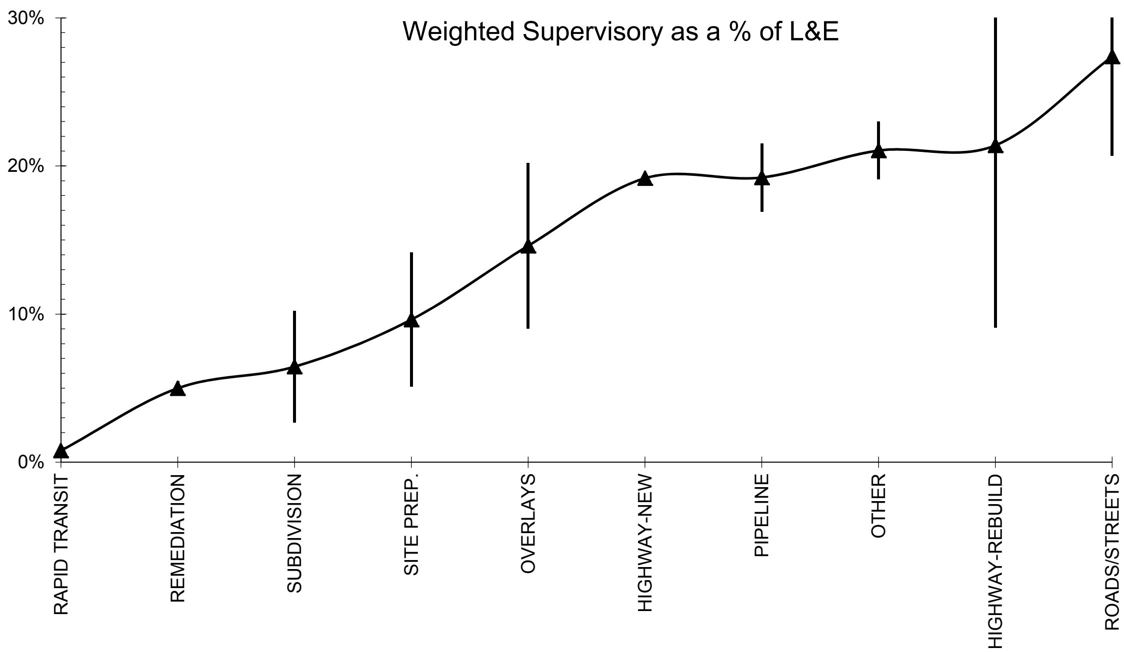




5%
4%
3%
2%
1%
0%
weighted Small tool % of labor
weighted Office & Yard % of TC
weighted Final Cleanup % L&E
RAPID TRANSIT
SITE PREP.
SUBDIVISION
PIPELINE
OTHER
REMEDIATION
ROADS/STREETS
HIGHWAY-REBUILD
HIGHWAY-NEW
OVERLAYS



60%
50%
40%
30%
20%
10%
0%
weighted Direct Equip % TC
weighted Sub + material % of TC
weighted Labor % of TC
SUBDIVISION
SITE PREP.
OTHER
PIPELINE
HIGHWAY-NEW
RAPID TRANSIT
ROADS/STREETS
HIGHWAY-REBUILD
OVERLAYS
REMEDIATION



6.6.7 Conclusion to Endogenous Relations

The effort necessary to audit the application of applied resources on the ReTRAC project was greater than the field engineering resources available. Each of the field engineers was heavily overloaded and left to their own to figure-out shortcuts and how best to audit the vendors and subcontractors they were responsible for in addition to their self-performed activities. During the project I wished for data integration – I had to enter the same data individually into each of the separate software systems. To share data across systems, I had to print the data report and key to the next system. This would have been fine if there had been a large team of field engineers and supervisors that provided clear channels of communication and hosted a platform of collaboration so the field engineers could function as one – unfortunately, that was also not the case. For most field engineers this simply precluded using real data during their decision making process. So much was decided based on opinion and there was nearly no check on the validity of those decisions. The ReTRAC project made a large profit so the sum of those decisions either was good or the project had a huge amount of inefficiency built into the contract value. After the ReTRAC project I investigated the use of macros to pull data from websites into spreadsheets at regular intervals. The macros were not well suited to this but in the process I became more aware of post-processing as a distinct process within quantification.

On the ReTRAC, I saw quantities post processed as part of audit checks, to build models for planning, and to derive submitted quantities from measured quantities. Often, the post-processing followed a repetitive, consistent, simple process. The problem was the magnitude of the process – some days I repeated a process over fifty times. Some tasks were exogenous – meaning they had to be measured from an outside source – and some tasks were endogenous – meaning I could derive the quantity through a relationship. The endogenous tasks could be automated using spreadsheet functions. The more tasks I could define as endogenous the fewer tasks I had. For example, the task “lookup haul truck unit cost” was originally completed by looking at the truck company and truck type then looking through a stack of vendor sheets to find the unit cost. As an endogenous task a spreadsheet function took the exogenous truck identification number - this provided the vendor and truck type - then based on this looked-up the unit cost from a table. This then feed into a large endogenous task that based on the exogenous hours calculated the cost quantity for a day. Therefore based on two exogenous inputs - truck identification number and hours – I was then returned the expected cost for the day to then compare with the invoice cost.

The implications of this endogenous system was reduced effort for increased accuracy and a complete audit of all truck invoices. The unexpected implication from this innovation was organizational disruption. I had made my job too easy and some of the other field engineers thought this was unfair and the workload should be readjusted so I once again was overloaded with work. This dampened any desire I had for investing the evenings needed to develop further innovations.

Regardless of organization disruption caused by innovations – I could see that if I had a library of expected ratios then I could automatically check my quantities and flag those outside the expected range. I began this investigation but could not complete the study because again organizational disruptions resisted the innovation. I suggest looking at historical ratios as a way to reduce the effort exerted on quantities.

The ReTRAC supervisors and the field engineers were not interested in exploring the use of endogenous relations or historical ratios as part of the quantification process.

At this point, through this chapter, I have presented the effort, context features, and methods of quantification. In the next (the last) I will present the sources of errors and mistakes in quantification, including what appear to be errors or mistakes but is in fact neither, it is purposeful fraud.

6.7 Sources of Errors and Mistakes in Quantification

Errors are those repeatable variances from correctness that are attributed to the measurement tool or measurement process. Mistakes are those variances from correctness that are attributed to human bias. In construction quantities these are often inconstant and difficult to precisely predict.

On the ReTRAC the field engineers diligently collected quantities to the needed level of detail and then audited weekly. As a result the quantities were +/- 10% accuracy[265], +/- 10% consistentency[266], and 100% complete[267], quantities with these attributes aided the engineering team to forecast cost to completion[268] with comparable accuracy. During the ReTRAC project and on other large projects, forecasting - particularly time - was an issue that presented the large projects division problems (Granite Construction).

As a field engineer, the longer I reviewed the records for offsetting errors the closer I came to reconciling the accounts. As I found and corrected errors, the errors became smaller and smaller in magnitude. Eventually, each correction resulted in a small variance of near equal value to one side or the other of a mean value. This indicated that while I would continue to find errors, they were offsetting: offsetting means that for each error that increased the quantity there was an equal offsetting error that decreased the quantity back to the correct value. The errors I would find could be left based on the offsetting errors theory. The work required to find the remaining errors would produce no perceivable difference in the final reconciliation. So, once the errors became small, I could stop checking.

In this section, I present the forecasting variance, the completeness' of monitoring, and the sources of errors and mistakes that affected the forecasting and monitoring.

6.7.1 Errors in Forecasting

During the ReTRAC project there was no effort correlating the project team's success at forecasting schedule activity durations with the actual durations269. Variances were found in the cost report since cost had to be moved to or from the account during the forecasting process, this was not the case with the schedule so variances were not noticed. If there was a large variance in activity duration, the project engineer might ask the field engineers what the reason was. After the project completion I reviewed the ReTRAC project schedule for the

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[265] Found through review of project total Job Cost Adjustment as percentage of cost
[266] Found through review of project total Job Cost Adjustment variance between codes
[267] Observed ethnographically on project
[268] The sufficient degree is unknown, these processes were intuitive and ad-hoc with no clear explanation for how they were cognitively calculated. The result was the cost was within 5% of the forecasted cost.
[269] This is true for the four levels of schedule detail used; these are the baseline, 6-month lookahead, 2-month lookahead, and 5-week lookahead (1-month).

backfill activity comparing the activity durations on the 5-week lookahead schedule with the as-built schedule. Comparing the durations I found a 0.70 correlation between the forecast and actual durations, see Figure 58 and Figure 59. Comparing the budgeted production rate with the actual production rate found that the estimated production of 5 CY/MH (cubic yards per man-hour) for the backfill operation is half the actual production of 10 CY/MH[270]. Several factors created this variance – these factors cannot be considered during the replanning without an unusual degree of effort. For one, there was no formal use of resource leveling in planning so as the project progressed the crew resources leveled through a pull demand system[271]. In addition to resource leveling, some of the factors I observed affecting the variance of expected to actual backfill are traffic, weather, and access to workzone (sometimes a function of traffic and weather but often due to other workzones blocking access). The source of why the forecast and actual varied to the degree they did was not explained in the publications, surveys, or my ethnographic observation.

One explanation is human mistake. Because the production was double the expected rate then the backfill activity should have been completed in half the time. This was not the case, the duration was equal. The question is why. In the next section, I will present several errors in the quantity of backfill estimated. From the outset the backfill activity was expected to have half the actual volume of material – this was due to a mistake with the quantity takeoff. The ReTRAC project constructed a trench to hold two railroad tracks, the trench had a north side and a south side, each required a backfill. The quantity takeoff used the plans to calculate the backfill volume and the field engineer used a spreadsheet for the north fill and a separate for the south fill. The field engineer that completed the quantity takeoff then provided these to the field engineer responsible for the earthwork – who then used the volume from one spreadsheet for the backfill quantity forecast. When I arrived on the ReTRAC they had nearly placed the expected volume of material and were quietly trying to figure out why the backfill was nowhere near completion. The prevailing theories were that the subcontractor processing the material had tampered with the truck scales so they could overbill the project – though this could not account for the wide variance in the quantity. The second theory was that a large amount of material had been spread around by the loader loading-out the material from the yard to the haul trucks and so there was a thick mat several foot thick in the material processing yard that was simply not noticeable. Even if the yard was a full acre and three-feet of material was still in the yard, this only accounted for 5,000 cubic yards and the variance was 70,000 cubic yards.

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[270] Not actual rates, altered to protect company information.
[271] I did not make an analysis of the project forecasting success.

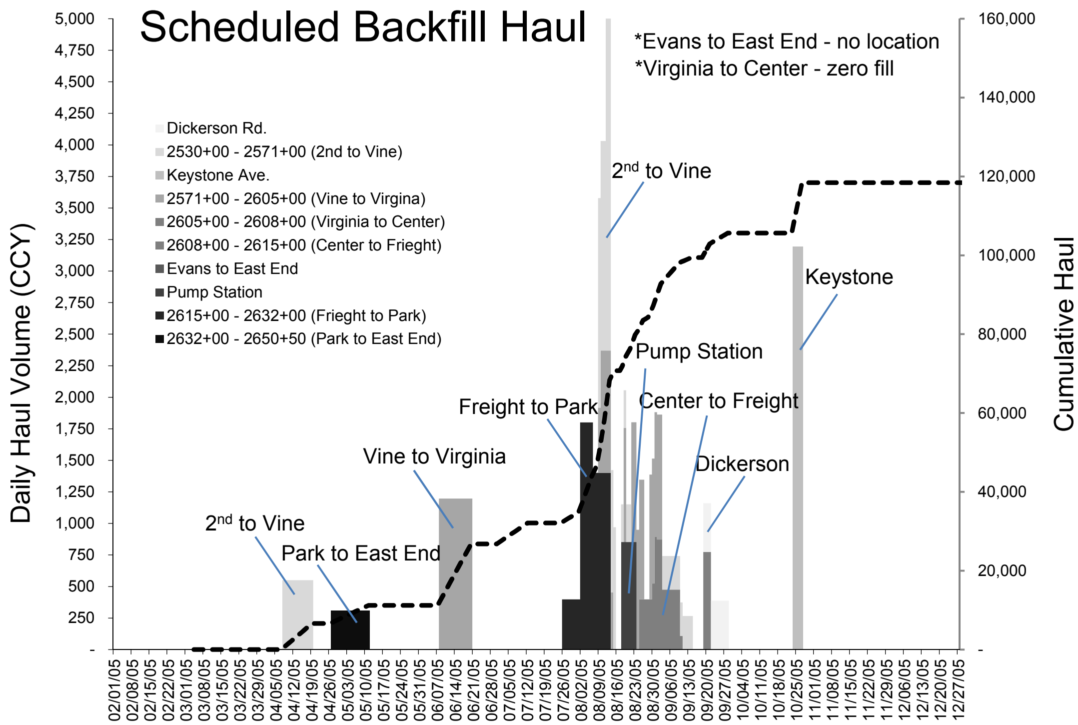

Figure 58 Scheduled retaining wall backfill operation as represented in the 5-week lookahead schedule.

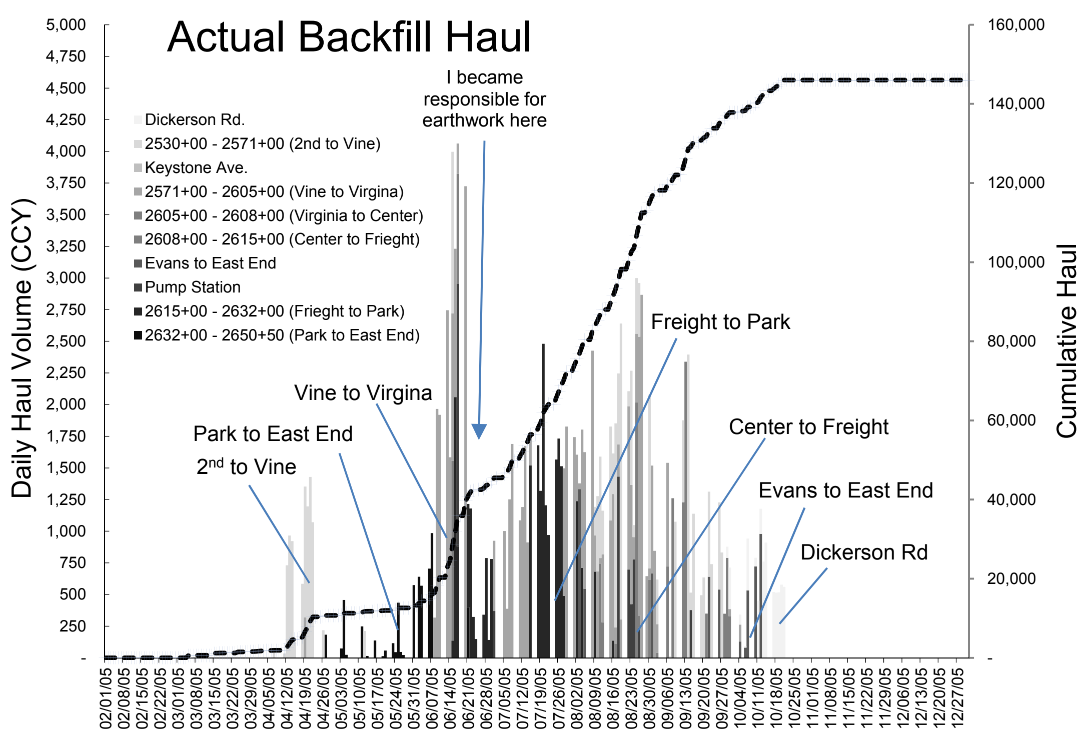

Figure 59 Actual retaining wall backfill operation: 0.70 correlation with plan and a 20% variance between the forecast and actual quantities. The planned backfill production was aggressive and had large gaps – these were filled with self-leveling resources – possibly to maintain employment for the haul truck drivers.

The third theory was that this activity was almost done and the remaining backfills were narrow slot trenches and these only held maybe 20,000 cubic yards of material – which they had already added onto the 75,000 CY base forecast on top of the 20,000 CY factor of safety volume already added. The forth theory held that after the quantity takeoff was completed there was a failure in the temporary shoring on a section of the excavation. The solution was to layback this section rather than try to rebuild the shoring – the effect was the backfill volume was increased in this section and that accounted for the observed increase in volume at that time. Up to that point, my experience in construction was as a concrete laborer and while I had done well in my upper division heavy construction coursework in construction management I was learning earthwork. Eventually it became clear that the material processing sub had not tampered with the scales, that there was not a thick mat of material in the processing yard, that the remaining backfill was not the narrow trenches they appeared, and the difference in volume caused by the layback was insignificant in the context of the total backfill volume. The base quantity takeoff entered in the forecast was half the actual volume. When I presented this conclusion to my supervisors backed by haul logs equal to the volume predicted by the correct quantity takeoff as well as the second quantity takeoff spreadsheet, they were skeptical and one berated my work as ridiculous and claimed no field engineer could maintain a reliable record of haul logs. Because the earthwork volume was double the expected volume and the production was double the expected rate, the duration variance between the expectation and the actual is nearly zero.

In the next section, I present additional smaller errors I found while investigating the backfill volume.

6.7.2 Cases in Completeness of Monitoring

Next, I applied the CIFE seven level breakdown structure (Peterson et al., 2009e) to the ReTRAC project documents. I used the CIFE WBS as a comparison due to the CIFE WBS inclusion of two location levels. With the CIFE WBS I found three quantity issues. First, I found a 3% double count, second, three 5-week schedule locations representing 7% of the project were omitted, and third, the location breakdown for the dimensional plans, schedule, budget, and quantities, are inconsistent.

First, I found an undiscovered error in the takeoff at the Evans Street location, one of 28 locations. The takeoff contains a double count of 4,500 CY out of 7,000 CY at that location – this is 3% of the total backfill material - due to an overlap in takeoff locations. Excluding this double count error, the takeoff is within 0.5% (1,000 CY) of the calculated volume of backfill material delivered to the site. For context, based on two haul trucks with 20 cubic yard end-dumps making 8 hauls per day, the variance is equivalent to 3 or 4 days' haul out of 180 days of hauling; that is a 2.5% variance by time, the schedule cannot be more accurate[272]. The project engineering team would not have noticed the error nor the longer timeline. At the field level they most likely made a field determination of quantity and guessed the duration. On day one they called for truckloads of fill material and then continued filling each day until it was done. On a six-month activity nobody really needs to know how long it will take and the number of trucks is just whatever seems like a good number – if the trucks are bunching-up they will send some home and if there are large gaps between trucks they will call for more. In relation to other tasks and within a larger network diagram to meet a completion date and have an optimal profit – then these other considerations become important. On the ReTRAC the quantity takeoff and schedule were not linked so the error was probably irrelevant to the schedule. There is a small possibility someone had actually done an analysis and derived a duration based on an assumed number of haul trucks, but not likely. Besides, they would have been using the baseline 5CY/MH production and would have been off by far more than 2.5%. Further, they would have had the wrong quantity and again would have been off by more than 2.5% if they had updated the production.

Second, the 5-week lookahead schedule does not contain three activities representing two of the 28 (7%) project locations; these are 'Backfill Vine – Washington North,' 'Backfill Washington – Ralston North,' 'Backfill Ralston – Arlington South.' I was the project scheduler: the field engineers, the project engineer, the superintendents, the construction manager, and the project manager reviewed the schedule during a several hour meeting each week, so it is not clear why the mistake was not found. This omission from the schedule represents 10,000 cubic yards of material, 6.5% of the total (the 3% double count offsets half). The field crews did the work without issues or noticing the omission from the schedule and as the earthwork field engineer, I reported the quantities. It just goes to show how little actual field operations rely on the project schedule – even when it is a detailed schedule with a weekly plan. The progress moves slow enough that the supervisors maintain the schedule collectively in their heads. For this type of activity, in many ways a good schedule reflects what the crews will do rather than direct what the crews will do. Reflecting back on Figure 58 and Figure 59, the actual is so far removed from the planned that it is clear the schedule was entirely irrelevant.

Third, the location breakdowns for the dimensional plan, schedule, budget, and quantities collection are different. The dimensional plan location breakdown is by plan sheet. The schedule followed several location breakdown formats with varying levels of detail depending

[272] Mike Jenkins of DPR advises during presentations to CIFE students that one week is the smallest realistic interval of time for scheduling performance.

on the project phase. The budget had no breakdown for locations in the chart of accounts. The project engineer added a location identifier to several of the account descriptions, Table 73 page 353. The field engineers broke down work-in-place measurements made in the field by locations to define what to measure - per instructions of the project manager based on his experience - Table 60 page 298: I found no mention of this quantification by location practice in the literature nor through survey nor interviews.

6.7.3 Sources of Errors and Mistakes

Due to fluctuations in the quality of reporting, the reliability of quantities were dependent on why the quantity was collected, weekly being the least reliable and the final quantity, the sum of weekly quantities and monthly reconciles, ideally the most reliable. The degree of accuracy for quantities reported by field engineers for a specific week varied due to several known sources and the intuitively low risk of affecting the project outcome[273] with a given weeks quantities. As a result, the cumulative weekly quantities were reconciled to-date on a monthly basis and on a quarterly basis. At the completion of an activity, the ReTRAC practice was to reconcile to a theoretical quantity of a neat line take-off, Figure 49 page 259. The underlying reason is the managers assume their field engineers have so thoroughly corrupted the months quantities with fraud, errors, and mistakes that the neat line was closer to correct than anything they would ever measure in the field.

6.7.3.1 Human Error

The following analysis of the project planning process I based on the ethnographic observations I made on the ReTRAC project and on my lab work to define what the observations mean. A project plan, including rework, contains five data entries of field quantities for each of three applications (scope, time, and cost) similar to Saidi(2002), see Figure 23 on page 140 . The rework results in manually keying an entry 15 times for each operation-level activity. A baseline project schedule - prior to adding 5-week lookahead activities - may have 1,000 activities.[274] This indicates that the field engineer will key 15,000 during project planning. Iteration of change results in further keying; assuming a 50% change in plan (changing dates and link logic) specifics during the planning process results in over 20,000 items keyed. A rate of 20 entries per minute is a pace for typing words in composition[275]. Assuming this rate is similar to data entry during the planning process – a five-

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[273] This example and the inherent inaccuracies issues provided in this section are related to the balance between data collection effort, (p159) and timeliness needed for specific purposes; the sections *Integrated Coding Process* (p231) (p249).

[274] Observed, as part of a CEE241 class project, used by Turner Construction on the design-bid-build $95 million Linac Coherent Light Source (LCLS) project at SLAC in 2007.

[275] Karat, C.M., Halverson, C., Horn, D. and Karat, J. (1999), Patterns of entry and correction in large vocabulary continuous speech recognition systems, CHI 99 Conference Proceedings, 568–575.

letter word is equivalent to a five-digit number – then with a four-person project planning team it should take 6-weeks[276] to manually enter the baseline quantity spreadsheet, the schedule without reuse of fragnets, and the cost estimate.

Medical research has found the human keystroke error to range from 1:300 to 6:100 and automation errors to range from 1:394,000 to 1:5,400,000 (Smith & Offodile, 2002; Kaushal et al., 2001). While likely optimistic for construction; the medical human error rate results in 100 expected errors or 0.5% errors (6:100) in the above-assumed project planning material. An error rate of 0.5% initially seems insignificant for construction planning. Converting the error rate to the affected scope in price equals $3,000 to $5,000 per $1M of project scope. On the $180M ReTRAC project a 0.5% error rate will contribute an expected $1M ($2005). Again, this seems insignificant to the layperson but considering that the ReTRAC contractor's 2011 earnings yield[277] is 0.6% then 0.5% is a large amount. The 0.5% keystroke error rate represents 10% to 20% of the misplaced resources in the 3% to 7% of known estimate error.

The secondary affects and criticality of the location of the error is not included in my analysis. These factors would result in variations in the leveraging of an error on the cost impact. For example, an error in the takeoff quantity of a critical project component would count as one error. If the error is a keystroke error in the first couple of digits, the error could be significant. The error would then cascade through the scope-time-cost analysis resulting in an incorrect material order, activity duration, and allocation of not just labor, equipment and material cost, but also time dependent indirect cost. The counter example is an error that has no effect on the project planning process, such as a keystroke error in the last couple of digits of a large value. The largest errors are likely found and the smallest errors are likely offsetting, *Auditing* (p413), but as seen in the haul truck analysis (see *Define Exogenous and Endogenous,* p329), the bulk of the errors are not found and potentially sum to a large amount, Table 70.

6.7.3.2 Bias Becomes Fraud

In the literature review, I found that the authors addressed the issue of *bias in reporting*. This may have been an issue on the ReTRAC project but I did not observe bias. During the last months of the ReTRAC project, the projects senior cost engineer accused the field engineers of bias due to their inability to forecast cost to completion with confidence, likely due to a combination of knowledge and resources (tools and labor). Over and under reporting of quantities by field supervisors, called *sand bagging* was found by Saidi (2002), p133, and is

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[276] As a reality check several heavy civil industry professionals were asked how long they thought a similar task would take a four-person team, including planning tasks, they felt intuitively it would take 4-weeks, 4-weeks, 6-weeks, 8-weeks, and the CEE241 TA thought 12-weeks.

[277] *Earnings yield* http://en.wikipedia.org/wiki/P/E_ratio

discussed in Construction Project Management, p388. The motivation of sand bagging is to level the reported progress and therefore reduce the variance in reported progress. The senior cost engineer applied this term to the ReTRAC field engineers towards the end of the project. It was not the case, I was either unable to forecast competently, possibly the ReTRAC planning system the field engineers were using was incapable of forecasting competently, or I was continually beating reasonable forecasts through innovative field methods.

If I was consistently 80% of forecasted, based on a historical library of project quantities, then it indicates I was realizing benefits from innovative methods - the learning curve is realized at this point. If it had been a lack of confidence in forecasting then there should be an over/under canceling effect to eliminate the variance. A review of ReTRAC project records could reveal if either case or additional possibilities are likely: a possibility is the estimators had placed a hidden contingency in one or more of the project trailing activities, it could also just been an estimating error in several of the last activities. An innovation I implemented on the ReTRAC project at this time – with the consensus of the superintendents and the project manager – was an edge organizational structure. In this format those actually doing the wrok at the workface are the supervisors and everyone in overhead does eveything they can to ensure those at the workface have everything they need to do what they need to do. Further, if those at the workface need anything, they immediately demand it from their supervisors, there is not the traditional hierarchy where this would be detrimental to a field engineer's career. No other changes were made on the ReTRAC in crews, methods, or equipment that can account for the increased efficiencies the project realized. Either way, the variance between actual and forecast profit was not due to deception on my part.

Additional reasons for bias in measurements are a perceived lack of value in recording progress measurements (Motwani et al., 2005). Motwani's survey found that contractors perceive that no two jobs are the same (35%) and the return on investment (ROI) is insufficient, for example, too time consuming (35%), too costly (22%), and too difficult (8%): a cumulative 65% that do not see the value. A solution to the bias of those reporting the measurements is to audit them to confirm honesty in reporting (Meredith & Mantel 1995). Meredith advises that to help prevent a source of bias, "the project manager must make sure that the bearer of bad news is not punished; nor the admitter-to-error executed" and "the hider-of-mistakes may be shot with impunity - and then sent to corporate Siberia." I observed these issues and solutions to bias in reporting on the ReTRAC project. Based on experiences at the Rocky Flats project, Stevens (Stevens, Titus, & Sanford, 2002) recommends educating the project staff on the value of field quantities (presumably including the need for good coding). To educate the staff takes time and even then will they really understand the complex relations in construction – once they have been educated they are essentially field engineers. This may be why field engineers are given the quantities task as recommended by several construction reference texts (APM, 2002; PMBOK, Ch6, 2008; CPM, 2000).

6.7.3.3 Complexity

The ReTRAC project on and off-site haul conditions had permutations of cost combinations to monitor, creating an issue with invoice verification. There were up to 50 highway haul trucks per day at five locations. They had over 80 separate daily tasks from five different trucking vendors. With a cumulative dozen trailer rates at both prevailing and non-prevailing driver labor rates, the task of validating a specific invoice was a time-consuming challenge, Table 68 page 329. Additionally, due to volatility in fuel prices a clause was in the contract to allow the vendor to weekly recalculate and add a fuel surcharge from a baseline unit cost set by the vendor and local company branch office at the beginning of each year. The surcharge was a 1% change in the haul hourly rate for each $0.10 of fuel cost change. Since fuel cost varies by region, a government website containing cost per gallon[278] for ten regions was agreed-on as the source for fuel cost. The problem compounded. First, the fuel cost website update frequency is weekly, therefore each week the haul truck hourly rates could change. Second, the fuel prices during the project did change and often; prices rose and fell, experiencing greater volatility than for the preceding decade. From the project start (late 2002) to completion (mid-2006), fuel prices doubled and tripled for a short time after Hurricane Katrina struck the southern United States oil-producing region in 2005.

As part of project controls the management on the ReTRAC project wanted the haul truck invoices checked. The preceding combination of features and unit cost changes results in each day assigning from a list of120 specific unit cost rates to a possible 20,000 unique location, action, applied resource tuples and then each week recalculating the 120 unit cost rates. Usually each truck was engaged in one or two actions and in one or two locations – reducing the problem to assigning 200 unique tuples, but still having a list of 120 unit rates to choose from. The task was impossible without writing a spreadsheet program. Prior to my employment on the project, the earthwork field engineer had conducted spot checks of the invoices. The task of reviewing the invoices was accepted - possibly industry wide - as impractical, so the earthwork field engineer reviewed a third of invoices, selecting the haul trucks with higher hourly rates for random audits.

[278] 1 US gallon = 3.78 liters.

As a solution to this check, I developed an endogenous method to calculate the billing invoice from nine exogenous inputs, Figure 45 page 248, therefore reducing exogenous inputs from 27 and therefore the applied labor needed to check invoices. My detailed review found numerous smaller errors; 10% of the total was not in the contractors favor and to the vendors appreciation I provided these as feedback to correct their invoice. During a lull towards the end of the project, I pulled the archived invoices from prior to my employment on the project and used these as an algorithm *learning* exercise for special conditions, edge scenarios, and therefore validating with a larger sample size the accuracy, repeatability, completeness, and robustness – important in an everyday industrial application. My retroactive check found one approved invoice for an unrelated project and numerous over/under charges. It was apparent the volume of invoices had overwhelmed the verification process and the efficiency of the check process was relatively low compared to my method relying on endogenous relations[279], Table 70 and

Equation 6.

Table 70 An analysis of errors reduction using endogenous (Figure 45 page 248), exogenous and database quantities, equations and rates, Table 68 page 329.

Haul Truck Error Analysis Net Result Resources	 Estimated value
Process: of checking and gleaning quantities and context from invoices	
Equations:	daily cost = labor * labor unit cost monthly cost = daily cost * 20 days development cost (M) = duration * labor unit cost Value of errors E
Baseline Method M_0:	
Labor Production and Cost	L_0 = 4hr/day * \$50/hr = \$200/day = \$4,000/month
Value of Errors Avoided	E_0 ~ \$200 / month
Endogenous Method M_1:	
Development Cost	M_1 = 100hr * \$50/hr = \$5,000
Labor Production and Cost	L_1 = 1hr/day * \$50/hr = \$50/day = \$1,000/month
Value of Errors Avoided	E_1 < \$10,000 / month
Conservative adjustments:	
L_1 Labor Production and Cost	increased to 1 hour 15 minutes
E_0 Value of Errors Avoided	increased (100%) to \$400 / month
E_1 Value of Errors Avoided	reduced (50%) to \$5,000 / month
Production Winter Adjustment	cycle time efficiency reduced to 10 months / year

Equation 6 An analysis of the return from implementing a new process in quantities collection and post processing. The conservative return (equivalent to one field engineer) is minor within the scheme of a project. An improvement, such as this at a low level across dozens of processes, multiple years, and

[279] A quantitative analysis was not done for this paper though the material needed for the analysis is available.

multiple projects potentially represents a cumulative improvement in resource allocation efficiency and therefore promotes a sustainable operation.

Cost of errors and 1st year return on investment		Inputs	
Method0 value V0 =	E0 – L0 = 200 – 4,000 = -3,800	V	= value
Method1 value V1 =	E1 – L1 = 10,000 – 1,000 = 9,000	E	= value of captured errors
R(1st year) =	12(E1 – L1) - 12(E0 – L0) - D	L	= cost of labor
		D	= development cost

1st year return on investment, economy of scale and best case observed scenario, assuming method1 implemented at earlier date

Ryear1 = 12(V1) - 12(V0) - D = 108,000 - (-45,600) – 5000 = $148,600

1st year return on investment with conservative assumptions

Ryear1 = 10(V1) - 10(V0) - D = 37,500 - (-36,000) – 5000 = $68,500

6.7.3.4 Level of Detail and Context Features

Scope quantities are inherently reported at one or more levels higher than cost, and scheduling at one or more levels higher than scope quantities, Figure 60. For example, a review of documents from the ReTRAC project, activity 305200 pipe demo contains four subgroup activities at the operations level of detail *211 to *260, these are given cost but not quantities; production is calculated at the 305200 level. It cost $393 to remove one manhole 305212 on the project[280]. It should have been reported as 305200, 391 LF, 0.55 MH/LF, $28.92/LF including an equipment cost of $8.39/LF. This report ignores that manholes and catch basins (CB) cost more to remove; CB are $1,000 each and require 21 hours to remove. Due to including the CB, the roll up account pipe demo 305200 is understated by $2.25 per LF and 0.04 LF per man-hour or a foot or two a day[281].

[280] labor $324, 10 hours regular time, $69 equipment cost.

[281] This is within an observed documented internal company policy of an accepted range of 10% error.

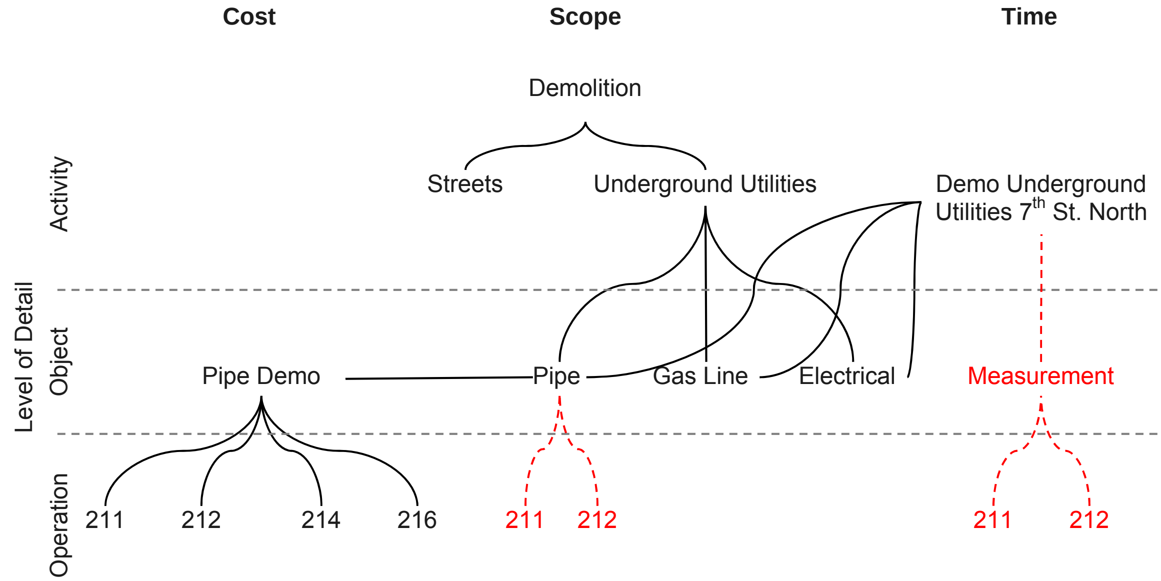

Figure 60 The inherent difficulty integrating level-of-detail across scope, time, and cost; inherently residing at different levels of detail. Changing the level of detail introduces feature assumptions when raising and removal of featureswhen lowering, this creates zones (in red) of dummy feature placeholders that are either more abstract or detailed than actually collected or planned. Adapted from Staub & Fischer, 1999, figure 4.

From a representation of the trench wall structural backfill with the location features, the overlap of activities and relative duration in each location is illustrated, Figure 61. The key point is that if the project engineer does not maintain the quantities in a historical library with the location feature then this valuable representation or a flowline representation is not possible in Figure 61. In Figure 62, the red dashed vertical bar represents the unit cost and/or production rate presented in the cost and productivity report, essentially a slice in time. In this time slice there are three linear production and unit cost rates, these are to-date (short-dash line), three-month rolling average (long-dash line), and this period (solid line). These are in addition to the baseline estimated production and the to-be-seen at completion final production rate. The estimators likely reuse the project production rate in future project estimates and the shorter interval rates the field engineers used for project forecasts. If a regression was built into the ERP (AS400 EDJ Accounting on ReTRAC) type software could potentially be useful to fit a trend. Possibly, forecasting based on the scheduled production and deriving the cost from the schedule will provide a degree of accuracy and consistency. Note that the linear rates shown in Figure 62are for illustration purposes, the actual productivity rates are a function of labor hours not project hours and the unit cost rates are a function of cost, though the differences are minor in presentation.

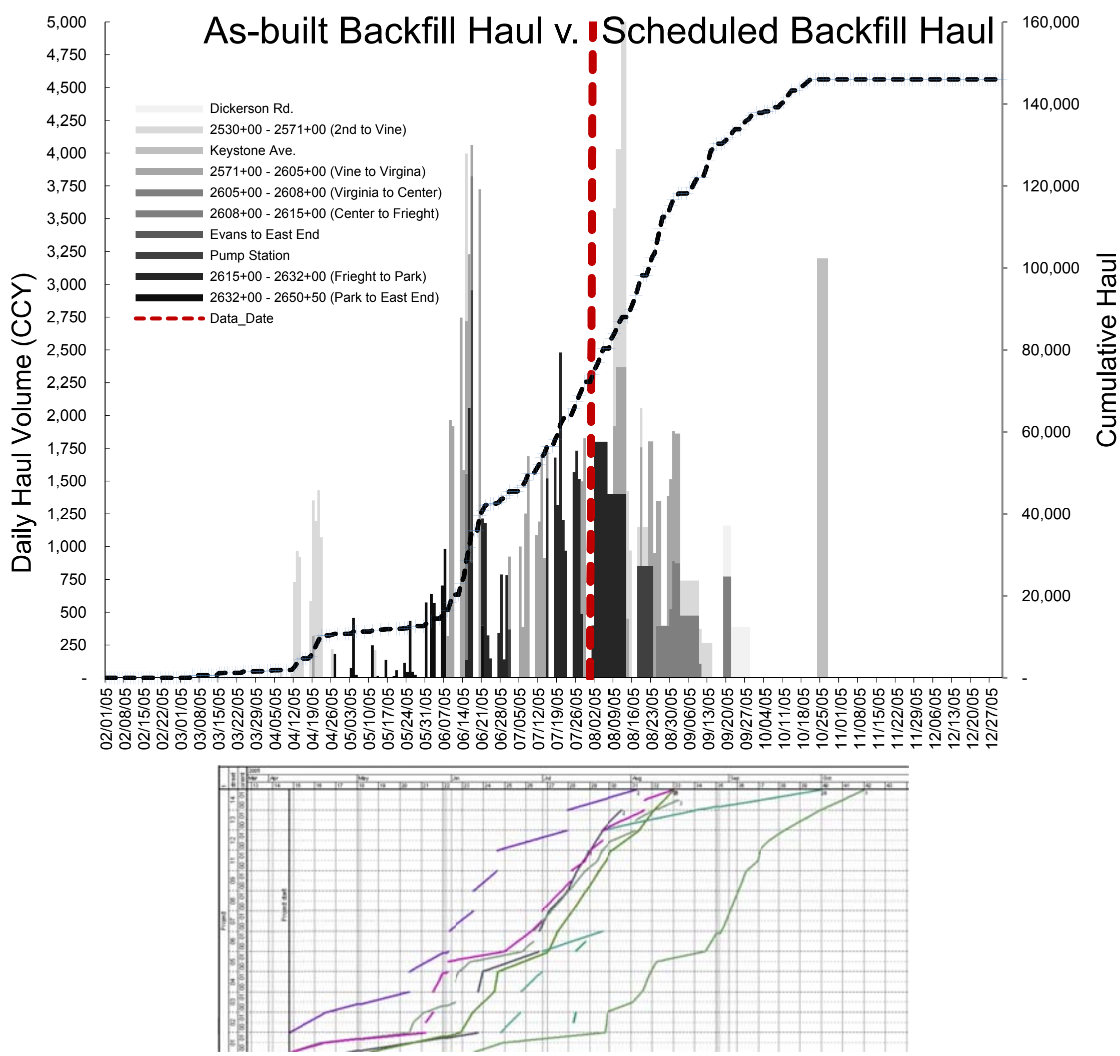

Figure 61 Representation of the daily trench wall structural backfill with the location level of detail included; if the quantities are not represented with the location feature this is not possible. The bottom table is from the Vico Control Line of balance scheduling – Vico provided a student license for this study.

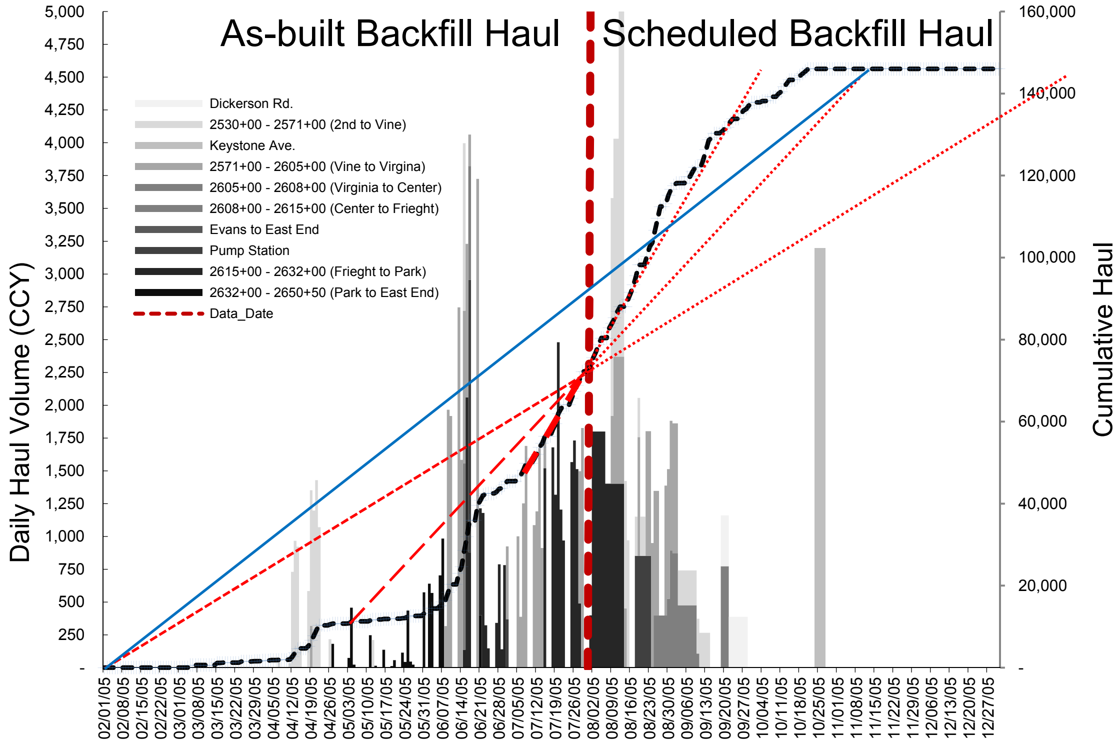

Figure 62 The dashed lines show the average production that would have been calculated at differing times such as to-date (short-dash), this period (dash), and the rolling three-month average (long-dash). The completion dates vary by five months depending on the production sample. These compare to the baseline expected production and the to-be-seen final production rates (solid). Due to learning and sticking, the production forms the classic s-curve. The initial production is slower and at the end the efficiency is reduced with confined workspace or crews slowing in anticipation of layoff. Note that the production lines are for demonstration since the unit rate is by time applied resources are applied not by calendar time.

The issue is that to a field engineer responsible for this activity during the early and late stages of the project the activity will appear continually under-production while those during the peak project production will be over-production, a characteristic of the s-curve. In hindsight, it appears the project engineer should acknowledge this during mid-project forecasting sessions and early project forecasting. It is difficult to perceive if production is below rate or simply early on the s-curve. The flowline axes are time and location, therefore implying quantity as a time ratio derived from the product of production and quantity. Notice the flow of activities across locations is observable; one flowline represents the previous chart, the additional lines represent multiple sub-operations such as haul, spread, and compact, using multiple methods. What is not represented is the daily haul quantity and total quantity.

At this time, the quantities for this style of forecast cannot be compiled by anyone but the best field engineers. The comparison of a project plan laid out by a project team with experience provides that planning is not correlated with actual events, Table 40 page 202. It is conceivable the schedule was a contract requirement not a *living document* with an *honest effort* placed in the planning. It is possible the project supervisors maintained an intuitive schedule of activities that the field engineers could not reflect in the electronic schedule; *sand bagging* could have been a factor. The project team applied management, labor, software, and machine resources to project scheduling, the entire construction team - managers, engineers, field superintendents, and in later project stages foremen - met for a couple hours each week (these meetings were mandatory) to update and forecast the schedule. The schedule revisions required up-to 12 hours of post-meeting scheduling labor. It was an honest effort to reflect actual field conditions, constraints and planned production.

As a niche case study with the project documents, I built a model-based project scope-time-cost, model-based takeoff, 5-week lookahead schedule, and budget, optimized for workflow, and resource leveled. The result was a transparent plan, Figure 61. The level-of-detail in project control was increased from a single project location - project documents have a reported single location, monitoring used 28 locations, and project planning had hundreds of workzones - to 13 locations and 2 sub-locations for a total of 28 locations. The location-based scheduling tool provided a resource-leveled schedule that defined resources similar to those actually utilized on the project through pull demand. This validates that if the location-based workflow line of balance method was utilized on the project - on a white-board, paper, or electronically - the forecasting would have been reliable. The application of resources to planning, without the use of software tools, would have required several fulltime engineers.

6.7.3.5 Context Features

The breakdown structure used on the ReTRAC project did not contain a location component and so several operation descriptions contain a location identifier to mitigate this, Table 73 page 353. The project team set the project's chart of accounts after the bid award. At that time, they converted the project estimate to a budget. The format they choose to follow resulted in 5x the codes necessary. As related by the field engineer present at that time, there was a discussion of this overloading of codes.

The chart of account was formatted along the breakdown structure to the operation level but then provided a separate code for each resource of labor, equipment (one for each equipment type), material (one for each material type), haul, and subcontractor, Table 71 and Table 72. This ignored the subtype codes provided in each code for these resources. In effect, each code had only one subtype, therefore becoming redundant. Additionally as noted earlier in the section *Types of Quantities* on page 217, not only was the material given an account but it was then separated from the direct operations and placed in an indirect material account. This resulted in redundancy and then consolidation and becoming disassociated unless re-associated based on assumptions. For example, in Table 71 the operation level is represented by 31.1.1.1.1.00 *Cut2Fill Streets*. The six subcategories are methods defined as labor and equipment needed for the operation. These are redundant to the subtype column and were not necessarily representative of the actual method used. For example, rather than a CAT 330 excavator a JD710 loader backhoe was used, an 815 compactor was not used, 25T single-side dump trailers were not used, and the foreman was likely a Laborer. The only item consistent with the actual method employed is that there were laborers present. The operation and six subcategories have the same quantity reported; this is unlikely the actual case.

Table 71 Example of observed chart of account breakdown at the operation and method level.

Code	Description	Labor Type	Equipment Type		Material Type	Sub-contractor	Unit of Measure
3111100	Cut2Fill streets	RT & OT	internal	external	closed	closed	BC
3111101	Load CAT330	RT & OT	internal	external	closed	closed	BC
3111103	Haul 25T snglside	RT & OT	internal	external	closed	closed	BC
3111104	Laborers	RT & OT	internal	external	closed	closed	BC
3111105	Operator foreman	RT & OT	internal	external	closed	closed	BC
3111106	Grade setter	RT & OT	internal	external	closed	closed	BC
3111107	815 compactor	RT & OT	internal	external	closed	closed	BC

The operation assembly was monitored at the method level of detail, for this reason, the quantities reported are not the same across the methods used but represents the measured quantities for each. This required additional resources through either a detailed measurement method or a greater frequency of measurements, Figure 37 page 228. Again, as was the previous case the haul method description is not the actual method. A search at an additional level of detail to equipment type and then equipment number or invoice number will provide the haul truck identifying number that allows looking up the truck to determine the type of trailer attached. Possibly the trailer number is recorded allowing a reliable identification.

Table 72 In contrast to Table 71, the field engineers monitored this operation assembly at the method level of detail. The quantity is a ratio.

Code	Description	Labor Type	Equipment Type		Material Type		Sub-contractor	Qty.	UoM
3111330	remove shoofly	RT & OT	internal	external	closed	closed	closed	1.00	BC
3111331	load cat330	RT & OT	internal	external	closed	closed	closed	0.92	BC
3111333	haul 25t snglside	RT & OT	internal	external	closed	closed	closed	0.23	BC
3111334	support	RT & OT	closed	closed	closed	closed	closed	1.00	BC
3111337	scraper	RT & OT	internal	external	closed	closed	closed	0.10	BC

I observed this redundancy while on the project and my inquiry for the logic behind this was given by another field engineer as follows: The JD Edwards (J.D. Edwards) reporting tool did not provide the option for the subtypes to be displayed when printed. On a previous project they discovered this report format caused a problem. It was difficult to determine if a variance was due to labor, equipment, material, haul, or subcontractor: further which specific item within these was the variance. The perceived solution was to provide a separate code of each of these in the chart of accounts then apply the same measured quantity to labor, equipment, and material as appropriate. The subcontractor and haul account did not have the same quantity as the other three accounts so reflected the quantity done by subs and the volume of bulk material hauled for the operation. This mitigated the potential issue of an inability to vary quantities by sub-type. However, the project engineer could have solved this through a selective application of redundant accounts. The degree of customization available for the JD Edwards accounting system is unknown. The low level of expertise present on the project and the remote use of support staff precluded the option to customize the ERP system.

To create spreadsheet models for reforecasting required pulling quantities from the ERP system. On the ReTRAC project I observed that the ERP system printed reports to paper and provided an on-screen user interface, but not an export to text file; transposing quantities from the ERP system to electronic spreadsheet was tedious, resource intensive, and error prone. I could copy (Cntrl+C) from the screen and paste to the spreadsheet one screen frame at a time, a process that eliminated keypunch errors but was tedious. An exported flat-file in *.csv (comma separated values) format from the ERP system was not provided though I requested it from the corporate ERP technical support multiple times[282]. The corporate large projects support could not make available to the ReTRAC project the skills needed for flat-file export from the ERP.

As an alternative solution, a native “print to csv file” function in the ERP system, or the ReTRAC project could have contracted with a software consultant to custom program an application; the Bay Area Branch in San Jose had custom interfaces to the ERP system they had programmed with a consultant.

Providing the reporting ability to view the subtype codes and within these the quantity and cost by labor, equipment, material, haul, and subcontractor type, would have reduced the chart of accounts complexity. A provision for location would also have provided a capture of project

[282] While possible, attempts at flat file downloads from the ERP database resulted in interesting results, the file naming format key was not available and appeared a sequentially assigned numerical code, therefore the files opened were of a random content.

progress. To provide these additional levels of detail - report printout allows defining the level of detail for the entire report - the project engineer must consider the resulting overly detailed report that would be hundreds of pages. A solution possible now is to review the report as an electronic medium rather than paper-based. This allows the use of expandable hierarchies of breakdown as needed during the review meeting. Maybe the solution was to have a computer and printer in the meeting room – if more detail was wanted for a specific account then one of the field engineers could just print that one instance out with the greater detail.

The nuances of reporting effect on the organization of accounts as work-arounds aside: I observed five types of errors in the chart of accounts breakdown structure within the ReTRAC project documents, Table 73, these are:

- codes containing misplaced quantities, i.e., miscoded
- codes that are misused, i.e., deliberately miscoded for various reasons including lack of tenacity
- codes that do not follow the established breakdown structure format
- codes that attempt to mitigate the lack of a location placeholder by including one in the description
- custom codes have exceptions to the rules

Table 73 A review of ReTRAC project documents turned up five types of errors in the chart of accounts. The inclusion of a location identifier in the description as an attempt to circumvent the lack of an identifier in the breakdown structure.

Level of Detail								
Discipline	Activity	Resource	Component	Operation	Unit	Delineated Code	Code as Used	Description
Contains misplaced quantities								
8	4	0	1	51	BC	8.4.0.1.51	840151	Load out material
8	4	0	1	53	BC	8.4.0.1.53	840153	Haul backfill
Misused cost code								
8	4	0	2	00	TN	8.4.0.2.00	840200	Aggregate import
8	4	0	2	54	TN	8.4.0.2.54	840254	Haul triple trans
Disorganized (does not follow WBS)								
2	8	5	2	20	SF	2.8.5.2.20	285220	Driveways
2	8	5	2	22	SF	2.8.5.2.22	285222	R/F/P driveway
Attempt at location								
2	8	5	2	13	LF	2.8.5.2.13	285213	Dickerson C&G repair
2	8	5	2	14	SF	2.8.5.2.14	285214	Amtrak bldg swalk
Exception (no example presented)								
*								

6.7.3.6 Issues with Visual Methods

Quantifying items visually is an abstract task (Nieder et al., 2002); medical research publications provide a concise guideline that is likely applicable for the use of quantification methods in construction that rely on human vision. Primates have the intuitive ability to judge the size of a group of foes and then decide to stay and fight or run (Nieder et al., 2002). This ability in humans is potentially a benefit in construction since it is often necessary to make an observation of a group and then return at a later time to make a repeat observation of the same group and determine if there is a variance, therefore indicating progress, lack of progress or even reversal of progress. In Nieder's example, a foraging scenario is provided, in a construction example this could be observing mass concrete placement compared to the plan set illustration of the same component. The primates' ability to judge quantity declined as the count increased, similar to that observed in humans (Nieder et al., 2002). An interesting finding is that the more complex the shape, for example, square (4 points) versus a triangle (3 points), the lower the degree of quantification accuracy. My intuition is that a base guideline on the application of quantification methods can be found through a literature review of the medical field and through empirical observation of methods utilized in other industries.

6.7.3.6.1 Human Vision

An imaging software vendor called I-Cube released a presentation (Dudley, 1993) that questioned the accuracy and precision of human vision, Figure 63. While the presentation promotes their product, the topic is relevant to the visual determination of percentage of completion. On the ReTRAC I observed visual determination used as a core method due to the low resource demands and is given as a method by the APM guidelines (p404) and was empirically found by Professor Motwani's survey (p56), Table 29. The presentation presented three issues, these are optical illusions, discerning variation in color, and the ability to reproduce measurements. While the presentation did not go into detail, it asked questions that are concerning and the citations led me to more research publications in optical illusions.

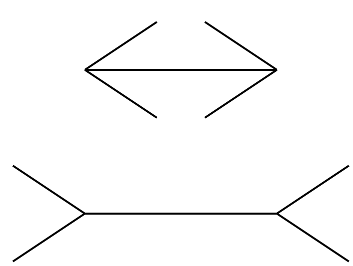

Figure 63 Are these lines the same length? Graphic adapted from Dudley, 1993.

6.7.3.6.2 Optical Illusions

Ophthalmology Professor Michael Bach[283] maintains a website with examples of the eighty-three known optical illusions (Bach) and has a similar publication (Bach & Poloschek, 2006). Of the illusions, five are geometric and angle illusions and twelve are space, 3D, and size constancy illusions. I think these illusion types are applicable to visual observation of the construction project percentage of completion and are the source of an unknown degree of inaccuracy and imprecision in construction project monitoring, Figure 64, and Figure 65.

Shepard's *turning the table* illusion replicates the similar situation of estimating surface area completion, Figure 66. Shepard's monsters Ponzo illusion may have similar issues with depth perception and determining the completion of mass concrete components or other volumes. The herring illusion could be an issue on steel structures or bridges, possibly as a perception of the structural soundness. The Gardner triangle puzzle illustrates potential accuracy limitations in estimating the area or volume of an component. To what degree optical illusions affect field quantities is unknown, though I think the possibility is sufficient to include here as a limitation to the visual percentage of completion method and other visual estimating methods, such as estimating count, length, area, and volume, Figure 42 and Figure 43.

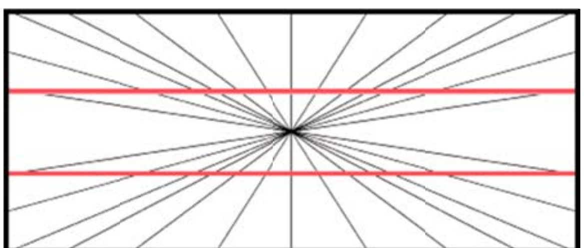

Figure 64 The Hering illusion (1861)[284]; the horizontal bars are not curved.

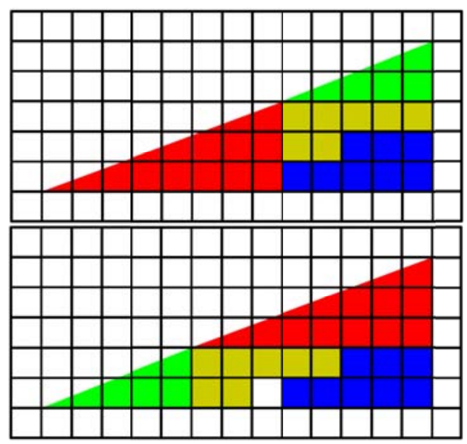

Figure 65 Triangle Puzzle, the missing square is due to the slight imperfection in the hypotenuse (Martin Gardner). The 13x5 triangle grid is 32.5 squares, the lower triangle has 33.5 squares for a 3% error.

[283] University of Freiburgmaintains Ophthalmology department, www.michaelbach.de
[284] Used with permission of Professor Michael Bach.

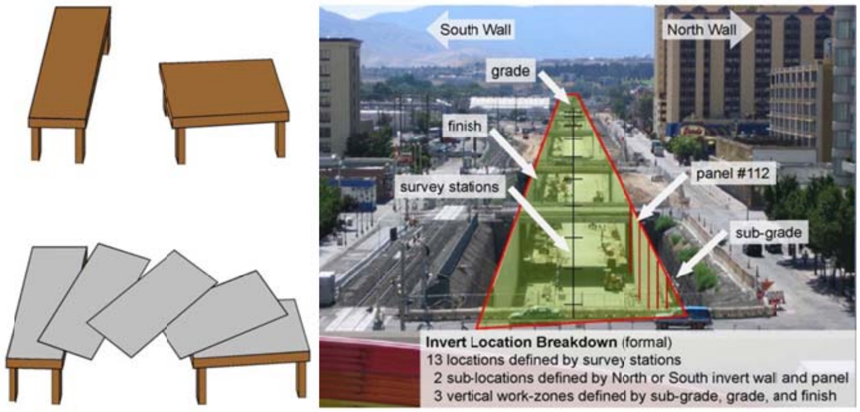

Figure 66 The retaining wall backfill aspect of Shepard's turning table[285] – the tables are the same. From the side the fills look narrow. The ReTRAC project continually undershot the fill quantity estimate. The earthwork field engineer finally estimated a quantity to completion based on a quantity takeoff and a sitewalk. The project team was unconvinced due to their perception of the narrow trenches they saw from their pickups, the project engineer said, "just look at how narrow the fills are – that is not much material."

Figure 67 Ponzo illusion: the two monsters are the same size (Shepard). Does the Ponzo illusion have an application here? I do not think it does – it does rase the question about perception and the degree of accuracy for quantities obtained through visual estimates of quantities.

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[285] Reproduced from Bach & Poloschek 2006 with permission of ACNR.

6.7.4 Conclusion to Sources of Errors and Mistakes

In this section, I have shown examples and explanations for large variances in the ReTRAC planning through errors, mistakes, and fraud. During the ReTRAC project while pressed for time and already overloaded it was nearly impossible to analyze and show these relationships. After the fact in the comfort of the CIFE lab it is much easier to review the ReTRAC quantities as case study material and pick out these distinctions.

From an overall standpoint I found that the correlation between the ReTRAC 5-week forecast and the as-built schedule is 0.70, this is a strong correlation and without a comparison project there is no way to know if this is above or below average. The ReTRAC project team diligently measured and applied the context features to quantities then audited for inconsistencies. The purpose of this effort was a database for reforecasting the project and presumably for reuse on other projects. The forecasting process - both baseline and reforecasting - does not have many software tools available, then or now, nor in the foreseeable future. The software tools available now are not very good – some are better than others but all are clumsy and require a high degree of manual manipulation.

With the errors removed the ReTRAC forecasting is surprisingly good – particularly considering the tools used. For example, the backfill activity I looked closely at was within 0.5% by volume and 2.5% by time. The mistakes I found were double counts and missing workzones – sometimes on a large scale, such as, the entire north backfill zone missing from the forecast quantity. Usually the error was on a smaller scale such as an omitted workzone or overlapping zone creating a double count – some of these canceled each other out. The process on the ReTRAC produced an error that is true of all projects in this era, that is the keystroke error. There was no integration on the ReTRAC, the closest was integrating two spreadsheet tabs. For this reason the errors from keying data are constant – I estimate 0.5% of the project quantities keyed, at best was erred. Almost certainly this was much higher. The third category is fraud, also called bias in some publications as a nicer term. On the ReTRAC I did not see outright fraud but there were instances that were difficult to explain. For example, the excavation laborers were attributed to have consumed 250,000 gallons of diesel fuel – this is impossible. Why was this represented is not known – if it was purposeful then it could have been field engineers gaming the annual end of year bonus system. The project contract was a lumpsum, design-build, with percentage completion progress payments – a system that has a minimal opportunity for gaming. Another possibility that support fraud is it was done to lessen the effort required from the field engineers and this may have been systemic.

A source of error I looked into further is the visual percentage of completion method of measuring quantities. With this method the project is viewed as pieces and each piece is estimated as a degree of completion based on what it is expected to look like once constructed. The question is, what degree of variation can the human eye discern. I did not answer this question – it must be answered similarly for all methods – but I did find factors that indicate this method has limitations. One limitation is the illusion created by some images – surprisingly one of these may help explain the misunderstanding about the backfill volume, this is the Shepard’s turning table illusion. The fills viewed from the side look narrow but viewed from the front look expansive. The project engineer specifically stated a group of fills looked narrow and must be small fills; I think Shepard’s illusion played a part in this opinion.

There are numerous sources of inaccuracies in project quantities that follow through to the planning – I demonstrate some of these here. I think these are the main sources of inaccuracies.

In the next section I conclude this chapter.

6.8 Conclusion to Discussion

The quantification process rests on two components, these are the measurement of the quantity as the features of that quantity. Each is a distinct task and not often presented as a joined relationship to define the quality of a quantity. Equally related with the quality of a quantity is the effort necessary to achieve that quality. The needs for quantities does not have a level need for quality – the need for quality differs with each purpose. Currently how to achieve the quality of a quantity is defined by the field engineer through the intuitive and sometimes learned application of a bundle of quantity features to meet the quality standards set by the field engineer. How to achieve that quality standard with the least effort is the goal of most field engineers and the optimal application of effort is in the best interest of the project.

In this chapter, I have presented discussions on selected quantification topics. The material I have presented as a bundle of publications, questionnaire survey, interviews, and ethnography appears representative of the methods used throughout the construction industry. The level of detail, indexical fineness, and quality of the quantification process may vary throughout the industry but the domain of the process is complete in my presentation. This material is skewed strongly towards the heavy construction industry and specifically towards large infrastructure projects. More specifically the contract type and organization structure or the project provides the closest fit with what I have presented. From this, I can back out from my ethnographic observations to say that what I observed on the ReTRAC is representative of the construction industry as a whole. Within the heavy construction domain the ReTRAC appears - with a few nuanced features - is representative of the best practice. This is not best practice research but in the process of compiling the material in this thesis, it has become clear to me that the ReTRAC stands as an example of a quality quantification process.

The quality of the ReTRAC quantities and the features of those quantities has held up surprisingly well under lab scrutiny. I have found example of quantities forecasts that are within 1% of the actual and activity scheduled duration that are within 3% of actual. That said, some of that was not entirely purposeful on the part of the ReTRAC field engineers, though pragmatically it stands despite clear cases of mistakes, errors, and bias. If I could do an ethnographic study of a larger number of projects I assume my observations would find practices that in comparison would make the ReTRAC appear polished with my magnifying glass removed. The effort exerted by the ReTRAC on quantification appears consistent with the industry standard of 5% of project resources. With this effort the quantities and resulting plans are not useable below the component level of detail and this precludes field level planning that is beneficial to the field crews. This means there is room for improvement. There are numerous inaccuracies in the project quantities that followed through to the planning system. Because the planning was not integrated the pass-through of an error from one system to another was limited. With the introduction of greater use of integrated systems these errors will become systemic and more difficult to detect due to the inherently fewer independent quantities used with integrated systems.

The core benefit of this chapter is presenting the relationship between quantification features and demonstrating the multitude of configuration that allow tuning the quantification plan to the purpose of the quantification with the goal of reducing effort while maintain quality. In this I have shown features of quantification. The implementation of these features is the responsibility of the reader of this thesis – whether it be for development of software, underpinning departing research, or application by field engineers on their project. A database of quantities that include the features of the context of not just the quantity buy also the features for how the quantity was measured allows for learning the behavior of the various features of quantification that I have presented. From this database, with the application of machine learning, I think the significance of each feature can be determined. With the features and the significance a predictive algorithm is then possible to determine that for a given purpose in a given context what specific bundle of quantification features will provide the optimal quality in quantity with the least effort. Today with field engineer responsible for quantification this is largely an exercise in theory but later when sensor based methods become prevalent I see this material applicable to determining which sensory methods to employ or when to allocate the quantification to a field engineer rather than sensory. Regardless of my speculative application for automation – today, independent of rules, field engineers use all the methods I have presented in this thesis to obtain quantities with the least effort. This thesis allows understanding that process and presents examples of considerations and examples of successes and failures.

The single most important feature of quantification that defines good or bad quality quantification is the effort necessary for the quality of a bundle of quantities. Towards this, in this chapter I have presented the measurement and assignment of context features both in breadth and with a follow-on section with pragmatic examples I observed of how to broadly reduce the effort necessary by reducing excess quality.

In the next chapters, I will provide the limitations I see in this thesis and them provide my concluding remarks. There is a large appendix of material after the conclusion, some is redundant and I kept it since I liked to format and other section is base material or other material I removed from the body.

7 Limitations and Suggestions

I have identified a problem in the heavy construction domain, the problem is beyond the scope of the Engineer thesis, and therefore at this point I must stop this study and make notes for future work. There are four topics that should be researched further from this study on quantities collection methods, these are:

- Experiments and empirical observation of tradeoffs,
- Investigating the monitoring aspect of the edge organization,
- Increasing the sample size of observations, and
- Observing monitoring methods used in other industries.

7.1 Basket of Attributes

The text *Construction Project Management* (Clough, Sears & Sears 2000; page 205) reviewed as part of the literature review on page 388 presents the research problem as status quo; the issue is a three-part problem:

First, “a system [project cost accounting] that only evaluates field performance intermittently in the form of occasional spot checks does not provide trust-worthy feedback,” Stallard – a senior cost engineer - reiterated this sentiment in an interview, p88. This leads to the question: what accuracy and consistency are provide with spot checks.

Second, *“project cost accounting must strike a workable balance between too little detail and too much detail,”* too much results in data overload and time lag, too little and the field engineer is not providing sufficient detail or scope for meaningful control. This leads to the question: *what inputs (spot checks) do endogenous calculations with assumptions need to change level-of-detail* to facilitate the research question in the first statement.

Third, the *“project cost accounting is meant to assist [field crews] by the early detection of troublesome areas.”* Saidi, this author, and the text emphasize that the field crew’s task is to construct the product not to collect quantities for the field engineers. The project monitoring system is for the benefit of field crews not a burden as the practice of *sand bagging - Field Observation* page 133 – indicates may be the case. Therefore, the last question is: *what field engineer resources are utilized to assist field crews to detect troublesome areas, i.e., monitoring* (indicates robustness, i.e., 100% robust = 0, 0% robust = 1, per $10M ($2005 US) of annual project revenue).

As a suggestion for future research: Place the known methods in context with their empirically observed application and then model the application[286]. For this formal process - empirically observe then model - of defining monitoring method, a set of metrics should be answered, Figure 42 on page 244. First, for each source, what sources were used, why used, by who and how often in a specific case. Second, what are the role of quantities for each purpose and what are the purposes? Third, record the pitfalls of specific quantifying methods, Methods of Quantifying on page 236. Fourth, from a history of observations determine what conditions are historically acceptable. These conditions should be for timeliness - what latency (p226) is acceptable for specific purposes; week – and what assumptions are accepted as part of the quantities. From these four studies an analysis can be made of the tradeoff in the limited resources (Table 56 page 254), of accuracy, precision, timeliness (production rate & crew) and risk. In post-processing extremes, everything could be measured in the field or nothing is measured in the field and everything is derived. A balance between these two extremes provides the optimum desired characteristic, for example: utilization of resources or quality of reported quantities. A validated tetrad tradeoff between level of detail, method and accuracy should be possible through:

- A correlation between feature breakdown structure, level of detail, and measurement method
- correlation between breakdown structure, level of detail, and accuracy
- correlation between method and accuracy

[286] This task is done and not articulated.

7.2 Organization for Monitoring

Explore the possibility that the issues identified in this paper are universal to mid-sized construction companies - defined here as less than $1 billion ($2010) in annual revenue - and is a transition phase as they move from a smaller company to a larger company and have the resources and need to improve their efficiency. There are philosophies of an edge organization structure that revolves around a four-person team. The edge organization has three core concepts, first, each person interfaces with only four people (three team-members and one support), second there is no management only support to facilitate performing as conditions will allow, and third the goal is for everyone to know and understand, complimented with universal knowledge sharing. It seems that the edge organization structure needs feedback of status and performance to facilitate those at the edge of the organization in deciding on their next action. Several documents are available discussing the edge organization; one is *Power to the Edge Command...Control...in the Information Age* written by Alberts and Hayes in 2002. Within the edge article in Chapter 3, p49 in the section titled *Industrial Age C2 – Simple Adaptive Control Mechanisms* is a discussion of the Observe, Orient, Decide, Act (OODA) loop. Alberts & Hayes cite a magazine article written by Hammonds as their source for the OODA loop process. This looped decision process is similar in concept to the *action research* process first coined in 1946 (Kurt Lewin). In the book, *Emotions* chapter 8 *Emotion Self-Regulation*[287] (2001) *G.* Bonanno describes a similar feedback loop the animal central nervous system utilizes for psychological self-regulation. This suggests that the OODA loop and action research loop, and other such problem solving loops are replicating and facilitating the human thought process. The literature review path continues from there. How the feedback process facilitates or limits this organization structure within the construction industry should be investigated.

[287] GA Bonanno "Emotion self-regulation," Guilford Press, 2001.

7.3 Sample Size

This study rests the core observations on a sample size ‘n’ for confidence interval ‘y’, in this case a sample of one project study with supporting literature synthesis and surveys. While the ReTRAC was a large project with activities representing most types of civil work activities, the sample is still one. I suspect that practices on other projects differ in ways not perceptible from this sample size, there are other contract types and design types other than lump sum design-build, these are: design-bid-build, time and material (T&M), and cost plus. There also are commercial products dedicated to project monitoring. A review of commercial applications available for quantities collection will cover the domain of knowledge that is entrepreneurial in characteristic. This may or may not differ from the academic research and traditional corporate aspects covered here.

7.4 Generalize Across Industries

It may be possible to generalize monitoring methods to the project production type. During this study, I made literature and survey observations of other industries; the picture seems unfinished. Through a comparison and contrast with other industries, some fields appeared to have irrelevant monitoring knowledge, but on closer inspection seem similar to construction project monitoring. For example, the nursing and agriculture fields have comparable methods. The nurse works in a mobile environment and must carry tools with them as they move and rely on permanent instruments. This is similar to the condition the field engineer works in and so it is possible a transfer of technology or methods would provide a benefit. A core difference is the accuracy and consistency in measurements; nurses do not estimate quantities, they must report measured values such as temperature[288]. In agriculture, specifically the heavy equipment and haul trucks are comparable to construction practices. The process of cultivation and harvesting shares operations with construction and even relies on the same resource book to derive production rates, the CAT handbook. There is the potential to transfer technology to agriculture and from agriculture. Neither the nursing nor the agriculture potential sources of transferable knowledge were sufficiently investigated. There are also likely practices in other industries that either are becoming applicable or are duplicate of practices in the construction industry. The meta academic field that precedes the individual project type fields, such as construction, mining, and shipbuilding is industrial engineering. For this reason, the methods employed in each field are likely derived from a common method. Comparing and contrasting how each exists today and has evolved in each field may illustrate specific attributes of construction that is otherwise taken for granted and may no longer be true.

[288] From discussion with California Registered Nurse R. J. Peterson.

8 Conclusion

As I stated at the 2009 CIB-IDS conference, construction status assessments are notoriously unreliable and labor intensive. I believe that current project control practice is comparable to early 20th century medical practices. Like doctors during the 1918 influenza pandemic[289] the only benefit the field engineers provide is collecting quantities and the features for future research. With the technology available today it is not possible to affect the outcome of a specific project. Some projects go well and some do not.

Quantities collection is a topic that is overlooked in favor of ones that are more spectacular. As a field engineer on the ReTRAC project I saw that experienced engineers shunned this work as tedious and labeled it a *pigeon hole* task that would not led to a bonus or promotion. For context of the significance placed on this topic, in the Association for Project Management Guide[290] (2002) a single subsection provides practices for quantities collection. Though the importance of an updated schedule is consistently defined as "essential to status" for schedule performance – not just in the APM Guide but most project management resources - the guide states the practice available today, *"estimate [the] time remaining to complete the task."*

Quantities are one of the variables in construction that due to the physical project site and project plans should be possible to determine both finitely as a measured independent variable and to save resources reliably estimated as a dependent variable. Even with this dual tangible and intangible attribute, in the construction industry quantities are often measured and estimated in ad-hoc ways, resulting in dubious results. A more exact measurement of quantities to-date than possible by following guidelines such as the APM guideline is increasingly possible. More exact measurements result in a higher degree of scheduling accuracy and repeatability. Better schedules result in a better understanding of what to expect and being prepared. With that, the ability to adapt will result in fewer impacts on the workforce safety, fewer impacts on the environment, and fewer impacts on the surrounding community. The overall achievement will be large construction projects that leave a lighter footprint.

The methods provided in this study, present the current states of practice though literature review, surveys, and ethnographic observation. This preliminary knowledge is now the basis of further research, investigation, and hypothesis testing.

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[289] Human Virology at Stanford "The Influenza Pandemic of 1918" updated February 2005 virus.stanford.edu/uda/
[290] A source for Earned Value Management (EVM) methods typical of the literature reviewed.

9 Appendix

9.1 Appendix A: AACE Recommended Work Breakdown Structure

The American Association of Cost Engineering AACE 20R-98, 2003 recommended work breakdown structure (WBS) contains ten categories. I paraphrased the following ten sections from the 20R-98 text, I rearranged the sequence to follow other work breakdown structures, such as the Construction Specification Institute (CSI) MasterFormat or the National Institute of Science and Technology (NIST) Uniformat. Notice that the AACE 20R-98 (2003) does not include the resource, operation, and method levels associated with detailed estimating and the accompanying project monitoring methods.

Timing

Budget approval year, fiscal year, and quarters are examples of timing characteristics. Budget approval year can be part of the features, but this is associated with the highest level on the project and not required to be a part of detail coding. The availability of project funding drives the start timing of projects and projects are driven by cash flows to the extent that scope and schedule are adjusted to accommodate cash constraints throughout the life of the project.

Organization

Primarily a responsibility characteristic, it is often combined with cost type to achieve a hybrid cost type and eliminate extra coding requirements. Responsibility, company, department, trade, discipline, internal/external are examples of organizational characteristics. Organization tends to be company and project specific than the discipline characteristic. Owner versus contractor is an organizational breakdown.

Direct and Indirect Cost

Direct costs are those that are readily or directly attributable to or become an identifiable part of the final product (for example, piping labor and material). Indirect costs are costs that are not easily attributed to a part of the final product, for example, costs for managing the project. Indirect costs are also called *prorates* or *distributives* because they must be allocated to direct cost categories to determine the total costs of a product or asset type. Indirect costs can also be called *overheads*, this is technically incorrect, because overheads are considered a subtype of indirect costs.

Cost Group

Represents a summary categorization used for cost reporting. A cost group may be a combination of the cost type and direct/indirect characteristics (for example, direct material, direct labor, and so on).

Geographical Location

Geographical characteristics, such as, country, region, state, province, plant, area, or unit.

Area and Unit

These are two separate characteristics, but they are routinely used in combination. Area refers to a geographical location with a defined boundary and is often a term used in the process industries. Units are a characteristic used in the process industries. A unit is a set of process equipment and ancillary commodities that together perform a defined process step (a unit also may be considered a product). There are several units within an area.

Discipline and Commodity

Discipline is a type of work, craft, profession, or trade. Each discipline employs a unique set of skills and knowledge and tends to work with different types of materials, i.e., commodities, and resources. Other names for the discipline characteristic are *major account*, *prime account*, and *class*. This is a characteristic of project control because grouping like skills and commodities together facilitates productivity and progress analysis. In addition, these groupings are for benchmarking because discipline level practices are applicable to any project, while asset-type accounts are project specific.

Work Process/Activity/Phase Characteristics

Represents the process steps or activities required to execute the work scope, for example, review model, write code, drill well, erect pipe, and install storm drain grates. *Work Classification Structure* (WCS), *Standard Activity Breakdown* (SAB), *discipline*, and *activity type* are other names used. Phases are stages of project development over time and represent summarized work process steps and activities. This characteristic is a basic part of job cost accounting.

Product or Deliverable (component)

Deliverables are the physical product or a key milestone that results from the execution of work activities. It may be the final product at the completion of a project or an intermediate product such as a requirement document. The product account rolls-up the costs, i.e., the disciplines and cost types invested in that product.

Cost Type

The type of resources, such as, labor, material, i.e., equipment and bulk materials, or subcontract, i.e., a combination of labor and material. In Construction Project Management (Clough, Clough & Sears) cost type is termed a distribution code.

9.2 Appendix B: Observed Assemblies

Observed Assemblies

Assembly description	Input	Source	UoM	Recipe-formula	Output	UoM
load count	density	Quarry lab or empirical test	TN/LCY	EA * volume * density (1.75 tn/lcy)	Bulk loose material, e.g., aggregates	TN
	volume	trailer mfg. specifications	CY			
	haul truck load count	invoice	EA	EA * volume * shrink factor (.64)	structural backfill trench walls backfill load out	BC
	Shrink factor	Spec. final density and initial density	PC		haul backfill	
distributed	concrete delivery	ticket	CY	distribute to misc. concrete activities	activity 0 activity n	CY
accrual	aggregates delivered	scale ticket	TN	TN * unit cost	haul	$
haul	aggregate quantity	scale ticket	TN	equals	aggregates aggregate import haul triple-transfer	TN
inspection	cost to date	ERP	$	equals	Inspection quantity	LS
grade, base & finish	% complete grading SW/CW	calculated	SF	takeoff * (PC(SW) + PC(CW)/2)	to-date quantity SW based to-date quantity CW based	SF
assumed completed	grade or base C&G	direct measure	LF	equals	grade C&G base C&G	LF
support correlation	direct work	direct measure	SF	equals	direct work support resources	SF
indirect	labor hours	timecards	MH	equals	first aid drug testing protective clothing safety award small tools fall protection	MH
cost	labor and equipment cost	ERP unit cost & quantities spreadsheet	$	labor assumed 70% Q * L&E/unit * .7	labor cost	$
man-hours	resource months	estimate	MO	Assumed 176 workhours per month MO * 176	resource hours	MH
material quantity	measured work-in-place	direct measurement	PC	=(IPF C&G + IPF CW/SW) * takeoff(CY) * TN/CY	base quantity	TN
unbalanced assembly	haul truck load count	timecard or invoice	LD	116,438 EA * volume * shrink factor (.64)	shoofly excavation shoofly cut to fill load cat330 haul 25t snglside support	BC
		timecard		97,966	screen 3in minus 3in minus sub	
balanced assembly	haul truck load count	timecard or invoice	LD	EA * volume * shrink factor (.64)	Dickerson ave exc. load cat330 haul 25t snglside laborers operator foreman grade setter D&C incoming matl water tanker	BC
sub-contractor	sawcut	field measure or invoice	LF	equals	sawcut sub sawcut AC	LF
material	cost with no	see material quantity	$	add cost with no	cost	NA

Observed Assemblies

Assembly description	Input	Source	UoM	Recipe-formula	Output	UoM
quantities cost	compatible unit	sheet		assigned quantity		
header codes	sum to percent complete	issue with mixed units & varied weightings	UoM	Sum ($x_0 \rightarrow x_n$) / n	header summary PC	PC

9.3 Appendix C: Data to Include with Measurement

The following fields were observed collected on the ReTRAC project. These fields are a mix of data collected as part of the project monitoring and equipment managing process. Note that the contextual features for equipment.

Data to Include with Measurement

Kiziltas et al., 2006	Saidi 2002	ReTRAC
		Company
Phase number	Contract item number	Job (project) Number
Where measured, i.e., location		Location
	Cost code	Cost Code
		Department
		Labor Type
		Subcontractor Type
When measured, i.e., time		Date
		Haul type
Material type, e.g., Soil conditions		Material Type
		Fuel type
		Equipment Type
		Equipment Model
		Equipment Year
		Specific database key (Equipment Number, License number (DMV), Employee Number)
		Specific Identification (Serial Number (VIN), Business License, Invoice Number, Social Security Number)
		Equipment Condition
		Rate group
		Rate
		Date Available [equipment]
		Assigned [equipment]
	Description	Description
	Unit of measurement	Unit of measure
Weather		
Shift of shifts, e.g., swing of three shifts		
Product features, e.g., total takeoff quantity or shape of components		
Cut depth or component dimensions, e.g., haul distance		Feature of work – rarely used
Resources & capacity, e.g., equip. labor capacity		
Method of measurement, e.g., laser scan (implied)		
The Measurement		
	Quantity adjustments	
	Previous period quantity	Previous period quantity
	Current period quantity	Current period quantity
		Total Quantity to-date (e.g., Odometer)

9.4 Appendix D: Literature Not Reviewed

Due to lack of time and resources, these publications were not included in the literature review. I briefly reviewed these publications though I did not find anything significantly deviating from this thesis.

Table 74 documents cited by or suggested for further reading by the Association for Project Management (APM) *Body of Knowledge.*

Title		Year	Organization
Association for Project Management (APM) referenced material			
Industry Guidelines for Earned Value Management Systems	ANSI/EIA–748	1998	American National Standards Institute /Electronic Industries Alliance
Guide to Project Management	BS6079-1	2000	British Standards Institution
Project Risk Analysis and Management Guide		2000	Association for Project Management
Guide to the Management of Business Related Project Risk	BS6079-3	2000	British Standards Institution
United Kingdom The Program Managers' Guide to the Integrated Baseline Review Process		2002	
Association for Project Management (APM) suggested reference material			
Department of Defense Handbook Work Breakdown Structure	MIL-HDBK-881	1998	United States Department of Defense
Cost Schedule Status Reporting (C/SSR) Specification and Implementation Guide	DEF (AUST) 5658	1994	
Australian Cost/Schedule Control Systems Criteria; Implementation Guide	DEF (AUST) 5657	1994	

Author	Univ.	Year	Title	Publication	Topic	Finding
		1994	Cost Schedule Status Reporting Specification and Implementation Guide	DEF (AUST) 5658	Status reporting	
Kang & Paulson	Gyeongsang Nat. Univ.	1997	Adaptability of Information Classification Systems for Civil Works	J. of Con. Eng. & Mgmt.		
		1994	Australian Cost/Schedule Control Systems Criteria; Implementation Guide	DEF (AUST) 5657	Project control	
Akinci	Stanford Univ.	1996	ENGR Thesis		Project risk factors	Literature review - cost overrun factor
		1998	Handbook Work Breakdown Structure	DoD MIL-HDBK-881	WBS	
Akinci	Stanford Univ.	2000	PhD Thesis		time-space conflict	
		2000	Guide to Project Management	BSI - BS6079-1	Project management	
		2000	Project Risk Analysis and Management Guide	APM	Risk analysis	
		2000	Guide to the Management of Business Related Project Risk	BSI - 4 BS6079-3	Risk analysis	
G. Humphrey		2002	*PM using EV*	Humphreys & associates	EVM	
		2002	UK IBR Guide			
		2006	Total Cost Management (TCM) Framework	AACE		
		2007	Industry Guidelines for EVM Systems	ANSI/EIA 748	EVM	
ISO/PC 236, *Project management*		2012	ISO 21500	ISO		
			Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results	NIST		
		2006	Project Management: A Managerial Approach, now in the 6th edition			
Memon et al.	Univ. Tekno. Malaysia	2006	A Systematic Approach for Monitoring and Evaluating the Construction Project Progress	Journal – Inst. of Engr. Malaysia	Project monitoring	Survey–manpower, cost, and time weighting methods
Wymm & Clarkson	Univ of Cambridge	2009	Design Project Planning, Monitoring and Re-planning Through Process Simulation	Intl. Conf. on engr design	Project monitoring	Non-ideal metrics used in practice
Staub & Fischer	Stanford University	1999	The Practical Need of Integrating Scope, Cost, and Time	Durability of Bldg. Mtrl. & Components	Scope-time-cost	
Zwinkels, P.	PEO	2006	Project (time) Control for an EPC Project	Planning Engineers Organization (PEO)	Project control	www.planningengineers.org/publications/papers.aspx#latestpapers
		2008	Practice Standard for Earned Value Management	Project Management Institute (PMI)	Baseline & forecast cost est.	

9.5 Appendix E: Parting Advice

On the ReTRAC project, three managers had started in the construction industry as field hands and did not attend a university or obtain a degree. Due to their age, this was likely one of their last projects if not the last[291]. They had a unique perspective on the construction industry since their knowledge was empirical. These senior managers gave the following points of advice for new field engineers that with time have showed themselves as the truth rather than spot comments or dry humor:

- “Encourage the employees to take-on debt; they cannot quit without a prearranged position on another project.”
- “Promote the least talented or productive to a management position so you do not lose anything; possibly a poor engineer is now valuable as a manager.”
- “On the next project, no one will know how you did on your previous project; what matters is they recognize your name and no one has an issue with you.”
- “Beware of the fingers you step on during your assent of the corporate ladder; they are attached to the people you will pass on your end of career decent.”
- “You field engineers are the same in knowledge and talent as far as I am concerned, I could put you all in a bag, shake it up, and pick one out; anyone can be a field engineer, even that bum pushing the shopping cart down the street; he may even make a better one.”
- “You [a superintendent] are not right for large projects if you focus on the field details; let the field crews handle the daily issues and focus on providing the resources they need to succeed.”
- “Recruit engineers from small regional universities; they do not expect the salary that graduates from prestigious ones do and have a low comprehension of their rights.”
- “Just figure it out; no one knows the answer.”
- “Just get it done; it is close enough.”
- “One day you will learn how to be an asshole.”

A last bit of advice given years before becoming a field engineer was from Charlie, a 29-year veteran of Laboring. When I told him during a lunch break that I wanted to attend a University he said, “You will go to school and you will do well; remember what it is like right now, remember this: how everything has been, remember this moment right now, do something that will make it better for us.”

[291] Recent searches indicates that for two this was their last large project, the third went on to the next large project.

9.6 Appendix F: Hazing

As a field engineer, a series of innovations progressively led to new methods in how I collected quantities. The innovations started practically as I needed to increase my productivity due to being overloaded with work as *the new guy* and then proceeding as something of a challenging game. It was apparently a hazing process in the corporate culture to overload the new field engineers until they were working 16 hours a day or quit. I asked one of the clerical staff what the previous field engineers - a couple quit. I was pulled from my new hire training at the regional estimating office as an emergency replacement for one (they saw my field experience as a laborer and decided I could take his place). I wanted to know what he had done for a bi-annual task that was particularly tedious, repetitive, and labor intensive. She said he worked all night. At least one of my fellow field engineers worked late evenings at home calculating his quantities. When I asked my supervisor about the field engineer that quit, he dryly replied that 'the wolves got him."

I became determined to not only diligently do the work assigned by the project engineer but also skew his perception of resource intensity by completing tasks quicker than usual. This is a trick I learned as a highway concrete Laborer. If a laborer was shirking work and could hide this from the foreman, then if given the opportunity for discretion I increased the work-pace. This appeared to create the perception that the work is easier than it was. I'd be done by lunch, claim it was easy work, and ask what I should do next, to the surprise of the foreman. A line of balance chart demonstrates the affect on resources of unexpectedly increasing production; the preceding and succeeding tasks must match the production to remain balanced. If the foreman is inexperienced he then expected similar productivity from the other workers, placing pressure on them to *pull their weight*. The concept is similar to the well-known phenomenon of *bending* in manufacturing lines. This is where a worker jabs an elbow in a neighboring worker for inadvertently working faster than the communal pace. In this case it is a jab to pick-up the pace for someone that is forcing the other workers to carry some of their work. My perception is that if a manager observes a worker proceeding at a faster pace they will expect the same production out of other workers. In this case, the elbow jabbing of the fellow worker occurs for variance (+/-) from a set work-pace (sustainable, safe, and healthy pace). Anyone working faster or slower than the pace will receive an elbow. As a Laborer, I received and possibly delivered both on occasion. It was difficult for the workers shirking work to maintain the new pace since they were out-of shape from the light work, similar to skipping a few days at the gym. The other guy got it. Empirically, from my experience, the result is the fellow laborer who was shirking work, would conform to the pace. Why not simply notify the manager; it is universally considered uncool to *rat* on a fellow tradesman, especially to management, regardless of the reason. The example given is one way of dealing with such issues. This issue is not unique to humans, my grandpa told a story about draft horses shirking work and hiding it by maintaining tension on their harness but not pulling. If the teamster did not notice and push the horse to work the reaction of the paired horse was to turn and bite the other horse to pull its weight. This narrative is included to illustrate that maintaining an equal workload is not unique to the experiences presented or specifically to humans, but appears to be a characteristic of animals, potentially dependent on the defining scenario, i.e., harnessed to work, and is a recurrent topic in the literature review and field observation as bias.

The success of this tactic as a field engineer is dubious; the managers never reduced the workload they placed on me. As the project began to wind-down, the project manager instructed the other field engineers to train me for their jobs as they were reassigned to other projects, Table 40. Since I had spent late-nights automating field engineering tasks, therefore resulting in a higher production rate, I was left with a mostly automated system of project monitoring rather than an assignment to a new project where I would have continued with the process of automating tasks. The unintended consequence is as management became aware of how I was calculating quantities they became concerned and instructed me to remove the automation and do the tasks the *real way.* Search Google scholar for innovation literature published by C.B. Tatum, such as Tatum, 1989 and Tatum, 2005, for a formal review of organizational disruptions caused by innovation, the scenario given here is a manifestation, p314. The managers did not understand how the system worked and seemed to think the use of automation was cheating. There was also the reliability issue that a replacement field engineer would not be able to learn the system without training outside the project management's capability. When I explained their changes would result in reduced quality of the reported quantities unless the project provided additional field engineering resources they backed off.

While a field engineer I had to research and experiment with methods of quantities collection while completing field engineer's tasks. Here at Stanford I am now able to research and experiment with quantities collection methods fulltime. Alternatively, divorced from the worksite, my resources and test-bed scenarios have been lost, therefore limiting experimentation. For example, a method attempted on the ReTRAC project facilitated by project resources but unable to pursue further due to knowledge and lab-time constraints was sensor-based monitoring. An engineer at the waste management facility wanted to experiment with sensor-based monitoring and so I distributed laminated cards with a barcode to the ReTRAC project Teamster haul truck drivers. The idea was the drivers presented the card at the waste management scales. The field engineer would then be provided an electronic invoice containing a barcode identifier, date, and time. Three issues were observed, first, the need to retrieve the cards each day and reissue the next morning, second, resistance from drivers and field supervisors, and third, the office practices at the waste management facility. The office staff retyped the electronic invoices into the invoicing system, therefore nullifying the intended electronic invoicing benefit. The balance between resource limitations of labor, equipment, material, knowledge (subcontracting), capital (funding), and time has been a tradeoff throughout the innovation of monitoring methods. While now the stimulus is innovation, the original stimulus was avoiding the wolves – whoever they were.

9.7 Appendix G: Notes: Reference Text Literature Review (original)

The following series of sections are my notes from literature reviews of reference texts and publications. In each section, I present the material, and then relate this across publications and with my ethnographic experiences. I specifically selected these texts to pull from a range of sources in an attempt to gain a compelete survey of the current domain of knowledge.

9.7.1 Field Engineers Manual

The *Field Engineer's Manual*, authored by R. Parmley (3rd edition, 2002) is a reference book published since the early 1980's specifically for field engineers. The purpose is a compact field guide - format suitable for carrying in a safety vest pocket. The book covers twenty-five topics: as a field engineer, the most useful for me were the sections on basic geometry formulas, material density, and design specifications. The book is a compilation of literature from technical organizations, societies, manufacturing firms, publications, and consultants. For example:

- Public works Inspectors' Manual
- Cooper Engineering, Morgan & Parmley, LTD.
- Practical Tables for Building Construction
- American Institute of Steel Construction
- Handbook of Steel, Drainage and Highway Construction Products

This reference book does not contain quantity collection material and I reviewed it as an example of a guide specific to field engineers that does not cover the topic. The absence of quantities knowledge could imply that field engineering does not include quantities collection, though empirically I have not found this the case. I cannot explain this contradiction. My guess is the editors of the book are 'pure' civil engineers and do not bother themselves with construction planning.

The CSU Chico construction management lecturers did not introduce the manual during my undergraduate education. However, the lecturers derived their handouts, lecture materials, and purchased course pamphlets from the reference materials. It would have been nice to have the material presented accompanied by the text so I could tab it for use in the field. Ten years into my construction career, I found the Field Engineer's Manual on a retired field engineer's (my uncle) bookshelf. I think the manual should be in the labor crew trucks along with the crew first aid kit, water jug, and safety equipment. The guide represents the tacit knowledge I learned empirically during ten years of practical experience and five years of courses.

There are multiple methods to perform an operation. On page 1-11 of the Field Engineers Manual is a diagram of how to construct formwork with wailers and a strong back. The added structural strength of strong backs is unnecessary in most cases but the guide would have been helpful in the field for design ideas. As a Laborer, my crew was told to build forms for a 24" concrete bridge approach slab. Everyone had a different vision for the formwork, in Figure 68, the design engineer (assumed envisioned) and superintendent, the journeyman finishing mason, and me, the journeyman concrete laborer that actually built it.

Figure 68 Three visions of formwork; as laborers we had not seen formwork higher than a 10" highway cross section and did not have reference material. The superintendent saw the design on the left (carpenter panels). Based on 'Vitruvi' experience we framed and sheeted forms similar to those in the middle (like a house wall). A journeyman mason saw the design on the right (mason forms).

The guide could easily add a section explaining project monitoring. It would be useful. For example, the field engineer needs a quantity takeoff to order material for delivery, the mixed use of project independent data from the guide and project specific data measured from the project can provide a reasonable estimate of quantities. The guide already has the base components for deriving quantities in the dimensions and densities. I see the chapter as a source of recipe formulas for conversion, geometric formulas for post-processing of measurements, conversion factors for post-processing, and project independent details and specifications to generate a takeoff quantity of the expected work-in-place.

For example, the field engineer could calculate the expected work-in-place with assumptions already in the guide. On page 14-2 there is a project independent roadway cross section and on page 16-20 pipeline bedding and backfill conditions. The field engineer can derive a quantity from these project independent details based on minimal field measurements, for example lineal feet. A takeoff of the detailed cross section multiplied by distance provides an estimated quantity for work items.

9.7.2 Estimating

Two reliable texts I reviewed focused on academic cost estimating. Neither of these gave much consideration to project monitoring. The value from these is they give insight into why quantities and the features of quantities are important. As inputs into the estimating process, without quality data as inputs the estimating process will suffer.

9.7.2.1 Estimating and Bidding for Heavy Construction

Estimating and Bidding for Heavy Construction by S. Bartholomew is a textbook originating out of the California State University, Chico. Bartholomew is a heavy civil engineer recognized in the underground heavy construction industry. The textbook review and an internet search did not provide the companies Bartholomew worked for or was associated, but an email to Russell Clough[292] found that “He mostly worked for Fruin Colnon[293] then taught at Chico for 25 years+.” This textbook is the core source for the estimating practices of heavy civil contractors.

In his estimating textbook Bartholomew ignores quantities in project monitoring – a reasonable expectation. What I gain from his text is why we need quantities. Many field engineers see quantities as a billing topic, not a planning topic. Without accurate quantities, we cannot accurately forecast. Bartholomew shows us that relationship and the categories we need quantities divided into. The text contains an example of a drainage canal project (Chapter 4) that is essentially the transportation rail access corridor project I use in the

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[292] Russell Clough, Lecturer at Stanford University (2011). www.russellclough.com
[293] The Fruin-Colnon Contracting Company is now part of Bilfinger Berger and was renamed BIS Frucon Engineering Inc. Website last assessed 2011. www.bisfei.com/index.php/about-us/company-history.html).

Ethnographic Field Observations chapter (p196). Therefore, the methods in the text relate easily with the observed project.

Quantities form the basis of production rates – which then form the estimated cost, ultimately, we want to use the quantities to plan our future. There are differing purposes for planning the future; Bartholomew gives these purposes for doing estimates based on two actor roles, the owner, and the contractor (Chapter 1):

- owners
- conceptual
- evaluation of alternatives
- owner expected cost
- contractors
- bid
- evaluation of alternatives
- for change or breach of contract damages

*The Bartholomew list of estimate types contrasts with the list given by the Industrial Engineering Text (p394), Table 75. The project and advanced approaches in the industrial engineering text are not in the Bartholomew construction estimating text.

Table 75 The level of detail of estimating methods is comparable to the level of detail of monitoring methods.

level-of-detail	Estimate Purpose	Estimating & Bidding for Heavy Construction	Cost Analysis & Estimating for Engineering & Management		Project Management Body of Knowledge	
		Estimate Types				
Owner	conceptual		universal methods -opinion -conference -comparison -unit		analogous (compare with previous project)	expert judgment (mix of methods)
Owner	evaluation of alternatives	unit price	project methods -power CER -other CER -factor			
Owner	owner			advanced approaches -expected value -range (PERT) -percentile -Monte Carlo simulation	parametric cost (statistical relationship)	
Contractor	contractor alternatives change breach of contract damages	unit labor-hour crew and equipment work-item analysis	operation methods -cost & time relationship (CER/TER) -performance time data algorithm	product method (learning CER method)	bottom-up (estimated at greatest level of detail)	
			If cost is known not estimating; an accounting procedure			

Each estimating method correlates with the historical library level-of-detail and defines the minimum level of detail (p255) or, if an acceptable approach, the output level-of-detail achievable through post-processing. For example, if I use percentage of time complete, that does not leave much room for inferring a greater level of detail. Maybe I can distribute the percentage complete across all the components in the project and assume they are all equally complete. As the counter example. If I carefully measure the tons of material hauled to the construction site and I know the density of the material. With tons and density I can calculate the volume – it will not be exact but I have confidence it will be close. With that confidence, I can use the calculated volume for my quantity measurement. With confidence in the conversion from tons to volume, I would probably reuse the volume to infer the progress on related tasks.

The highest level of detail in estimating and monitoring is the project type. For example, excavation have an average duration *t* to build. Therefore, at duration *t* the contractor assumes the excavation is finished, progresses the schedule to finished, presents the owner a payment request, and mobilizes their resources for the next project. The lowest level of detail in estimating and monitoring is the bottom-up method. Using the same example of an excavation, the contractor monitors by both a truckload count and a survey - for example laser scanner - of the excavation. The schedule is progressed in relation to the quantity percentage of completion compared to the expected total quantity. When the quantity installed equals the quantity expected, then the contractor assumes the excavation is finished, progresses the schedule to finished, presents the owner a payment request, and again mobilizes their resources for the next project

A dedicated chapter out of 13 chapters (Chapter 4) indicates the importance of The Quantity Takeoff. The takeoff quantities are broken-down into four subcategories, these are permanent items, removed items, temporary items, and altered items (e.g., soil treatment), Figure 69. Within these categories are five takeoff categories, each has specific conditions given in the text. The text provides examples for takeoff calculations; each essentially is an example of a recipe-formula for different scenarios.

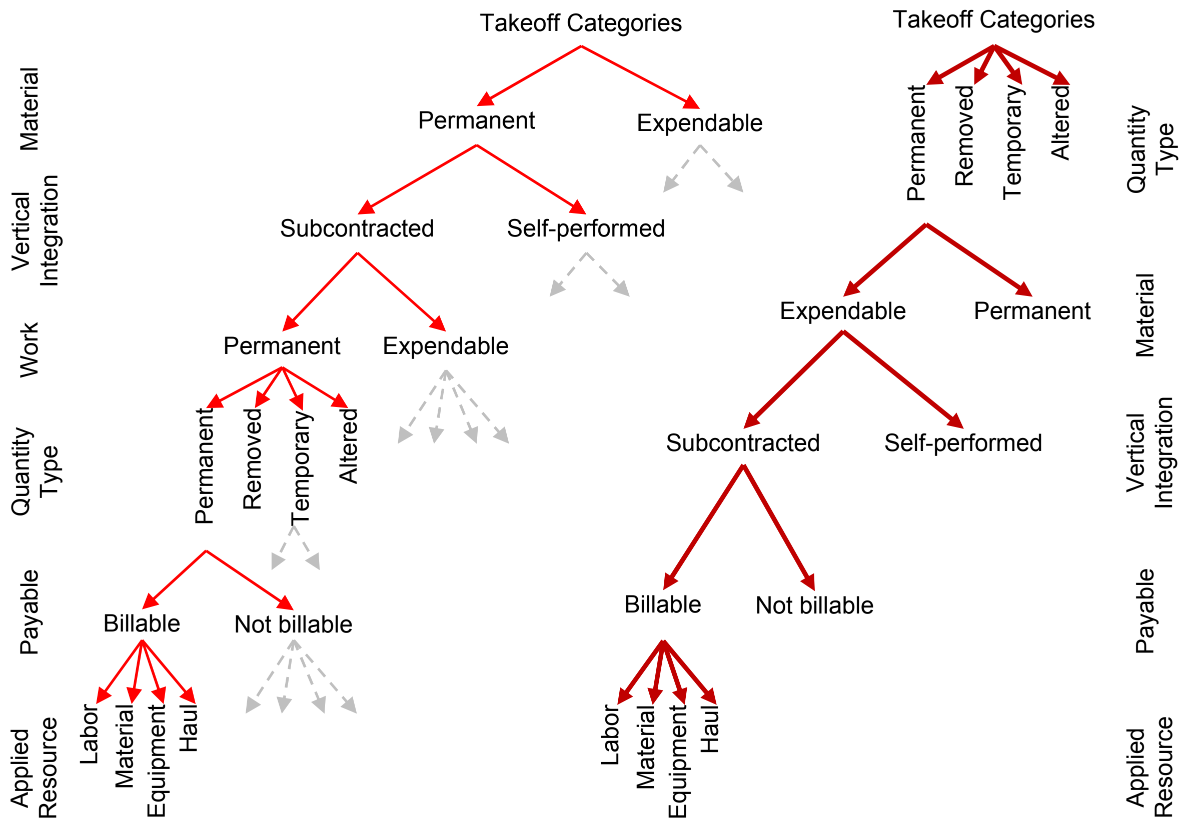

Figure 69 The Bartholomew takeoff breakdown structure. Bartholomew discusses the four takeoff categories as one level and they logically represent two levels. On the left is Bartholomew's breakdown and on the right is my modified interpretation.

The text provides details on different types of materials, such as direct and indirect, and - without using the term - defines between project specific data and project independent data. *The Quantity Takeoff*, provides the project specific items as (same as the five takeoff categories): temporary items, altered items, permanent material (subtotaled as either subcontractor or prime contractor), expendable material, payable quantities, and quantities of work by operation (Chapter 4). *The text implies the field engineer uses the project plans and specification as the source of the take-off, though the specific source of the takeoff is not in the text. The breakdown structure Bartholomew gives is the basis for a nomenclature like what the text *Construction Project Management* (p388) describes. Bartholomew does not go into this detail – that seems strange since he does discuss forming cost libraries from historical costs, so he had some concept of categories of costs. From the text, I can only assume he used text descriptions for the categories.

Project independent and project specific items are represented as indirect, i.e., activity/operation independent and direct, i.e., activity/operation specific items. The text does not distinguish between independent and specific. The activities, components, operations, and methods could be project independent or specific. Peurifoy and Schexnayder do not distinguish between project independent specification and plan detail libraries. The estimators assemble these libraries prior to the bid. I assume Bartholomew intended that these were already in an estimating office.

Note that while Bartholomew primarily focuses on the estimating process he also addresses project oversight. One representation issue he discussed, and I repeatedly found throughout this study is the topic of monitoring material and equipment. The method of representing material and equipment is with a direct-work account or an indirect-work account. This incredibly important topic is deceptively easy to dismiss. On the ReTRAC project the managers decided to dismiss this and it created numerous problems with documenting the allocation of resources. Representing material and equipment input and output is addressed in (p298), in *Estimating and Bidding for Heavy Construction* (p388), and as a special condition in the Stallard interview (p88). Bartholomew does not specifically address the representation issue, note that Bartholomew does not categorize the equipment and material as an indirect (Chapter 11). There is a subsection addressing carrying applied resources as an indirect or direct (Chapter 3, p42). Individual estimators inconsistently group items as an indirect or direct; the estimators estimate the indirect items after the direct items are finished; I assume these instructions apply to the budget. There is also a section dedicated to distributing equipment resources across the direct work (Chapter 5). The project engineer covers the equipment costs by distributing the equipment costs using a distribution method, such as percentage, level of effort, or cost ratio[294]. As an alternative the project engineer can define equipment as a cost center and cover the equipment costs with the apportioned effort method as the product of a predefined rental rate and a measurable unit, for example equipment operating hours (p388 and 297).

Next, I review outside of construction the larger project management industry. Looking outside of construction gives context to this literature review; construction is a special subdomain of project management. There may be lost knowledge in construction practices and practices that field engineers specifically do not use in construction for implicit reasons. Through a review, I will find these differences.

[294] Bartholomew does not specifically give these methods by these terms they are implied as intuitive methods available to the field engineer.

9.7.2.2 Industrial Engineering Text

For industrial engineering knowledge, I reviewed *Cost Analysis and Estimating for Engineering and Management (2004)* by P. Ostwald & T. McLaren*.* The authors Ostwald and McLaren present cost engineering knowledge as it applies to the broader manufacturing industry, Table 76. Initially, the difference between the broader industry and construction appears as the sophistication of the estimating methods.

Table 76 Industry attributes; the comparison with agriculture does not capture the nature of construction. In construction, the project-to-project location is variable but within the project, the location is fixed. Second, while the total construction product is expensive, similar to agriculture the components that make-up the product are not. Additionally, harvesting durations are equivalent to project activities and have similar changes in location, methods, and equipment. From *Cost Analysis and Estimating for Engineering and Management, table 7.1*.

Comparison Industry	Plant & Equipment	Location of Plant Site	Output of Industry	Relative Value of Output, Customer's View
Construction	Portable	Variable	Immobile and unique	Expensive
Agriculture	Mobile	Land fixed	Moves off the plant site and is numerous	Inexpensive
Information & Service	Transitional	Virtually anywhere	Temporary	Low price
Manufacturing	Fixed	Fixed	Moves off the plant site and is numerous	Cheap to expensive

There is an introduction to double entry accounting (Chapter 4.1), as first presented by the Italian Benedetto Cotrugli (1458). The simplest form of double entry accounting is the *T-account.* Double entry accounting is a core component of defining and optimizing return on investment - the meta empirical goal of these project monitoring methods in this study - derived from feeding the financial accounting system with cost and context. In respect to optimizing return on investment: Producing metrics, such as productivity and unit cost are by-products that benefit the project's management team. The core goal of the metrics is representing the degree positive or negative value generation - not micromanaging productivity and profit margin.

The industrial engineering text provided a precise presentation of concepts and terms that field engineers use. The meaning of these concepts has sometimes drifted from the original meaning, have differing terms (or no specific term), or has taken on entirely different meaning. The accounting term *standard cost* is defined as what the dollar amount should be, also known as the estimate (Chapter 4.10). For project monitoring field engineers measure *variance,* or the deviation from the average. As an extension, *quantity variance*, measures the change in units that were required to produce the product. Field engineers do not use the term quantity variance. The term is not in the construction specific literature, observations, or indirect observations. Logically, the quantity variance concept appears in construction with differing terms such as re-work, scrap, over-excavation, and waste; the Stallard interview captured quantity variance as yield, p182. Ostwald and McLaren present forecasting as a statistical analysis such as graphical analysis, single and multiple linear regression, correlation, indexes, moving averages and time series (Chapter 5). The range of forecasting methods contrasts with construction where forecasting is not statistical. They present the methods of estimating in detail and cover a broader domain of methods than construction texts (Chapter 6).

Monitoring and estimating share aspects in deriving a numerical value. The universal methods are personal opinion (i.e., guesstimating, p249 and page 254), conference (nonqualitative), comparison with similar product, and unit (qualitative), Table 75. The unit estimating method - popular in academic classes and observed in the heavy construction industry - has subcategories of average, order of magnitude, lump sum, function, parameter, module, and factor. The range of methods in addition to the universal method (each with sub-types) includes the universal methods, operation methods (Chapter 7), product methods (Chapter 8), project methods, and advanced approaches. The core takeaway from chapter 6 is that estimating involves unknowns, otherwise it would be accounting. In *Product Estimating* (Chapter 8.3.1), the *bill of material* is presented (Chapter 8, p359). Ostwald and McLaren do not discuss the details of how industrial engineers derive the bill of material beyond features for completeness and level-of-detail. The project planning theory presented by the authors integrates the *costed bill of materials* with the labor and material cost estimates but does not include the time, overhead, or equipment components.

9.7.3 Project Planning

9.7.3.1 Construction Project Management

Construction Project Management (CPM) is both a textbook and reference book: the authors are professors at the University of New Mexico. The first author Clough had a background in construction and was a senior executive at a construction company. Neither author is associated with the large heavy civil contractors that I use later in this thesis (p197). However, the methods the textbook provides are similar to the knowledge engineers previously employed by those companies are passing on. The text has been in publication for the past forty years (1970) and utilizes a couple heavy civil projects as examples.

In the preface, this book describes the construction management process as the five M’s: Men, Machine, Material, Method, and Money. The 5M correlates with labor, equipment, material (function of quality), method (labor and equipment are a function of method) and cost (function of previous four manifested as, scope, time, and scarcity of capital). They define field project management as monitoring *actual cost* and *progress of work* at periodic intervals against: a "budget" and "time schedule of operations" (CPM page 17).

The preparation of both the budget and schedule should include a scope takeoff from the project plans. The text subcategorized managing of cost [escalation] as management of job resources: labor, equipment, material, subcontractors, and the project billing cashflow.

Chapter 9 is dedicated to the monitoring feedback process. One project status method is given. At regular intervals, on the reporting cutoff date: report those activities finished and those activities in-progress. For activities in progress, report the degree of completion.

The text gives two equations to assist with calculating degree of completion, see Equation 7. The method to measure the inputs to these equations - percentage of completion and work units put in place - is described as dependent on the type of work and if the measurements are also used to check field costs and is not discussed further, Figure 70. I think these equations are basically useless, as well as redundant – the equations are more confusing than the concepts they represent. The difference between a guessed percent complete and the calculated percent of total units based on measured completed unit to date, does not justify two distinct equations. If these are provided to input to an spreadsheet, the actual calculations will be more complex that this simplified representation. In the 'Vitruvi' style, it is to the reader to understand that the author has shown them to be aware, but the author cannot explain it. Fair enough, that is a start.

Equation 7 Calculate days to completion - there is no discussion of how the inputs are measured. (*Construction Project Management)*

Formula	Inputs	Input source
days to completion = d(1 - PC/100)	d = duration in working days	=(QTO*prod)/crew
by generic: PC = P	P = estimated percentage of completion	guesstimate
by work: PC = W/T	W = measured work units in place	field measurement
	T = total work expected	plan QTO

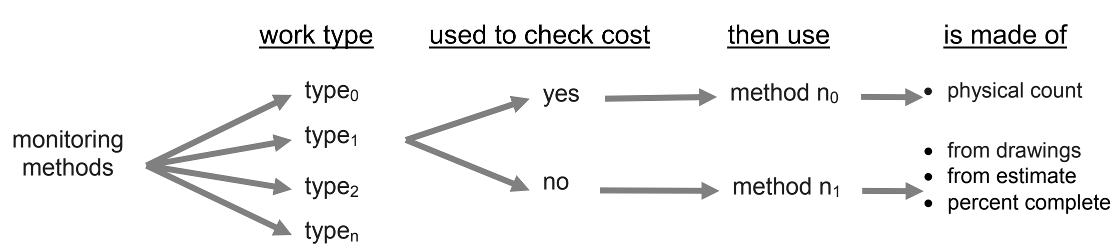

Figure 70 According to *Construction Project Management*, the process of "how a contractor expresses activity completion," (p236) is dependent on work type and if the data is used to check cost. Are the methods singular or plural, for example method n_1 in this example is actually a bundle of applicable methods that field engineers could use individually or in combination.

Table 77 Sources of measurements and method in Clough, Sears, and Sears.

method[295]	source	measure	contributor	latency	completion	accuracy[296]	cost check	work types	purpose
physical count		units in place	CPM, p184, ch9.7						
physical count	drawings	scale & color-in	CPM, p184, ch9.7						
accept 2nd party	delivery tickets	weight or volume	CPM, p184, ch9.7						
physical count	sitewalk	direct measurement	CPM, p210, ch10.11						
percent complete	time		CPM, p 183, ch9.6						
percent complete	qty of work-in-place		CPM, p 183, ch9.6						
[a priori]	bid sheets	estimated quantities	CPM, p210, ch10.11						
[a priori]	f(activity)	determine from network logic	CPM, p210, ch10.11						

A limitation noted for estimating percentage of completion (PC) in terms of time is an assumed straight-line linear relation between time and work completed. The linear assumption may not be true. The text adds a caution in chapter 10 for using quantities scaled from the contract drawings; scaling does not capture the variation between actual quantities and planned quantities. Also, a limitation of project monitoring is the quality of the measurements. The text advises not to give the quantities task to a field supervisor due to their incentive to level production by hiding low production to correct later and hiding higher production to use as a buffer for future low production; called *sand bagging*. Field engineers must make progress measurements conscientiously and with accuracy within +/-10% (CPM, 2000). Conscientiously is defined as, the person responsible for progress reporting understands the importance of factual and correct determinations of project progress, an echo of Professor Meredith. The text uses the term *"person responsible for"* rather than *"the person making"* the progress measurements. These terms imply a management to engineer relationship and that the manager is responsible and not the engineer. The text likely intended to apply the responsibility to those actually making the measurements and progress report rather than those supporting the process.

Field engineers define the progress reporting frequency based on the perceived time control rather than accuracy. The field engineers should consider the balance between costs of

[295] A question I cannot answer: What work types are associated with each method? I do not think there is a correlation. It is a many to many relationship.
[296] A question I cannot answer: What accuracy is suitable for checking cost? The easy answer is, as good as you can get. CPM says within +/- 10% of actual. In my experience, anything more than 30% from actual, if noticed, will be a topic of discussion amongst the field engineers.

resources exerted in monitoring and the benefit the monitoring provides - return on investment (ROI). A second consideration is correlating the intervals between time and cost reporting so to leverage the measurements for both purposes.

Table 78 Example feature breakdown structure represented in a ‘cost code’ nomenclature

Year WL0	Project# of year WL1	Contract type WL2	Product type WL3	Area code WL4	Work division WL5	Work type WL6	Systems and materials WL7	Project account number WL8	Distribution code WL9
2000	08	x	x	05	03	15	7	20	3

In Project Cost Systems (Chapter 10) there are discussions on project cost codes, usage of project cost code, measurement of work activities (refer back to chapter 9 discussion), and special cost accounting problems. The authors provide a 18-digit code identification (CPM, p203, chapter 10.4), similar to OAR and AROW work breakdown structures used in CIFE (Darwiche et al., 1989; Ito et al., 1989; Mourgues, 2008) to represent quantity features. The authors use an example nomenclature (2000.08.x.x.05.03.15.7.20.3) based on a work breakdown structure. From encoding the breakdown structure the authors derive a chart of accounts.

The breakdown (CPM, chapter 10.4, p203): The first level is the year followed by a sequential count of the bid for the year. They suggest that additional features, such as the product type and contract should be included with the ‘Project’ code. The second two digits are a single location breakdown, used as an x, y-axis location in the example. Next is a seven digit code based on the CSI 16 division MasterFormat[297], these seven digits represent four work breakdown levels, these are discipline, activity, resource, and component. The last digit is a distribution code, representing labor, equipment, material, subcontractor, or the sum of these four.

[297] Note that this format relies on the CSI MasterFormat 16 division classification; the CSI MasterFormat was modified in 2005 to include 50 divisions.

The codes purpose is to allow mapping resource utilization from actual use to planning calculations and reports. For example, the code allows mapping from one facet (usually reality) to another, such as, project estimating, financial accounting, and field cost accounting. The quantity takeoff is also applied the code but in my ethnographic experience, these are assigned after the quantity takeoff rather than applying a quantity takeoff to the code. The consistent use (there is not an establish word for 'use') of each code is important. How the field engineer achieves consistency and how to apply the codes is not in the book. They almost advise concatenating the code from feature tokens rather than memorizing a long list of codes – but stop short of that, nor do they explain how would be done.

They do mention time lag in reporting project production (CPM, chapter 10.6). The text does not discuss the time lag in detail, only the mention of a tradeoff between level-of-detail and latency in reporting. I assume in the tradeoff that the text held resources in monitoring constant.

The last section from *Construction Project Management* I include in this literature review is 10.23 *Special Cost Accounting Problems*. This topic is interesting since the second example (CPM, chapter 10.23) is given a detailed discussion in observed *Types of Quantities* (p217) as a special problem, also discussed by Stallard (p176), in Bartholomew's Heavy Civil Estimating book (p389), by Ron Dukeshier (p168), and finally given an explanation by Paul Teicholz (p172). These are six independent discussions of the same issue. The problem is accounting for bulk material the field crew uses on multiple direct work activities but field engineers represent in an indirect account[298]. The solution in CPM is the field engineer temporarily holds the material (or equipment) cost and quantities in an indirect *clearing account*. As operations consume the material (or equipment), the field engineer credits the clearing account and debits the work accounts[299] consuming the material.

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[298] The text applies this same problem to equipment, which also was a problem I saw on the ReTRAC project. This issue was resolved with an existing equipment accounting system. The system was not utilized up to that point, despite memo requests from corporate accounting. Rather than code the equipment cost directly to the work account, the previous process, I 'rented' the equipment to ourselves at a set rate. The accounting software (JD Edwards AS400) contained an equipment module that allowed the equipment manager (me at that point) to give equipment an asset number and set rental rates and then pay the equipment asset number similar to how you would pay a labor employee number.

[299] This solution was not available on the ReTRAC project due to the lack of material distribution accounts associated with direct work activities. Rather, similar to the old way given in the Stallard interview, a spreadsheet was constructed by the field engineers with a list of associated activity codes. By the time the spreadsheet was constructed the distribution of these accounts was no longer known, though if it had been, each account would have been assigned a percentage distribution. Obviously, the solution provided in the text should have been employed. Or as Stallard points out, the effort exerted is not worth the return in his opinion.

9.7.3.2 Construction Planning, Equipment, and Methods

Construction Planning, Equipment, and Methods by R. Peurifoy and C. Schexnayder provide a section on calculating earthwork quantities from a plan takeoff. The text presents the three formal earthwork views of plan, profile, and cross-section (Chapter 2). They give a method to estimate earthwork volume: The product of the average area of the cross sections and length is the earthwork takeoff volume. The field engineer must modify the volume for the material state since the state used for calculations or reporting may differ from the measured state. The volume removed from the excavation is calculated in-situ as bank cubic yards (BCY). Once removed the material is now in loose cubic yards (LCY) which I noticed is not included in the text. If material is moved to a location as fill material it is then compacted to become compacted cubic yards (CCY). The volume of the soil for the same weight is different in each state due to the changed density.

9.7.3.3 International Standard: PMBOK Guideline for Schedule Update

The *Guide to the Project Management Body of Knowledge* (PMBOK Guide, 2008) published by the *Project Management Institute* (PMI) and accepted as the IEEE 1490-2003[300] is a source for project management practices and provides several professional certifications. The PMBOK core component is the *Earned Value Management* method, an integrated scope-time-cost process. The procedures outlined arrive at a point termed *Project Scope Management* in chapter 5.5; the process of monitoring project status based on a pre-defined project plan of "how requirement activities will be planned, tracked, and reported" (PMBOK Guide, 2008).

Within the scope management are two subtasks: schedule (PMBOK chapter 6) and cost (PMBOK chapter 7), Figure 3. The cost control is dependent on the schedule for start and finish dates; an estimate for cost to completion is forecast at each reporting period. The details of the reporting period interval is for the reader to discover empirically through trial and error. Reporting frequency is a frustrating omission but consistent with ad-hoc practices, possibly necessary for readability given the level of abstraction that must be maintained for the broad topic, and existing theory does not allow a formulaic response, therefore requiring judgment from experience. The cost management (Chapter 7) provides seven aspects to define, these are:

- level of accuracy[301]
- units of measurement
- organizational procedure links [integration with subcontractors]
- control thresholds (percent variance from baseline)

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[300] As standard 1490-2003, www.ieee.org.
[301] The ReTRAC project team used significant figures rounding to represent accuracy.

- rules of performance measurements
- work breakdown structure control points
- method of measuring progress
- recipe-formula equations
- reporting formats
- process descriptions (estimating, budgeting, and control)
- the text provides four methods of estimating cost, three individually and the fourth method combining all three, Table 75:
    - Expert judgment (mix of the next three methods)
    - Analogous estimating (comparison with total cost of previous project)
    - Parametric cost (statistical relationships)
    - Bottom-up estimating (estimated at greatest level of detail available)

For details of the seven planning aspects and four methods of cost estimating – both baseline estimate and forecast to completion estimate - the PMBOK points to the *Practice Standard for Earned Value Management*, another PMI publication[302]. Publications suggested as alternatives to the PMI publication are indirectly reviewed in this literature review, the APM literature review (p404) references ANSI/EIA-748 and Humphrey (2002) is referenced as context in the Senior Cost Engineer interview (p175).

The schedule is how field engineers using the EVM method monitor the project status (Chapter 6). Therefore, the schedule is the core driver of the EVM method. At the PMBOK level of detail, the process field engineers use to update the schedule is both implicit and explicit. Three metrics are measured; these are start date, progress, and finish date. The process given to communicate project status data from the project through the documents is with notations on the project schedule to indicate the three metrics for each activity; it is implicit how progress is measured or who makes the schedule notations. Cost [escalation] management is an example for measurement techniques (Chapter 7) these are: weighted milestones, fixed-formula, and percent complete.

9.7.3.4 Project Management 10th edition Guidelines for Measurement Methods

The text *Project Management: A systems Approach to Planning, Scheduling, and Controlling* by Kerzner, now in the 10th edition 2009, is one of the formal sources of methods for determining project *percent complete*. The text gives seven methods (p656), these are:

[302] An amazon.com (an online retailer) customer review states that this publication does not provide sufficient detail and suggests the ANSI/EIA-748 standard (www.ansi.org) and US DoD publications as an alternative; the definitive publication is given as Project Management Using Earned Value (2002) by G. Humphrey - a consultant that provides corporate training.

- 0/100 (start / finish): no progress in percent complete, i.e., 0% until at completion advanced to 100%; intended for activities less than one month.
- Milestone: milestones throughout the duration of a larger activity are established for control points; intended for activities greater than one month and less than 3 months.
- Percent complete: calculated as percentage of budget; intended for activities longer than 3 months.
- dollars complete: percentage in 10% intervals
- 50/50 rule: book 50% of budget at the start date and 50% at the completion date. This method eliminates continuously determining percent complete.
- Equivalent units: this method converts partially completed units into an equivalent number of completed units
- Cost formula (80/20): A variation on percent complete for long duration work packages. I perceive that cost formula should be included as a subcategory of percent complete.
- Level of effort: Based on passage of time, for overhead cost; measured in applied resources[303] consumed over a given time period.
- task duration: method observed used most.
- schedule: determine percent complete using a resource loaded schedule
- Apportioned effort: Intended for work not easily quantifiable but is in proportion to another measured effort (appears similar to the *assembly* concept to me).

The four sub-methods provided under percent complete and level of effort are described prior to the seven methods. I included them as subcategories since they logically are. There are suggested durations for determining the application of methods; I found no discussion on how the authors derived these or their source.

[303] Labor, Equipment, Material, Haul, Subcontractor, Finance Capital (L/E/M/H/S/$).

Table 79 Expanding the table derived from Construction Project Management with the Project Management Guidelines.

method[304]	source	measure	contributor	latency	completion	accuracy[305]	cost check	work types	purpose
physical count		units in place	CPM, p184, ch9.7						
physical count	drawings	scale & color-in	CPM, p184, ch9.7						
accept 2nd party	delivery tickets	weight or volume	CPM, p184, ch9.7						
physical count	sitewalk	direct measurement	CPM, p210, ch10.11						
percent complete	time		CPM, p 183, ch9.6						
percent complete	qty of work-in-place		CPM, p 183, ch9.6						
[a priori]	bid sheets	estimated quantities	CPM, p210, ch10.11						
[a priori]	f(activity)	determine from network logic	CPM, p210, ch10.11						
0/100		finished t/f	PM10th						<1mo.
milestone		finished t/f	PM10th						<3mo.
percent complete	budget	dollars expensed	PM10th						>3mo.
equivalent units	endogenous formula	exogenous measure	PM10th						
cost formula	budget	percent complete	PM10th						>6mo.
level of effort	schedule	duration	PM10th						
apportioned effort	endogenous formula	exogenous measure	PM10th						

9.7.3.5 Association for Project Management (APM): Guidelines for Measurement Methods

In the United States the Project Management Institute (PMI)[306] and their PMBOK is the source for project management methods. In the United Kingdom, the independent source for project management is the Association for Project Management (APM)[307] and their publication the *APM Body of Knowledge*. The APM guidelines provide for Measuring Earned Value (APM, p24, section 6.2.6.1) and Earned Value Techniques (EVT) (APM, 2002).

There are differences: unlike the PMBOK, the APM guidelines provide a lower level of detail in methods. While the PMBOK states, update the schedule with notations of start, finish, and progress, the APM guide states, the update method is dependent on the type of work. At least

[304] A question I cannot answer: What work types are associated with each method? I do not think there is a correlation.
[305] A question I cannot answer: What accuracy is suitable for checking cost? The easy answer is, as good as you can get. My best guess is within 10% of actual. Anything more than 30% from actual, if noticed, will be a topic of discussion amongst the field engineers.
[306] See www.pmi.org
[307] See www.apm.org.uk

the APM gives a warning that the field engineers need to tailor their method to the worktype – a cue to look for reference material on methods. The following five methods provided by APM are similar to those provided by Dr. Saidi from *Construction Industry Institute* (CII) publications, and the *Project Management: A systems Approach to Planning, Scheduling, and Controlling* text:

- Milestone
- Percent complete
- Equivalent units (units to date/total units)
- Level of effort (no product to measure, such as project oversight), measure by time, that is, time variable.
- Apportioned effort (no product to measure but easily associated with activity) such as quality inspection

The APM guide advises to use a monitoring method that allows the field engineer to "make [the] measurement at [the] lowest practicable level of work breakdown structure," Figure 71. And, to "collect costs at or below the work package level (at a level to identify source of variance)." The measured data to collect are labor, direct expense, material, and subcontractor. If no measurement is available then add the actual cost to an estimate of outstanding commitments and report the sum. For schedule status updates similar metrics are given (APM chapter 6.4.1 page 32) as the PMBOK actual start / finish dates and again the instructions does not include instructions on how to estimate the time remaining to complete; the *APM Body of Knowledge* gives additional references, Table 80.

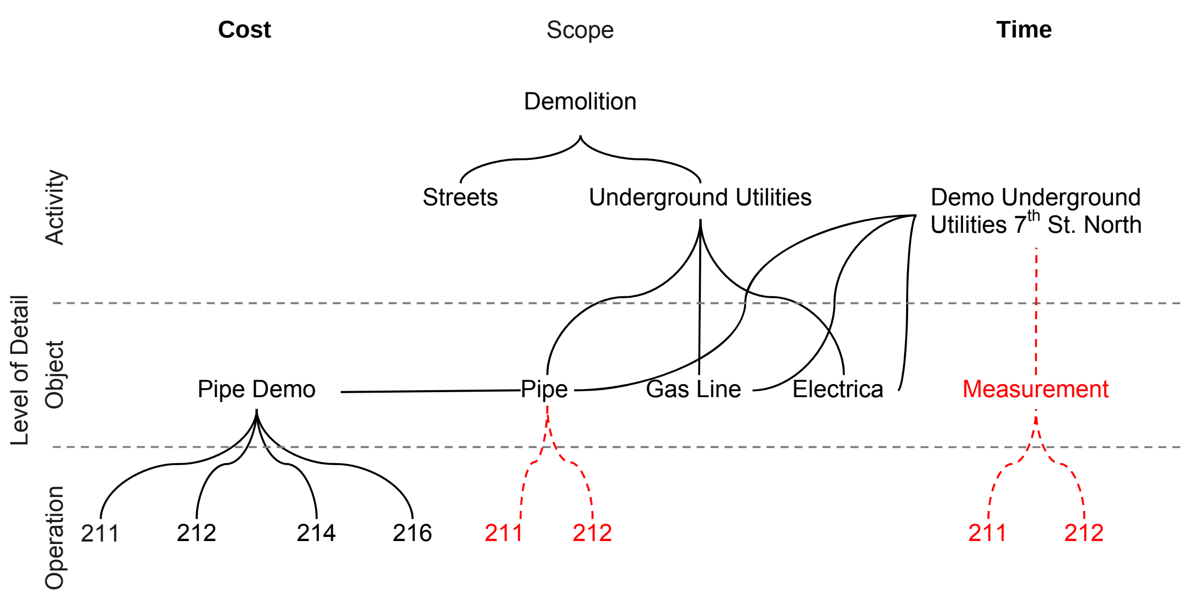

Figure 71 The APM guide advises to measure progress at the lowest practical level of the work breakdown structure; at a minimum collect cost below the work package level. In this graphical example, the monitoring should be at the operation level of detail. Adapted from Staub & Fischer, 1999, figure 4.

Table 80 documents cited by or suggested for further reading by the Association for Project Management (APM) *Body of Knowledge.*

Association for Project Management (APM) referenced material			
Title		Year	Organization
Industry Guidelines for Earned Value Management Systems	ANSI/EIA–748	1998	American National Standards Institute /Electronic Industries Alliance
Guide to Project Management	BS6079-1	2000	British Standards Institution
Project Risk Analysis and Management Guide		2000	Association for Project Management
Guide to the Management of Business Related Project Risk	BS6079-3	2000	British Standards Institution
United Kingdom The Program Managers' Guide to the Integrated Baseline Review Process		2002	
Association for Project Management (APM) suggested reference material			
Department of Defense Handbook Work Breakdown Structure	MIL-HDBK-881	1998	United States Department of Defense
Cost Schedule Status Reporting (C/SSR) Specification and Implementation Guide	DEF (AUST) 5658	1994	
Australian Cost/Schedule Control Systems Criteria; Implementation Guide	DEF (AUST) 5657	1994	

9.7.4 Features of Quantities: Coding Guidelines

In the preceding sections I found mentions of cost codes and in the case of the *Construction Project Management* text, they provide a specific example (see Table 78). In this section, I take a deeper look at the cost code and the act (*verb*) of assigning features with these codes, as opposed to the breakdown structure (*noun*) of these codes. I found the cost coding (*verb*) literature through a web search for key terms such as *cost code*, *work breakdown structure*, and *cost coding*. Last, I present an empirical example of cost coding to illustrate underlying issues with misrepresentation of project resources.

9.7.4.1 Chart of accounts theory

The Department of Energy standard DOE 430.1-1, 1997[308], chapters 5 and 16 specifically address cost codes and the work breakdown structure. Chapter 5 provides the concepts and chapter 16 provides examples. A take-away from chapter 5 is the correlation between the Work Breakdown Structure (WBS) and the Chart of Accounts (COA); this - while obvious - is implicit

[308] U.S. Department of Energy (DOE) "Cost Estimating Guide." DOE Directive 430.1-1, Washington, D.C., Department of Energy, directives, Regulations and Standards, 1997. https://www.directives.doe.gov/directives/current-directives/400-series-current

in other literature. The COA embodies the WBS as a representation of the unique feature sets of reality and is customized through adherence to the WBS guidelines to create new accounts.

The DOE guidelines include four parts to the chart of accounts; these are the work breakdown structure, a nomenclature, a description, and conditional statement, Table 81. The description and conditional statement guide the coder to the code. The coder (*person*), codes (*verb*) the code (*noun*).

Table 81 Department of Energy standard DOE 430.1-1, 1997 four parts of the chart of accounts

Work Breakdown Structure	Nomenclature	Description	Conditional Statement
Action-Resource-Object-Workzone	032-115-053.01-23	Build Forms Retaining Wall Zone 23	Includes labor to build wood forms for structures – excludes crane and supporting equipment.

I see the main contribution of the DOE guidelines is the conditional statements to act as a guideline. I have never seen conditional statements attached to a chart of accounts. The conditional statements in the guideline are open to interpretation and therefore the potential for a miscode, for example:

> *“This **includes** labor and material costs that **are not** addressed by other subaccounts under the 501 account, such as the labor and material **required for installation of bridge and gantry cranes**, monorails, conveyors, and pipe handling trolley assemblies, including related electrical feed rails, crane rails, internal wiring, erection, and rigging.*
>
> *Also included are the labor and material required for installation of miscellaneous building equipment attached to and part of the building, such as elevators, dumbwaiters, lunchroom equipment, and metal lockers, etc.”*
>
> *“This cost code **excludes** process equipment and equipment includable in building systems, such as monorails, **bridge cranes, gantry cranes**, pipe handling trolley assemblies, shop equipment, and installation of temporary construction overhead cranes.”*

The distinction between the code used for labor and material and the code used for process equipment is confusing. Novice coders and experienced coders do not perceive this distinction; gaining the feel for and respect for distinguishing between accounts takes time. As an experienced coder on a large project I initially would have had no idea what this example account includes or excludes and would likely code inconstantly to this account. Reading this statement, wanting to reuse the associated data, I would probably apply it inconsistently. In this breakdown structure, there are two equipment types, the construction equipment, and the product equipment.

To clarify the terminology I referenced the AACE 20R-98, 2003. This defines material to include equipment, therefore blurring the distinction even further. Is process equipment different from equipment as defined in AACE 20R-98, 2003? After closer reading, it is clear that this account is for labor and associated material, there are other accounts for the equipment itself and the haul cost. To me the equipment terminology is initially confusing since equipment refers to the construction process itself. For example, a crane is equipment used for the process, while material is the product itself, for example, equipment like permanently installed sump pumps. In this case the Gellish standard would probably help with a formal representation of relationships, see Table 82.

Table 82 A *Gellish* representation of observed assemblies. Gellish is a development of ISO 10303-221 and ISO 15926. A subset of the Gellish dictionary (STEPlib) was used to create ISO 15926-4 (Gellish, Van Renssen 2005).

Left hand object name	Relation type name	Right hand object name	UoM

9.7.4.2 Chart of accounts in practice

While AACE 20R-98, 2003 is a compelling source for the use of chart of accounts to integrating the scope, time, and cost components of the project, exactly how to achieve this is for the reader to figure out. The Association for the Advancement of Cost Engineering (AACE)[309] provides guidelines for what they call *Code of Accounts* (COA) and everyone else calls *Chart of Accounts* (COA), and the Work Breakdown Structure (WBS) as AACE 20R-98, 2003. The Chart of account is also known by the following terms:

[309] See www.aacei.org

- chart of account
- coding matrices
- nomenclature
- charge accounts
- asset classification accounts
- material classification accounts
- value categories
- cost elements
- breakdown structures
- work breakdown structure
- resource breakdown structure
- component breakdown structure
- activity breakdown structure[310]

The AACE 20R-98, 2003 provides the following six benefits derived from the chart of account:

- a means to relate work scope to schedule and costs
- integrates between accounting, cost reporting, and cost and schedule control
- categorizes performance and productivity measurement and analysis
- simplifies cost and schedule forecasting
- classifies estimate items, budgets, and expenditures for cost control and capitalization (APM)
- reference for content of accounts (job cost accounts)

The AACE 20R-98, 2003 reviewed numerous proprietary formats used at specific companies, several work breakdown structures, and proposes a new format as a synthesis of existing formats. Two formats relevant to the construction industry are the MasterFormat and the Uniformat. The synthesized format is in Appendix A: AACE Recommended Work Breakdown Structure (p369).

9.7.4.2.1 Standardized Chart of Account

The MasterFormat is notable in that it does not emphasize cost accounts in process projects, such as equipment, piping, and process control. The Construction Specification Institute (CSI) organization intended the *MasterFormat 2004*[311] for project specifications and does not provide support for project planning and control purposes[312]. However, some self-performing contractors use the MasterFormat as a hierarchy to organize their estimating and project monitoring. For this reason, software developers such as Autodesk Revit and Reed RSMeans expanded the MasterFormat to include additional levels of detail, Table 83.

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[310] How does an activity breakdown structure differ from the work breakdown structure.
[311] Construction Specification Institute (CSI), *MasterFormat 2004,* www.csinet.org
[312] I emailed them and asked – this was their response.

Table 83 The RSMeans Work Breakdown Structure (WBS) and the derived Chart of Accounts (COA) compared with a CIFE compiled format. The internal inconsistency is not my mistake, that is how RSMeans has it[313].

Work Breakdown Structure — Chart of Accounts Text Description

Company and Division	Bid Number for Year	Product Type	Location	Sub-Location	Building Units / Discipline	Master Schedule Activities	Resource	Objects	Operations	Operation method	Workzone	Chart of Accounts	Text Description
					31							31.	Earthwork
						05						31.05.	Common Work Results for Earthwork
							13					31.05.13.	Soils for Earthwork
								10	00	10		31.05.13.10.00.10	Borrow
									00	20		31.05.13.10.00.20	Spread 200HP Dozer No Compaction 2MI RT Haul
									02	00		31.05.13.10.02.00	Common Borrow

313 I called and asked – the engineer told me she thought I was way overthinking these codes – she claimed they do not have this 'breakdown structure.'

Table 84 The language of construction. Notice that an activity has resources - which give form to components (Mourgues, 2008) - which are constructed with an operation by a method. For example, a rail trench can be excavated with excavators and haul trucks, or by shovel, basket, and mule cart.

Context breakdown | Location breakdown | Organization breakdown | Product breakdown | Work breakdown | Cost breakdown

Standard	Code	Facility	Time mm.dd.yyyy	Company &/or Division	Project attributes[5]	Location	Sub-location	Organization	System	Discipline	Feature	Action (activity)	Resource | Material	Sub-resource | material	Function	Object | feature	Sub-object	Operation	Method	Action-space | Work-zone	Sequence constraint	Distribution (L/E/M/H)	Description
e-cognos																							
AROW[9]	text description											xx	xx			xx				xx			*format: OAR + workzone*
IFD: iso12006-3																							
OmniClass[8] Product	23-15 10 11 21 24											15	10	11	21	24							pavement roadway curb & gutter traffic safety barriers and protection
OmniClass[8] MF Work	22-32 16 13 13									32		16	13			1	3						exterior improvements concrete + *MasterFormat* + as single object
Revit Keynote MF	32 16 00.B1									32		16	00			B1							6" curb & gutter
CIFE format[7]	text description				x	xx	xx			xx		xx				xx		xx					*CIFE CEE241 material*
FOAR[4]	text description										xx	xx				xx						xx	*format: features + OAR*
AACE 20R-98 2003	alpha-numeric		x		xx	xx	xx	x		xx		xx										x	
Heavy Const. Div.	300188 285101		x	300	188					2		8	5			1		01				0000	curb & gutter grading
Generic work-spac[6]	text description											xx				xx				xx		xx	
NIST Uniformat	G2013								G	20						1	3						site roadway curb & gutter
Civil CICS	alpha-numeric	xx				xx										xx		xx				xx	
CARS[3]	text description											xx				xx					xx	xx	*format: OAR + sequence*
RSMeans MF	32-16-13.13.0430									32		16	13			1	3	04	30				*MasterFormat* + straight, wood forms, .055CY/LF, 6" x 6"curb, 24"gutter
Clough, Sears & Sears	alpha-numeric				xxxxx	xx				xx		x	xx			xx						x	
CESMM	8.28									8						28		c					road & pavement kerb excavation
OARplan[1]	text description											xx				xx				xx		xx	*format: object-action-resource (OAR)*
CSI MasterFormat[2]	32 16 13.13									32		16	13			1	3						cast-in-place conc. curb & gutter

1 Darwiche 1989
2 1978, rev.1995, 2004
3 Fischer & Aalami 1996
4 Staub-french 2003
5 bid #, work type, contract type
6 Akinci et al. 2002
7 Peterson & Fischer 2009
8 iso12006-2 based
9 Mourgues 2008

9.7.4.2.2 Standardized Assemblies

The Uniformat has a systems orientation that facilitates conceptual estimating. The National Institute of Standards and Technology (NIST) publication *UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis* NISTIR 6389 (1999) - developed through the ASTM's Building Economics Subcommittee E06.81[314] - is an assemblies-based breakdown structure. Due to its ability to abstract to the assemblies level of detail the UNIFORMAT is more prevalent in the design stages of a project than the construction stages. The assemblies used for estimating are often based on UNIFORMAT components, while the subassembly components are based on MasterFormat.

9.7.4.3 Pragmatic coding guidelines

I found a guideline used internally by the University of North Carolina (University of North Carolina, 2005)[315]. This was the only guideline I could find, illustrating the lack of literature pertaining to the coding process itself.

9.7.4.3.1 Coding guidelines

The first document[316] looks like a guide from an Oracle accounting knowledgebase. The guide provides instructions for two methods of coding items. The first method is to code one item at a time by selecting the code from the chart of accounts drop down list. The second method, auto fill, assigns one code to multiple items.

> *"To assign cost codes, one item at a time, simply click on an item in the topmost section of the items tab. Then, in the bottom left part of the window, click on cost code group title in the "Cost Code" column. Then select a "Cost Code" from the drop-down list in the bottom center of the Items tab. Repeat the above steps to cost-code all your items, one by one."*

The auto fill instructions are similar with additional steps for making multiple selections and an auto fill command.

9.7.4.3.2 Miscode audit

These guidelines address out of balance accounting checks and where to look for the cause. The guidelines provide for two types of errors, the *double code* error and the *different cost code* error, also known as a miscode; an online search for these keywords did not return additional sources. The guideline:

- If the *Expenditure* column does not balance then check if a transaction was *double coded*. Adjustments are made on a *Journal-Entry* document.

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[314] ASTM Building Economics Subcommittee E06.81, www.astm.org/COMMIT/COMMITTEE/E06.htm
[315] University of North Carolina 2005.
[316] University of North Carolina its.unc.edu/ccm/groups/public/@its/@eapps/documents/content/ccm1_002940.pdf

- If the *Encumbrance* column does not balance then look to see if a transaction was coded to a different code in the *Transaction Redistribution* document than from the original transaction. Adjustments are made on an *Encumbrance* document.
- To reduce miscodes, the guideline advises to not code the original *open order* - an order status indicating that an order that has been placed and no part of the order has been executed (Fidelity glossary) - instead code from the invoices.

9.7.4.3.3 Auditing theory and practice

Quantities are reported as numerical numbers, and like accounting are likely susceptible to similar errors such as transpositions and calculations. Found through a web search, an auditing text *Auditing Theory and Practice* by Robert Montgomery (1912)[317] explains an issue that can be a source of error in quantities or a source of indifference to errors - given in *Estimating* (p388) – this is the *offsetting error* (Auditing, 1912; p 16).

An offsetting error is an error offset by a counterbalancing error so the accounts balance, producing a false positive. This error is found when conducting reality checks (audits) of reported quantities or attempting to calculate or recreate a quantity from known quantities – often done due to missing or corrupted measurements, p262.

As a field engineer, the longer the records were reviewed the offsetting errors that were found and corrected, becoming smaller and smaller in magnitude. Eventually each correction resulted in a small variance to one side or the other of a mean value. The offsetting error is an issue with an intuitive source in marginal objects and other issues with representation.

9.7.4.4 Empirical example of coding issues

At the 2002 Waste Management Symposium, Jeff Stevens, Ralph Titus, and Peter Sanford, published and presented a review of the partially integrated scope-time-cost estimate and monitoring methods used on the Rocky Flats Building 771 decommissioning project[318]. The paper concludes that the use of a detailed estimate was a success. They were able to support the planning, scheduling, and project control.

Steven describes the issue of miscodes of the coded association with work activities. This was due to the foreman’s learning curve, changes in the chart of accounts during the project (reversing the learning progress), and managements' learning curve. Because Stevens mentions the foreman making errors in cost coding, it is assumed the foreman are the primary cost coders. To alleviate the incidence of miscodes four procedural changes were implemented, these are:

---

[317] While this text is old it presents the topic clearly without digressing into computerized methods of accounting.
[318] Rocky Flats was a plutonium purification and fabrication site constructed in 1952.

- Identify each work activity on the schedule with a code placed on the schedule
- Assist the foremen with preparing for the weekly progress meeting defense. The author does not provide an elaboration of what progress is, for example, either unit-less percentage or quantities, or how or why foremen are defending the progress.
- Educate the staff on the correlation between improved project control and the coding[319] accuracy; what the benefits of improved project control are is not reviewed
- Move efforts to improve the degree of coding accuracy from the *sets* level of detail to a *media* level of detail, for example, by pipe

The Rocky Flats engineers recommend two changes to the method they used: first, assign a universal chart of accounts with the work breakdown structure to the schedule and the POWERTool[320] - a U.S. government department of Energy estimating tool. They found that cross-referencing the multiple project nomenclatures made the planning labor intensive. Second, a universal chart of accounts used as part of a scope-time-cost system must be flexible so that custom codes can be added or removed as needed; this is consistent with theoretical findings made by Suchman (1987)[321]. Suchman essentially says any system must allow for customization by the user to accommodate the phenomenological realities they encounter.

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[319] The term used is “charging.”
[320] U.S. government department of Energy estimating tool (POWERTool).
[321] See Forest Peterson General Qualification Exam proposal.

9.8 Appendix H: Reference Text Authors

In my review of reference books, in addition to Vitruvi, I looked at the works of thirteen separate authors. The experiences of these authors' and the experiences of those they pull from, spans a wide domain: I believe this selection of literature is a good cross section of the existing knowledge. In this section, I introduce the authors and provide a short explanation of why I selected them.

The Association for the Advancement of Cost Engineering (AACE)[322] provides guideline AACE 20R-98 (2003) for what they call *Code of Accounts* (COA) and everyone else calls *Chart of Accounts* (COA). This document has a committee as the author. One of the authors is Alexia Nalewaik[323]. Nalewaik's background is in physics and structural engineering. After earning a masters in structures at the University of Southern California, Nalewaik worked with the the oil and refinery engineering-procurement-construction (epc) contractor KTI Corporation as a cost estimator and on-site as a project controls engineer. Later Nalewaik moved into a broader role of cost estimating for facilities, then into the owner representative role, and eventually as a consultant cost engineer where she contributes publications to the AACE and ASCE. Nalewaik has a solid foundation in the pragmatics of field experience. This shows in the standard. I assume Nalewaik's experience is representative of the rest of the AACE 20R committee. In my opinion, the AACE 20R standard is an excellent resource.

In the United Kingdom, the independent source for project management is the Association for Project Management (APM)[324] and their publication the *APM Body of Knowledge*. The APM guidelines provide for measuring Earned Value (APM, p24, section 6.2.6.1) and Earned Value Techniques (EVT) (APM, 2002). The APM and Project Management Institute (PMI) are competitors and rivals with a poor relationship (Chartered Update, 2014). A former PMI co-founding trustee founded the APM. The APM mirrors the PMI and their *Guide to the Project Management Body of Knowledge* (PMBOK) with their own *APM Body of Knowledge*. I was impressed with the APM publication and added it to this review as a counter to the PMI centric focus often encountered in project management. Unlike the PMBOK, the APM guidelines provide a lower level of detail in methods. While the PMBOK states, update the schedule with notations of start, finish, and progress, the APM guide states, the update method is dependent on the type of work. At least the APM gives a warning that the field engineers need to tailor their method to the worktype – a cue to look for reference material on methods.

[322] Association for the Advancement of Cost Engineering www.aacei.org
[323] AACE 20E-98 committee member: Alexia Nalewaik http://www.aacei.org/wpc/library/reprints/2006-05.shtml
[324] Association for Project Management www.apm.org.uk

Quantities are reported as numerical numbers, and like accounting are susceptible to errors such as transpositions and miscalculations. I searched online for a simple explanation of these accounting errors and I felt the modern texts digressed into computerized accounting methods. Though ancient by today's standards, the *Auditing Theory and Practice* by Robert Montgomery (1912) provides a clear explanation of basic accounting and had a good review of some accounting errors that are the result of human-centric data entry. These errors are particularly relevant since construction relies almost exclusively on data input by humans.

Estimating and Bidding for Heavy Construction by Stewart Bartholomew is a textbook originating out of the California State University Chico. Bartholomew is a heavy civil engineer recognized in the underground heavy construction industry. This textbook is one of the core sources for the estimating practices of heavy civil contractors – possibly because of its use in one of the largest construction management programs in North America. Bartholomew worked for Fruin Colnon[325] then taught at Chico for 25 years[326]. Note that while Bartholomew primarily focuses on the estimating process he also addresses a few project oversight topics. The value of this text is it gives insight into why quantities and the features of quantities are important. Further, field engineers learn estimating methods from this text and reuse those approaches to estimate their field quantities.

I took a text from outside of construction to find the methods in the project management industry as a whole. There may be lost knowledge in construction practices and practices that field engineers specifically do not use in construction for implicit reasons. I reviewed *Cost Analysis and Estimating for Engineering and Management* by Phil Ostwald & Tim McLaren, published in 2004. Professor Ostwald authored several estimating texts and lectured mechanical and industrial engineering at Colorado State University. Professor McLaren lectured manufacturing engineering at Washington State University. Initially, the difference appears as the estimating sophistication: Ostwald & McLaren present parametric and statistical approaches that are not taught in construction. Like Bartholomew, Ostwald & McLaren do not give much consideration to project monitoring. Again, the value of this text is the same; it is the insights into why quantities and the features of quantities are important.

Construction Project Management (CPM 4th, 2000) is both a textbook and reference book: the authors are professors at the University of New Mexico. The first author Clough had a background in construction and was a senior executive at a construction company. CPM has

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325 The Fruin-Colnon Contracting Company is now part of Bilfinger Berger and was renamed BIS Frucon Engineering Inc. Website last assessed 2011. www.bisfei.com/index.php/about-us/company-history.html).
326 Russell Clough, Lecturer at Stanford University (2011). www.russellclough.com

been in publication since 1970 and uses a couple heavy civil projects as examples. In my opinion, this is one of the best all-around construction books. Neither author is associated with the large heavy civil contractors that I use in this thesis as my *Relevance*

After working as a field hand for ten years, I enrolled in a university construction management program and at completion accepted a field engineer position. This chapter presents the ethnographic observations of the quantities monitoring methods practiced on the one project I was employed as a field engineer. Throughout this chapter the discussion centers on project accounting, also known as job cost accounting, rather than financial accounting or managerial accounting. Job cost accounting differs from the financial accounting practices found in the corporate offices of heavy civil companies; the output of job cost accounting is the forecasted revenue or loss at completion and feeds into the financial accounting process (wiki Cost accounting). A conservative assumption is that only heavy civil contractors use the job cost accounting method, therefore excluding commercial specialty subcontractors from this study. With this assumption and the 2006 U.S. construction industry population (IRS corporate tax returns with net income), 17% of U.S. construction, and 27% of U.S. commercial and heavy construction use the job cost accounting practice. Because of my background in construction as a union Laborer working on the same types of activities as on this project, and in some cases having worked alongside some of the same Laborers that I was now responsible.

Scope of Observation (p197). However, the methods the textbook provides are similar to the knowledge the engineers previously employed by heavy construction companies are passing on to me and consistent with my own experiences.

The Department of Energy standard DOE 430.1-1 (1997)[327]: cited numerous times in various United States federal documents. I cannot find the anything about the author of this document other than it was authorized by the Associate Deputy Secretary for Field Management. The Office of Field Management was abolished sometime in the ten years after they published 430.1-1 and before 2006. A subsequent office was not formed until 2014. This is one of the few texts that details the act of cost coding. The standard appears thorough and I consider it a must read for estimating or project planning.

The *Field Engineer's Manual*, authored by R. Parmley (3rd edition, 2002) is a reference book published since the early 1980s specifically for field engineers. The purpose is a compact field

[327] U.S. Department of Energy (DOE) "Cost Estimating Guide." DOE Directive 430.1-1, Washington, D.C., Department of Energy, directives, Regulations and Standards, 1997. https://www.directives.doe.gov/directives/current-directives/400-series-current

guide - suitable for a safety vest pocket. The book covers twenty-five topics: as a field engineer the most useful were the sections on geometry formulas, material density, and design specifications. It would have been nice to have this book while I was a laborer. The book is a compilation of literature from technical organizations, societies, manufacturing firms, publications, and consultants such as *American Institute of Steel Construction (AISC), Handbook of Steel, Drainage and Highway Construction Products,* and the *Public Works Inspectors' Manual*. The author has published a wide array of engineering field guides, is a licensed professional civil engineer with experience on heavy civil projects, and owns his own engineering firm[328]. This guide captures nearly the entire field engineer's knowledge. During my undergraduate education the CSU Chico construction management lecturers did not introduce the manual: many of their handouts and lecture materials were from the guide or the same referenced material[329]. The one omission is measuring and estimating field quantities. Parmley replied to an email (2015) that the omission was due to content restrictions but agreed it should be included. Since first publishing in 1981, in 35 years my inquiry about quantities estimating was the first he had received. I reviewed this guide because it is specific to field engineers but excludes quantities.

I found a cost code guideline used internally (an internal guide – but not a construction company guide) by the University of North Carolina (2005). This is the only coding guideline I could find, illustrating the lack of literature pertaining to the coding process itself. There is not much more to say, it is pragmatic and that is real.

In the United States the *Guide to the Project Management Body of Knowledge* (PMBOK) published by the *Project Management Institute* (PMI)[330] accepted as IEEE 1490-2003[331] is a source for project management practices and provides several professional certifications. The PMBOK leaves a lot unexplained. For example, it is implicit how progress is measured or who makes the schedule notations they relay as their preferred approach to communicate progress from field to planner.

At the 2002 Waste Management Symposium, Jeff Stevens, Ralph Titus, and Peter Sanford, published and presented a review of the partially integrated scope-time-cost estimate and monitoring methods they used on the Rocky Flats Building 771 decommissioning project[332]: an incredibly contaminated plutonium purification and fabrication facility first constructed in 1952.

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328 Morgan and Parmley Ltd. http://www.morganparmley.com/
329 It would have been nice to have the material presented accompanied by the text so I could tab it for use in the field.
330 Project Management Institute www.pmi.org
331 Standard 1490-2003, www.ieee.org
332 Rocky Flats Plant, last accessed 5/12/2015 http://en.wikipedia.org/wiki/Rocky_Flats_Plant

The paper concludes that their use of a detailed estimate as a foundation for integration was a success. While this is a conference proceeding rather than a reference book, based on the experience of the authors and their non-academic status, I included it as a reference text. Jeff is an employee of Kaiser-Hill, this was a joint venture between CH2M Hill and Kaiser Group Holdings, formed specifically for the Rocky Flats decommissioning project[333]. Within the joint venture he was employed by BNG America[334] [335].

The text by Harold Kerzner[336] *Project Management: A systems Approach to Planning, Scheduling, and Controlling* 10th edition (2009) is one of the most complete sources for determining quantities by *percent complete*: the text gives seven methods (p656). Harold holds a PhD in aeronautical engineering from the University of Illinois and lectured at Baldwin Wallace University for 37 years. He is closely associated with the Project Management Institute (PMI): the Ohio chapter annually grants an award in his name. For several years after graduating, he worked with Morton-Thiokol[337] [338], a chemical company that produced rocket motors. Presumably, this is where he gained his practical experience in project management.

Construction Planning, Equipment, and Methods by Robert Peurifoy and Cliff Schexnayder. Robert Peurifoy was a Professor at the University of Texas at Austin, a respected university with an excellent construction engineering program. While an excellent researcher, I cannot find a record of Peurifoy's project site experience. Each year a Peurifoy Research Award is presented. Past winners include Professor Ray Levitt (2006), Professor Boyd Paulson (1993), Professor John Fondahl (1990), and Professor Clarkson Oglesby (1988): all four had a strong influence on the Stanford construction management and engineering (CEM) program (Levitt, 2007). Based on the 'research' in the award title, I assume Peurifoy had a strong research focus. Professor Levitt found that all the Peurifoy awards have gone to academics with a strong belief in CEM as a legitimate profession and they wanted a community of CEM researchers. Cliff Schexnayder was a Professor at the Arizona State University Del Webb School of construction, another excellent school. The Construction Planning, Equipment, and Methods text has a strong bent towards a professional tone and presents the material with an engineering approach through equations.

These authors and their experiences form the knowledgebase I present as the reference texts in my literature review. Cumulatively the experience looks comprehensive and clearly these

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[333] CH2M last accessed 5/12/2015 http://en.wikipedia.org/wiki/CH2M
[334] See http://www.energysolutions.com/category/completed-projects/?post_type=project
[335] See http://desd.ans.org/newsletters/Oct_2005.pdf
[336] Harold Kerzner http://en.wikipedia.org/wiki/Harold_Kerzner
[337] Thiokol http://en.wikipedia.org/wiki/Thiokol
[338] See http://www.pmineo.org/index.php/professional-development/kerzner-award-and-project-of-the-year-award-2014

authors have used their experience to draw on the experiences of other practitioners. I believe these authors form a complete representation of the knowledge available through reference texts.

9.9 Appendix I: Ethnographic Experience Building Forms

A similar issue to quantities collection, each field engineer visualizes their own solution based on experience without leveraging others experiences. The following narrative illustrates the difficulty in perceiving what field engineers should measure. Once when I was a highway concrete laborer, the project superintendent asked the labor foreman to form a 24" thick highway bridge approach slab. The labor forman gave my crew the task to form the approach slab in time for the next day's concrete placement. Although the crew had worked with forms for the previous couple of years, these were 10" steel highway forms that pin together with a sledgehammer. There were also wood form-boards we used in place of steel forms, they are the same dimensions as the steel forms. At the end of a form run there was usually a short section that we filled with a wood board. Union foremen do not instruct Laborers to work with wood materials; we had not seen or framed with wood. Wood is the Carpenters' scope-of-work and from my experience, Carpenters are not on white-paving crews[339]. In the years I was a Laborer only one Carpenter was on the same project and he was a foreman that had stayed with the company after a structural project with lots of wood formwork. So based on my vocational education ten years previous as a residential framing carpenter we constructed the forms how the instructor taught me to frame walls, with a top plate, bottom plate, and studs. I placed kickers along the top and bottom of the forms Based on intuition, we guessed the stud and kicker spacing to hold back a slab of wet concrete 24" high and the width of two traffic lanes (24 feet). We [white paving prep-crew] assumed height and width governs the structural design, we did not know of loading slopes and that only height governs the design. The next day the masons arrived and placed the concrete. A section of form began to blowout due to poorly compacted soil that did not support a couple kicker stakes[340]. As laborers we did not fully appreciate that the stakes would not hold. I quickly fixed the problem by driving in several steel stakes and reset the form.

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[339] When I was a laborer we had friction with other trades. One was a joke about Carpenters having a difficulty sharing a project with other trades.

[340] This is an example of knowledge from experience; a mason told me that next time in poor soil conditions, rather than use the two-foot ½-inch steel stakes, take a 2"x4" board several feet long, cut a point on one end, and drive this into the ground to support the kicker. I had not thought of that scale of stake but afterwards, I started thinking 'bigger.'

Figure 72 The three design options for forms.

One of the masons described an alternative to the superintendents' instructions to sheet the forms in plywood. Unfortunately, he made his knowledge known in front of the superintendent and used foul language to describe what he thought of the design. He reasoned that a design using plywood was inefficient with respect to the reusability of material. Instead of plywood, in his experience he thought a better design is to use 2"x10" form boards stacked vertically and backed by 2"x4" studs. Presumably, his reason was to allow the reuse of material and reduce the custom fabrication – the superintendent did not let the mason finish explaining the reasons and significance. The reusability of the material and transportability by one Laborer in the broken-down state were intuitively governing factors for the mason. The super did not give his reasons for wanting pre-built panels.

As Laborers we did not have immediate access to the plans. The plans were kept in the office on large rolls of papers. We usually were not allowed in the office and asking to see the plans or simply walking in and looking at the plans – was just something we did not do. In retrospect, of course we could have, but we would need to have a reason, and as Laborers, we simply did not have the communication skills. As an added issue, if anything went missing in the office, we'd most likely be suspected as the thief. As Laborers, it was better to stay away from the office.

We had no way of knowing the panels we built would be reused for the duration of the project. After we had built the first panel to the exact dimensions for that specific application, we realized we might reuse these. The second panel we undersized and blocked up to height and then placed dirt along the gap at the bottom. Throughout the project, the one irregularly sized panel caused problems. On page 1-11 of the Field Engineers Manual is a diagram of how to construct formwork with wailers and a strong back. The guide would have been helpful in the field for design ideas. (Field Engr, 2002)

9.10 Appendix J: Permissions to Reuse Material

permissions

Re: permission to use graphic

Michael Bach <michael.bach@uni-freiburg.de>

Tue 5/26/2009 10:33 AM

To:Peterson, Forest Olaf <granite@stanford.edu>;

Dear Forest Peterson:

> While looking for literature concerning the ability of the human eye
> to discern between percentages I found your illusions website, that
> introduces a new variable. Will you give me permission to use figure
> 4 of the table surface in "Bach & Poloschek (2006) Optical Illusions
> primer"? The graphic will appear with your permission in my Engineer
> degree thesis.

from my side: yes. However, the original is from Shepard, and the journal has the copyright.

> As part of research in construction project monitoring I have been
> reviewing the methods used to determine the current state of project
> progress. One method relies on a visual determination of the
> percentage of completion. This usually relies on some illustration
> depicting the finished state compared with a visual observation of
> the current unfinished state.
> Are there any papers you suggest that cover the topic of the eyes
> ability to distinguish between states of completion?

Not that I am aware off. Typical progress bars in software use various techniques: a bar that fills, or a circular cake diagram that fills.

Best, Michael Bach

--

Prof. Michael Bach PhD, Ophthalmology, University of Freiburg,
Killianstr. 5, 79106 Freiburg, Germany.
Michael.Bach@uni-freiburg.de <http://www.michaelbach.de>

RE: permission to use graphic

Rachael Hansford, ACNR Publisher <Rachael@acnr.co.uk>

Sun 5/31/2009 3:02 PM

To:Peterson, Forest Olaf <granite@stanford.edu>;

Hi Forest
We are happy for you to use the figure if you credit ACNR - no cost involved or paperwork to complete. I hope that helps!
Regards
Rachael

Rachael Hansford, Publisher
ACNR (Advances in Clinical Neuroscience & Rehabilitation)
1 The Lynch, Mere, Wiltshire, UK BA12 6DQ
Tel. +44 1747 860168/+44 07989 470278

Normal office hours: Monday 9.30am-4.30pm, Thursday 9.30am-4.30pm. Outwith these hours please call me on my mobile, 07989 470278.

www.acnr.com

-----Original Message-----
From: Forest Olaf Peterson [mailto:granite@stanford.edu]
Sent: 26 May 2009 21:56
To: rachael@acnr.co.uk
Subject: Fwd: permission to use graphic

Hello,

per the conversation included below, Professor Bach indicated that I should contact you for permission to reuse figure 4 from Bach & Poloschek "Optical Illusions" Visual Neuroscience, ACNR • VOLUME 6 NUMBER 2 • MAY/JUNE 2006. pp20 - 21.

Forest

----- Forwarded Message -----
From: "Michael Bach" <michael.bach@uni-freiburg.de>
To: "Forest Olaf Peterson" <granite@stanford.edu>
Sent: Tuesday, May 26, 2009 10:32:56 AM GMT -08:00 US/Canada Pacific
Subject: Re: permission to use graphic

Dear Forest Peterson:

> While looking for literature concerning the ability of the human eye

> to discern between percentages I found your illusions website, that
> introduces a new variable. Will you give me permission to use figure
> 4 of the table surface in "Bach & Poloschek (2006) Optical Illusions
> primer"? The graphic will appear with your permission in my Engineer
> degree thesis.

from my side: yes. However, the original is from Shepard, and the journal has the copyright.

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> progress. One method relies on a visual determination of the
> percentage of completion. This usually relies on some illustration
> depicting the finished state compared with a visual observation of
> the current unfinished state.
> Are there any papers you suggest that cover the topic of the eyes
> ability to distinguish between states of completion?

Not that I am aware off. Typical progress bars in software use various techniques: a bar that fills, or a circular cake diagram that fills.

Best, Michael Bach

--

Prof. Michael Bach PhD, Ophthalmology, University of Freiburg,
Killianstr. 5, 79106 Freiburg, Germany.
Michael.Bach@uni-freiburg.de <http://www.michaelbach.de>

--

Best

Forest Peterson

Graduate Research Assistant, Construction Engineering & Management
Center for Integrated Facility Engineering Stanford University granite@stanford.edu

Re: permission to use graphic

Michael Bach <michael.bach@uni-freiburg.de>

Wed 5/27/2009 2:37 AM

To:Peterson, Forest Olaf <granite@stanford.edu>;

Dear Forest Peterson:

> Are you able to give permission to reuse the standard Hering illusion,
yes

> triangle puzzle
no, it's from Gardner (but I would / have) use it.

> and monster Ponzo Illusion
no (Shepard, I got personal permission from him)

> you provide as examples on your website.

Best, Michael Bach.

PS: You wrote it's for a thesis -- there I would simple go ahead, use them, and of course mention the source.

--

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9.11 Appendix K: Lewis Metzler Clement Technical Report "Railroads in California"

Introduction omitted – I added the following headers

9.11.1 Features of Construction

As in everything else, railroads are made up of their constituent details and it is in the difference of the conditions affecting these that railroad construction and the management of works in other climates differ from the same descriptions of work in the most populous and temperate portions of America.

Many of the works are very dissimilar in character. Many constantly recurring on eastern lines occur but rarely in the country now under consideration. While several of those which are there of only inconsiderable magnitude assume features of the first importance here.

9.11.2 Applied Resources, Production, and Supervision

9.11.2.1 Supervision

In the one case, we can generally command almost any amount of the best workmen, skilled and unskilled. They are experienced in their work; they are in every sense completely under control and move with almost as much regularity as the parts of well constructed machinery. The amount of supervision they require is inconsiderable and we know almost to a moment when it is needed.

In the other, it is generally the reverse. More particularly at the commencement of operations. We have almost always to do as best we may in the early stages of construction, with a very limited amount of most insufficient labor of every description.

The work is generally new to the men we have to employ and they are often very unfitted for it by their previous habits and perfectly innocent of any idea of system or discipline or of the value of combined labor.

These unfavorable conditions continue until the evil is gradually alienated and the difficult task of training performance by Americans who have affordest the greatest difficulties to contend against to entrench and teach men and who unfortunately and most unwisely for all parties are not always selected on account of former experience, ability, or character, but often from classes utterly disconnected with the work to be performed.

In itself and under any circumstances this is a great evil to contend with and one which very soon makes itself severely felt and is the cause of many shortcomings but in the case of that description of labor and under the condition to which we now refer it is of incalculable damaging influence and every day's work bears the stamp of that inefficiency and confusion, which exists in the mind of the man who is attempting a task of which he has but a vague idea and never has performed.

Where such instances of incapacity are very soon remedied by speedy detection. Here too many causes hold ground for a remedy to be easily attainable and the evil has to be counteracted as much as may be by infinite labor, great expense, and anxiety, and endured always with an immense loss to those most deeply interested.

When this occurs at several places along a line of works no supervision from what should be headquarters can control the mischief. It is however very different with able superintendents and foremen.

9.11.2.2 Labor

The Chinese are far from unintelligent or unamenable to discipline. Although generally frivolous and devoid of the American energetic intent of purpose they are perfectly capable after a time of being directed in the requisite course and performing a very fair amount of labor.

They are speedily far seeing enough to ascertain when they are well directed and ready to respect an able body and obey him, but like other beings, they are prone to feel great contempt for incapacity. They are obedient to a rule of calm firmness but sulky to extreme and vindictive towards that brutal violence which is too often exerted against them.

Although perhaps as a rule, working men of Asia generally are of a somewhat slighter frame than in most parts of Europe and America. They are frequently not of a large stature and vast muscular power - capable of performing any of the heaviest railroad work.

9.11.2.3 Material

Good material of many descriptions and for various purposes are often as scarce as good labor unless imported and we do not always meet with such intelligent arrangements that such importations are made with the truest economy in every acceptation of the world. It is true however in the other hand that where native materials are adopted for the purposes that are required for, they are obtained and worked after a time very economically. When however such is not the case the Engineer must bring all his skill to bear to obviate any evil results arising from such cases, often by great changes in the disposition of his materials or of his workers and he will often have to turn his attention to new features in construction on this account the more earnestly from the necessity of keeping before him the hard fact that by whatever difficulties he may be driven into a failure he must never the less bear the blame for it is everywhere a special feature of our calling that what we cannot effect by one means we must by another.

Unless the understanding be commanded on all sides by ability and intelligence of a superior order. With judgement and forethought capable of establishing wise provisions of an early stage of the works. The work will be to a greater or less degree a failure in man or all of its details.

In many instances, men whose skill and experience had been refined into greater value by knowledge of the habits and capabilities of the men they had to lead and by man technical advantages to be acquired by residence alone have become lost to the company.

It would be futile to attempt disguising that scandals and discredit seized upon with avidity by intriguers of every description and most deeply felt and candidly acknowledged by the most sincere will-wished of the undertaking, and consequences sure to arise. They are of much greater importances to all the vast interests engaged than is generally contemplated.

9.11.3 Access Roads

In the great railroad territories of America it is rarely that we find any serious deficiency of good roads for the forwarding of materials - in the country of California and in similar regions the roads are generally - except in the immediate neighborhood of large towns - but primitive tracks.

The subject of means by which we may push the works forward is one deserving of much concentrations from the first and one that can only be neglected at great present expense and infallibly with the most fatal consequences to the company thereafter.

When we consider the great expenses incurred on account of the laborers and mechanics employed, material on hand, etc., How desirable it is to open up to public travel any section of the line as speedily as possible in order to obtain a return upon the large capital invested and of far more importance in the end give the most substantial proof of the value of the undertaking to the inhabitants of the country the great advantage of breaking ground in as many places as may be judiciously done becomes self-evident. But, this cannot be done unless provisions are made for the purpose.

During the rainy season, little or nothing can be done to the roads. But as soon as the general spring of our latitude and the early summer have set in the ground dries and hardens very rapidly. Many improvements may then be effected with an inconsiderable expenditure so as to render the roads passable in defective places for moderate quantities of material carried in light vehicles adapted to the roads.

By these means combined with two or three others to be treated hereafter the energies of the company Engineers are more widely available and the plant is not locked up on a short length or division of the works. More important still, a delay of a year or two may thus be avoided much to the gratification of the population who often express their surprise that with all our boasted energy and activity we do not manage to push our work forward more rapidly and that we do accomplish is not at least better than they could manage themselves.

In this country, the subjects of roads and means of transit from the stations to the towns in the neighborhood of the line are also of great importance to the traffic to be brought onto the railroad. Not only ultimately but immediately after its opening. When the shareholders, merchants, landowners, and contributors, as well as the inhabitants generally and the Government from where in all probability we are still seeking favors are one and all anxiously watching to note what changes the transportation may well effect.

If judicious measures have been taken beforehand, so as it were to lead the way for the public mind to enter gradually in the new phase which the ordinary road traffic must assume in connection with the new railway then these changes and improvements will be speedily developed but otherwise it will be found that very inconsiderable advantage will be gained even from larger towns from which a considerable traffic was originally anticipated and might readily have been obtained if by a little forethought arrangements had been made to adopt the old general conditions of the ordinary road and river traffic to the new and special feature of railway transit.

All men of experience know that when the public mind has once refused to adopt a “new order of things” it is afterward a work of time and patient labor to lead a whole population to agree to and enter upon that for which they have contracted feelings of eversion or ideas of inconvenience.

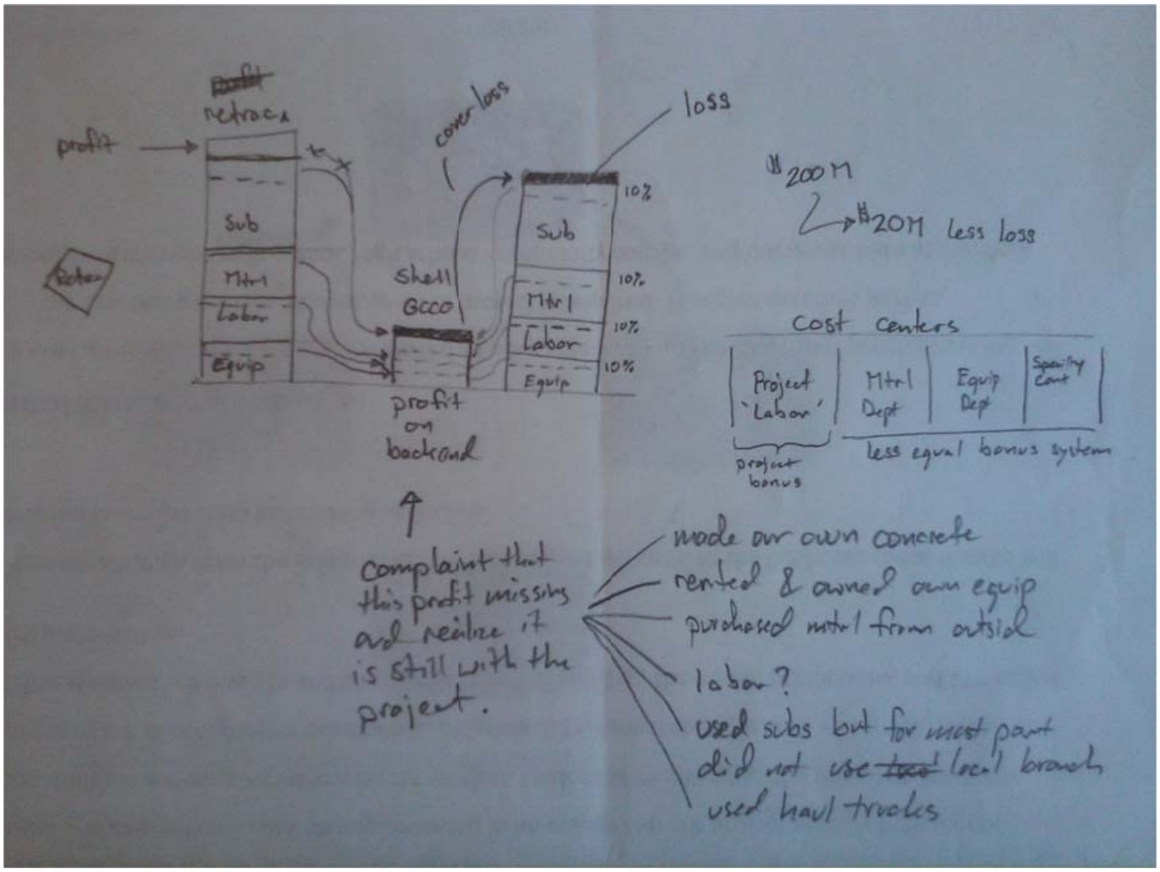
But the introduction of a good or improved roads leading to the railway stations and gradually constructed more or less simultaneously with the railway works would ensure very different and much more beneficial results than those which have frequently been obtained. The proof of this is demonstrated in the history of all American railways more especially those of earliest date.

It would also be found that until mismanagement had created apprehension of failure Government would be prepared to grant readily all possible encouragement, facilities, and privileges for the establishment of the communications from important centers of populations and trade of railroad stations. The importance of every description of communication that can be made between the railway and the surrounding country laterally is sufficiently established. The establishment of such roads as they have in Europe is no more requisite than a fine display in the stations. Simple economical utility is the requirement of the country as well as of a railway company to meet present demands.

9.11.4 Regional Inquiry

Another important matter demanding the earliest and most earnest attention and consideration of Engineers and all the company officers is that of obtaining the widest possible local information from as many sources as available. All however have some grounds for their adoption must be carefully sifted and examined, as circumstances will admit. We can scarcely listen to too much from the fear of missing perhaps only one portion of valuable information. We must take nothing for granted but test everything to the satisfaction of our own knowledge. This is an Engineering law, even in districts of which we may fairly suppose ourselves generally informed “a fortiori” is it to be attended to in strange and wild regions of which we do not know even the general features of capabilities and still less the multitudes of details connected with them.

9.12 Appendix L: Shell Games Defined



9.13 Appendix M: Indirects Complied

9.13.1 Problem

As quantities change for the direct accounts forecasting cost to completion based on quantities and unit cost needs to vary and is a reason why it is important to put material in the direct costs and not carry material in overhead (Teicholz Interview).

A brief review – material purchased for a project, for example lumber, is purchased for two reasons, either it is to use on a specific task or it is to use on many tasks. If it is for one task then that is easy, I apply the material to that task. But, if I will use the lumber on many tasks then when I buy it where do I park my material in the planning system? The solution is an indirect account – a holding account until the material is used.

On the ReTRAC items are represented as *indirect* (activity independent) and *direct* (activity specific). The production quantity for indirects (also known as undistributed) are often time-dependent and the production quantity for directs are time-independent. Indirects cannot be traced to a specific activity while directs can be traced to a specific activity. In theory, all indirects could be associated to a specific activity. Pragmatically, if all the applied resources were distributed it would exceed the benefit of knowing the quantities do that degree. For this reason there is the indirect account. With simplified accounting methods - another benefit of undistributed quantities is to monitor the purchase of bulk materials by type. A drawback is quantities must be reported redundantly on the indirect account and then again on multiple direct accounts.

The question of direct and indirect was raised by Ron on the ReTRAC project – he had seen materials accounted for using the indirect warehouse and direct activity at Atkinson – this was Paul Teicholz's method. At Granite Ron saw the material grouped as indirects across the board – this was Bob Stallard's method. The question is why the difference. By the ReTRAC project the knowledge of charging the material from indirect warehouse accounts to direct activities had been lost. We compared and contrasted but could not understand why Granite's accounts did not accommodate the direct material. This rendered the material accounts useless.

The ReTRAC planning system still allowed for a material production quantity but this was an abstracted quantity that did not have a matching material applied resource.

The questions I have:

- Why on the ReTRAC there is no applied material resource in direct activities?
- One of the relationships I would like to understand is the role of indirect and direct materials. Where is the line between direct and indirect?

- Formwork lumber is purchased by the project but is consumed by numerous concrete activities. Which activities reflect the use? How is the material resource applied to those activities?

9.13.2 Conclusion

I have eight independent discussions of the indirect and direct quantity issue:

- The second Construction Project Management Special Cost Accounting Problem example (CPM 4th, Ch10.23, 2000),
- Bartholomew's Heavy Civil Estimating book
- American Association of Cost Engineering (AACE) 20R-98, 2003
- discussed by Stallard (p167) during his interview
- discussed by Dukeshier (p167) during his interview
- discussed by Goodson
- discussed by Teicholz (p163) during his interview
- my ethnographic experience

As part of this study I distributed a questionnaire survey – the survey missed representation of material as a direct or indirect in both the pre-survey and the questionnaire. My literature review found a few texts that address indirect and direct but the topic was presented flatly without giving the why it was done that way. My most prominent sources are my ethnography and interviews.

As a field engineer, I tracked the quantities for the earthwork discipline. The earthwork scope during that project timeframe included 400 indirect accounts and 120 direct activities. These counts are prior to adding the applied resource suffix – the direct accounts on average had six applied resources in addition to the production activity and the indirect accounts had one applied resource. With the applied resource suffix, my earthwork scope was represented by 840 direct applied resource activities and 400 indirect accounts. The direct activities I planned, supported, and monitored totals to $10 million, the indirect accounts were less. The project engineer divided the project quantities into indirect and direct. From the survey interviews, I now know that the indirect quantity is a warehouse quantity – at the time of the ethnography this distinction was not fully understood by anyone on the project.

On the ReTRAC project, the managers used four practices to broadly reduce the effort needed for quantification: these solutions created numerous problems with accounting for the use of resources.

- First, they carried the material applied resource as an indirect.
- Second, they dismissed associating indirect applied resources with direct activities.

- Third, they had the field engineers code actual equipment cost directly to the activity. This meant there was no record of the equipment hours used on each activity.
- Fourth, they provided a weekly series of stakeholder meetings to negotiate solutions to exceptions the planning system could not accommodate – this was the Goodson system

On the ReTRAC project, temporary material, permanent material, cranes, and overhead supplies were tracked as indirects: I observed that removed material and modified material was tracked as a direct quantity. While the modified material was monitored as a direct material, it was given a separate 'quarry' work division and then treated like an indirect material. The earthwork field engineer had the trench spoils hauled to an on-site stockpile where a subcontractor processed the material to remove cobbles over 3" (contained up to 3' boulders), they then hauled the material back as backfill for the structural retaining walls. The material in this case was not identified as an applied resource material, it was a production quantity.

There are features common to indirect quantities such as consistent values, low risk to project success, and can be tracked on a long interval such as monthly or quarterly. For example, the indirect non-material quantities such as overhead labor, equipment, heavy equipment hour meters, project truck odometers, and cell phone count; the field engineers tracked these on a monthly basis. Presumably, the project engineer specified the monthly interval due to the consistency of the quantities.

On the ReTRAC, the Project Manager (Ron) could see problems with applying material quantities to direct accounts. Material that will be used by one activity is purchased and the quantity applied to that activity – bypassing the warehouse indirect account. Later, the same material such as forms are reused and each use is recoded as a quantity, so there is no record of the original quantity. He then saw the counter problem: If the material is applied as an indirect, there is no record of how much input material was used by an activity – only the production output.

The solutions I observed – they apply to any of the applied resources and in these examples applies to material and equipment:

- Indirect: carry as an indirect (method used at Granite HCD)
- Direct
- Direct: When applied resource is procured charge it directly to the activity that used it – the problem is if the purchase was for more than one activity or will be reused on subsequent activities.
- Distribution: Apply applied resource to activities using methods such as percentage, level of effort, or cost ratio. There are problems with this split. First, individual

estimators inconsistently group items as an indirect or direct. Second, the estimators estimate the indirect items after the direct items are finished.

- Warehouse:
- The answer from both Teicholz and the CPM (2000) is to purchase bulk material for large projects – and account for the material purchase in a *warehouse* or *clearing* indirect account. Then, as the material is used, sell to the direct activity. Pragmatically, Stallard found there is an insufficient benefit from knowing the material quantity and cost for each direct activity: all material can be an indirect.
- The problem with traditional warehousing is that once the project is done, there is no record of the original material purpose – this was relayed by Ron. For example temporary material, each time the material is used the quantity of is recoded with the direct activity, if the material is used five times than the sum of direct activities material will be five times the original purchase – a single indirect account resolves this problem. The counter problem with maintaining one indirect account – there is no record of what was used for each activity. A solution is to redundantly maintain the applied resource in the distributed activity and maintain the sum in an undistributed account.
- Direct Asset: Assign an asset number and rent (not observed or found used) to the direct activity to cover the applied resource cost with the apportioned effort method as the product of a predefined rental rate and a measurable unit, for example operating hours or quantity of material worked (Bartholomew, 2000). The rent solution is the most complex and requires the field crews to record their use.

The Stallard planner is based in pragmatics. This means that Stallard has evaluated the benefit of the Teicholz and Goodson systems then retained those aspects that are providing a return on the effort expended. For the most part the Goodson system is used – this system fills the gaps left by exceptions in the Teicholz planner theory. The Stallard system for the most part replicates the Teicholz system with the exception of the applied material. Stallard maintains the indirect accounting of the warehouse but does not record the handoff of material from the warehouse to the activity. Stallard found the benefit of A) knowing the quantity and cost of material on each activity and B) the calculation of cost to completion including material cost, as insufficient to justify the effort.

Under the Stallard planner the forecast to completion includes the labor and equipment cost. Under the older Stallard system the material cost is calculated separately using a spreadsheet and then is entered to the planner as an indirect, but after observing this system Stallard found no benefit of a separate tracking system and did away with this as well. Stallard did not say specifically, but it makes sense to eliminate material. Material cost inherently has less variability to the final cost as has labor and equipment. The material quantity cannot change absent a design change or quantity takeoff mistake. This provides a basis of stability that labor and equipment do not have. Labor and equipment cost are based on quantities that are estimates based on production from some other project with similar work – there is no grounding bottom. The labor and equipment are inherently volatile.

Stallard makes some core arguments for his pragmatics – I have to agree with Stallard since I saw these issues first hand on the ReTRAC. First, Stallard saw an inverse relation between the level of detail in the quantification plan and the accuracy of those quantities. The reason is the highly detailed quantities - while in theory good - was pragmatically a tedious system to maintain and the field engineers do not have the patience of accountants, so they simply start entering dummy numbers to the system that they think will pass audit checks. The planner becomes a huge gamed system.

Monitoring material resources is characterized by field engineers *chasing* delivery tickets to a specific cost code. Due to bias in reporting field engineers hide items in the wrong codes. For example, plywood and form lumber have a code in each operation. These are also a temporary material, i.e., an overhead cost, the practice is to estimate overhead cost for plywood and form lumber as a lump sum. Under the Teicholz system field engineers track the material as a lump sum in an indirect account and as a direct cost in an activity. This created an issue – the process became a shell game to follow an ideal scenario and not the actual scenario. A *shell game* means the field engineers report the expected quantity rather than the actual quantity. The field engineer has two benefits from a shell game: First, resource intensive field measurements are not necessary since they can derive the quantity from a plan quantity takeoff. Second, there is no variance from the expected quantities therefore not triggering a variance warning.

Backing up Stallard: In the survey there are indications that bias takes the form of everything from taking a shortcut with quantities and reporting something easy though incorrect, to purposefully misrepresentation for a financial gain. This echoes the findings by Saidi (20002) and Kiziltas (2006). Bias in reporting can mean quantities that are misrepresented and/or misrepresenting the features of those quantities. Several senior administrators from well respected companies - though anonymous - indicated in their questionnaire that bias in reporting is usually directed with the purpose of fraudulently obtaining a greater financial return than otherwise possible. Often this was accomplished by misrepresenting the cost code. For this reason, cost codes are an important focus of a construction audit.

I agree with Stallard that with the current theories the material is overly tedious to include as a direct applied resource. Stallard's planner allows the field engineers buy-in – Stallard purposefully leaves out the lower breakdown structure levels and lets the field engineers fill in this detail throughout the project as needed to reach measurable sources of quantities.

9.13.3 Suggestion

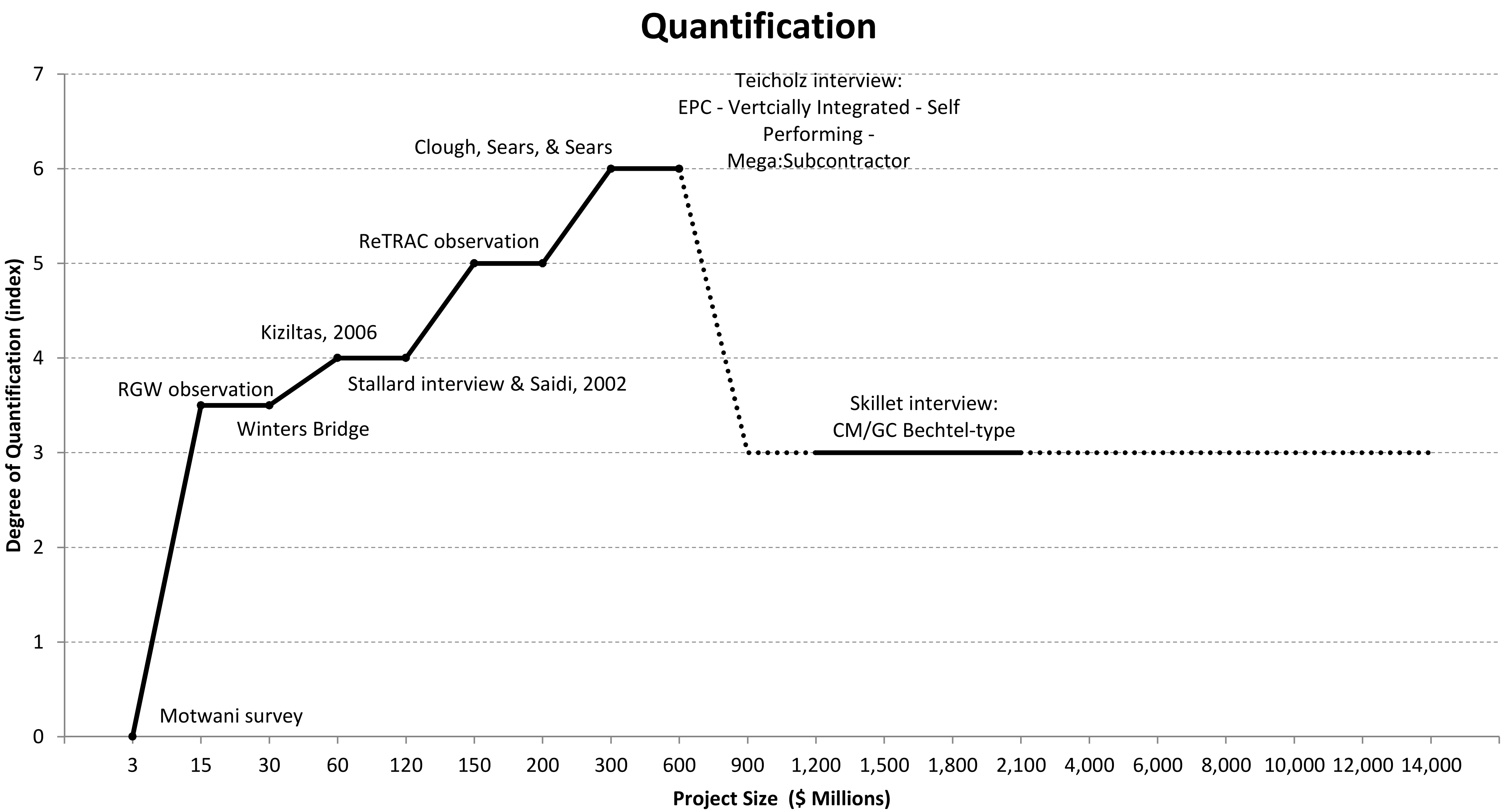
The planners given by Goodson, Teicholz, and Stallard, combined into a hybrid system provides for a robust and pragmatic planner. The indirect subaccount modification Ron identified is the missing component.

For the indirect accounts, there needs to be an additional level of detail showing the distribution from indirect to direct accounts – and probably some breakdown in purpose of distribution, maybe by material types: permanent (concrete), temporary (forms), and modification (lime). I need to see the distribution of the material at a sub-distribution level for the indirect accounts with sub accounts for sources of inputs and the outputs. For example, purchases from material suppliers (or purchased from another project) versus material returned from other activities are two separate inputs. For outputs, each use of the material is a unique line item.

With advances in automation the inclusion of materials as a direct applied resource should be feasible at a reduced effort. For the direct accounts – the tedious task of quantification and context will be automated with sensors and features assignment. The technology for automated sensing is not far off – the use of RFID tags is becoming common. These sensing technologies will remove the quantification task and leaves the automated features assignment. Again, sensing will resolve some aspects of features assignment and the remaining aspects will be resolved through model-based features assignment algorithms.

The use of indirects should decrease with time until eventually there will be no indirects.

9.14 Appendix N: Transition of Quantification Scope


Quantification
Degree of Quantification (index)
7
6
5
4
3
2
1
0
Teicholz interview:
EPC - Vertcially Integrated - Self
Performing -
Mega:Subcontractor
Clough, Sears, & Sears
ReTRAC observation
Kiziltas, 2006
Stallard interview & Saidi, 2002
RGW observation
Winters Bridge
Skillet interview:
CM/GC Bechtel-type
Motwani survey
3 15 30 60 120 150 200 300 600 900 1,200 1,500 1,800 2,100 4,000 6,000 8,000 10,000 12,000 14,000
Project Size ($ Millions)

9.15 Appendix O: Ethnography Scope of Observations

For the application of my ethnographic observations, this table provides the activities I observed and the magnitude of my observations. The materials are zero due to the difficulty pulling these quantities from the ERP system. Some accounts are zeroed for confidentiality and all the values have been rounded. I removed the columns with production and unit cost rations. Further, the crew applied resource and sequence were not part of this table outside the notes given in the margin. The notes in the right margin or those of the field engineers, some are mine though at this time I can no longer decipher which I wrote. These notes were for the ReTRAC Project Final Report that was never written beyond the table given here. I have not edited the notes.

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
100000	*	******UNDISTRIBUTED******														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
101000	*	**ADMINISTRATIVE**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
101101		PROJECT MANGER	1412	1414										1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
101200		CRAFT/SHIFT SUPER	1412	1414										1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
101300		ENGINEERING PERSO	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
101400		OFFICE PERSONNEL	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
110000	*	**FIELD OPS / WAGES**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
110100	*	**QA/QC SERVICES**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
110101		QC MANAGER	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
110102		QC ENGINEER	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
110103		QC PERSONNEL	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
110125		QA (SUB)										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
110201		MOBILE LAB							1432	1434						0	PC	-	$ -	$ -	$ -	$ -	$ -			
110204		LAB SETUP	1412	1414			1422	1424								0	PC	-	$ -	$ -	$ -	$ -	$ -			
110208		FURNITURE & EQUIPMENT							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
110209		OPERATIONAL SUPPLIES							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
110300	*	**SAFETY**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
110301			1412	1414												0		-	$ -	$ -	$ -	$ -	$ -			
110302		SAFETY ENGINEER	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
110409		OFFICE FURN / EQUIPT							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
110410		FIRST AID SUPPLIES							1432	1434	1436					0	MH	-	$ -	$ -	$ -	$ -	$ -			
110411		PROTECTIVE CLOTHING							1432	1434	1436					0	MH	-	$ -	$ -	$ -	$ -	$ -			
110413		FIRE EXTINGUISHER							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
110417		SAFETY AWARDS	1412	1414					1432	1434	1436			1480		0	MH	-	$ -	$ -	$ -	$ -	$ -			
110421		SNIFFER ALLOWANCE								1434	1436	1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
110422		REGULATED MATL TEST							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
110500	*	**SURVEY**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
110603		OUTSIDE SURVEY										1440				0	MO	-	$ -	$ -	$ -	$ -	$ -			
120000	*	**OFFICE/ENGRNG EXPENDITURES**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
120102		INTERIM LIVING EXPENSE							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120103		PERSONNEL MOVES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
120104		EXPENSE ACCOUNTS							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120105		CORPORATE TRAVEL							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120106		MEALS							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120107		COMMUNITY RELATIO							1432	1434	1436	1440		1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
120108		DRB EXPENSE							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120109		LIVING ALLOWANCE	1412	1414					1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120110		MEALS-EMPLR CONV								1434	1436			1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
120202		CREW WAGES	1412	1414												0		-	$ -	$ -	$ -	$ -	$ -			
120301		CONSULTING ENGR								1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120302		MATL TEST NOT Q/A							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120303		FIS (SHARECHIVE)									1436					0		-	$ -	$ -	$ -	$ -	$ -			
120304		AUTOCAD SYSTEM							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120305		SCHEDULE SYSTEM							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120306		COMPUTER HARDWARE							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120307		COMPUTER SOFTWARE							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120308		NETWORK EXPENSES							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120309		PROFESSIONAL PHOTO							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
120401		JANITORIAL SERVICES							1432	1434	1436			1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
120402		OFF/ENGE/PHOTO/SUPLIES							1432	1434	1436			1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
120407		UTILITY/SRVC DEPO							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
120501		LEGAL FEES							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
120507		PRECONSTR SURVEY										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
121000	*	**DESIGN SERVICES**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
121001		WATER RIGHT CONSULT							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
121002		PARSONS- DESIGN										1440		1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
121003		PARSONS- ODC										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
121004		PARSONS- PRE-AWAR										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
121011		PARSONS- POST-DES										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
121013		PARSONS- WITHOLDING										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
121021		OFFICE SPACE CREDIT							1432	1434	1436			1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
121031		GLENDALE WTP MONITOR							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
121041												1440				0		-	$ -	$ -	$ -	$ -	$ -			
121042		GROUNDWATER STUDY										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
140000	*	**CONTRACTOR OFFICE / YARD**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
140100	*	**FACILITIES & BLDGS**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
140101		Office Trailer							1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
140102		PARTS/TOOL VANS					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
140113		OFFICE SET-UP	1412	1414			1422	1424	1432	1434	1436	1440				0		-	$ -	$ -	$ -	$ -	$ -			
140114		OFFICE SET-UP MAT							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
140115		OFFICE SET-UP SUB										1440				0		-	$ -	$ -	$ -	$ -	$ -			
140117		OFFICE FURN EQ							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
140118		MAINTENANCE SHOP							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
140121		PHONE HOOKUP							1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
140122		POWER HOOKUP							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
140125		YARD FENCE							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
140126		YARD SURFACE							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
140128		TENANT IMPROVEMENT	1412	1414			1422	1424	1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
140200	*	**OPERATIONS & UTILITIES**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
140202									1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
140203		TELEPHONE							1432	1434	1436			1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
140204		SANITATION							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL MATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
140205		DRINKING WATER / ICE							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
140206		WATER SUPPLY							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
140207		POWER OFFICE / YARD							1432	1434	1436			1480		0	MO	-	$ -	$ -	$ -	$ -	$ -			
140208		TRASH / GARBAGE SERVICE							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
140209		LAND RENTAL							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
140210		SECURITY SERVICE							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
140212		CELL PHONES							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
150000	*	**YARD OPS / PROJ VEHICLES**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
150109		ROUSTABOUT	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
150112		FORKLIFT OPERATOR	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
150113		HYDROCRANE OPERATOR	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
150117		TRANSPORT DRIVER	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
150201							1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
150202		BOOMTRUCK					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
150203		FORKLIFT 5-10T					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
150204		HYDROCRANE 18T					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
150205		LOW BED TRANSPORT					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
150301		PICKUPS					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
150302		BUSES					1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
150401		YARD CLEANUP	1412	1414			1422	1424								0	PC	-	$ -	$ -	$ -	$ -	$ -			
150402		GRAFFITI PAINTING														0		-	$ -	$ -	$ -	$ -	$ -			
160000	*	**EQUIPMENT MAINTENANCE**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
160103		EQUIPMENT SUPT	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
160106		MECHANIC	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
160110		LUBE TRUCK DRIVER	1412	1414												0	MO	-	$ -	$ -	$ -	$ -	$ -			
160201		MECHANIC'S TRUCK					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
160202		LUBE/FUEL TRK LRG					1422	1424								0	MO	-	$ -	$ -	$ -	$ -	$ -			
170000	*	**GENERAL PROJ EXPENSE**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
170100		SMALL TOOLS	1412	1414			1422	1424	1432	1434	1436					0	MH	-	$ -	$ -	$ -	$ -	$ -			
170100	*	**MISCELLANEOUS**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
170113		INSUR CLAIMS DEDUCTIBLE					1422	1424		1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
170201		PROJECT SIGNS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
170301		TRAINING	1412	1414												0		-	$ -	$ -	$ -	$ -	$ -			
170302		MISC TRAINING EXP							1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
170303		MEDICALS / PHYSICAL							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
170304		DRUG TESTING							1432	1434	1436					0	MH	-	$ -	$ -	$ -	$ -	$ -			
170305		PARTNERING	1412	1414					1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
170309		EMP DEV 2 EDI	1412	1414			1422	1424		1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
170401		NIGHT LIGHTS	1412	1414			1422	1424	1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
170500	*	**SCAFFOLDS & LADDERS**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
170501		SCAFFOLDS & LADDERS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
170502		WORKBRIDGE BEAMS							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
170503		FALL PROTECTION	1412	1414					1432	1434	1436					0	MH	-	$ -	$ -	$ -	$ -	$ -			
170511		WK BRIDGES	1412	1414			1422	1424	1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
170512		WK BRIDGES-SUB										1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
170515		SET & MOVE RAIL	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			
170700	*	**PROJECT MAINT**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
170702		POWER BROOM	1412	1414			1422	1424		1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
170800		FINAL CLEANUP	1412	1414			1422	1424								0	PC	-	$ -	$ -	$ -	$ -	$ -			
170801		CLEANUP MATL							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175000	*	**LICENSES / FEES / BONDS**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
175100		PERMITS/TAXES/DUE							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175100	*	**PERMITS / TAXES / DUES**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
175102		AIR QUALITY MGMT							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175103		EQUIP / PROPERTY TAX							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175104		GROSS RECEIPTS TAX							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175106		CITY BUSINESS TAX							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175109		AGC DUES							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175110		BUILDING PERMITS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175112		DEMOLITION PERMITS							1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
175115		TEMP EASEMENTS	1412	1414				1424		1434	1436	1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
175141		INT ON RETENTION										1440		1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
175208		POLLUTION INS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175211		E&O INS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
175300		CONTRACT BOND							1432	1434	1436					0	M$	-	$ -	$ -	$ -	$ -	$ -			
175401		SUBCONTRACT BOND									1436	1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
175402		SPECIAL BOND									1436					0		-	$ -	$ -	$ -	$ -	$ -			
175500		FINES / PENALTIES								1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
180000	*	**PROJ PLANTS / SERVICE**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
180300	*	**CENTRAL WATER SYSTEM**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
180301		WATER SYS IN/OUT	1412	1414			1422	1424								0	PC	-	$ -	$ -	$ 6,000	$ -	$ -			
180303		TANK MATLS					1422	1424	1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
180305		PIPE & FITTINGS ETC							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
180306		WELL PUMPS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
180307		ABANDON / RAISE WELLS										1440				0	VF	-	$ -	$ -	$ -	$ -	$ -			
180308		DRILL WELLS SUPPORT	1412	1414			1422	1424	1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
180500		PROJECT ROAD MAINT	1412	1414			1422	1424	1432	1434	1436	1440				0		-	$ -	$ -	$ -	$ -	$ -			
180502		DUST CONTROL	1412	1414			1422	1424	1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
180800	*	**PROJECT DEWATERING**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
180810		DEWATER SYS W/ BKU-DEMO WELLS	1412	1414			1422	1424	1432	1434	1436	1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
180821		DEWATER SYS W/ BKU							1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
180822		SALVAGE SYS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
180824		PIPING							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
180828		PORTA DAMS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
180830		OPERATE DEWATER SYSTEM	1412	1414			1422		1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
180831		OPERATE DEWATER SYSTEM - SUB										1440				0		-	$ -	$ -	$ -	$ -	$ -			
184500	*	**PROJECT ALLOWANCES**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
184501		BRANCH EQ RATE ADJ					1422	1424								0	PC	-	$ -	$ -	$ -	$ -	$ -			
184504		KWIKBOND DECK SEAL	1412	1414			1422	1424	1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
184505		REGULATED MATL CREDIT							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
185000	*	**EQUIP MOB / DEMOB**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
185100		EQ ERECT / DISMANTLE	1412	1414			1422	1424	1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
185200		FREIGHT IN / OUT														0	PC	-	$ -	$ -	$ -	$ -	$ -			
199999	*	**KEYPUNCH ERRORS**	**1412**	**1414**	**1416**	**1418**	**1422**	**1424**	**1432**	**1434**	**1436**	**1440**	**1450**	**1480**		**0**		**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
200000	*	******DIRECT JOB COST - MATL******														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
200100	*	**TRAFFIC CONTROL**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
200101		SIGNS CONES BARR							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
200108		BARREL ARRAYS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200119		FLAGGING							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
200121		LIGHTS & BATTERIES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200151		VMS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200152		VMS SALVAGE							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200156		ARROW BOARD							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200157		ARROW BOARD TKMTD							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200500	*	**DEMOLITION**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
200510		DUMPSTERS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
200521		DUMP FEES							1432	1434	1436					0	LD	-	$ -	$ -	$ -	$ -	$ -			
200522		DUMPSTER (REGULATED)									1436	1440				0	LD	-	$ -	$ -	$ -	$ -	$ -			
200525		DUMP FEES (REGULATED)							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
200531		MISC SALVAGE												1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
201000	*	**EROSION CONTROL**														**0**	**MO**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
201001		SANDBAGS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
201010		EROS CTRL MISC MATL							1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
201031		GEOFAB BUY							1432	1434	1436					0	SY	-	$ -	$ -	$ -	$ -	$ -			
201045		POND LINER							1432	1434	1436					0	SY	-	$ -	$ -	$ -	$ -	$ -			
202000	*	**AGGREGATE**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
202005		TYPE II BASE							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202009		SELECT BACKFILL							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202013		DRAIN ROCK							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202021		IMPORT							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202026		CTB CL A							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202033		RIPRAP - 1 TON							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202034		RIPRAP - CL 150							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202041		SAND							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202051		BLAST SAND							1432	1434	1436					0	SK	-	$ -	$ -	$ -	$ -	$ -			
202371		CONC. SAND							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202415		CONC. AGG NO 67							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202431		SUBBALLAST 1-1/2							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202500	*	**ASPHALT**														**0**	**TN**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
202515		TACK							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202580		AC TY A							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202583		AC PATCH							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202587		TEMP AC							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
202589		BRANCH FIELDTECH							1432	1434	1436					0	HR	-	$ -	$ -	$ -	$ -	$ -			
204000	*	**CONCRETE**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
204011		CURE COMPOUND TY1							1432	1434	1436					0	GA	-	$ -	$ -	$ -	$ -	$ -			
204014		WATER CURE ALLOW							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204015		P&P MATL							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204021		MISC CONC. SUPPLIER							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
204022		EPOXY							1432	1434	1436					0	GA	-	$ -	$ -	$ -	$ -	$ -			
204025		CONC. CURE BLANKET/HEATER							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
204026		WATERSTOP							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204030		JOINT FILLER							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204034		POURED SEALANT							1432	1434	1436					0	GA	-	$ -	$ -	$ -	$ -	$ -			
204052		2 SACK SAND SLURRY														0		-	$ -	$ -	$ -	$ -	$ -			
204140		CONC4000							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
204141		CONC4000 FIBER							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
204142		CONC 4000 RED							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
204143		CONC 4000 GREY							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
204309		GROUT BAG INFILL							1432	1434	1436					0	CF	-	$ -	$ -	$ -	$ -	$ -			
204310		MORTAR/DRYPACK							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204311		SAND CEMENT GROUT							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204314		CONC. LEAN MIX							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
204341		5000 PSI SHOTCRETE							1432	1434	1436					0	CY	-	$ -	$ -	$ -	$ -	$ -			
204401		AEA							1432	1434	1436			1480		0	CY	-	$ -	$ -	$ -	$ -	$ -			
204402		SUPER P								1434				1480		0	CY	-	$ -	$ -	$ -	$ -	$ -			
204403		WRA							1432	1434	1436			1480		0	CY	-	$ -	$ -	$ -	$ -	$ -			
204407		FLYASH / POZZOLAN							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
204408		ACCELERATOR								1434				1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
204410		CRYSTALLINE WATERPROOF							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
204421		CEMENT TY1/2 BULK							1432	1434	1436					0	TN	-	$ -	$ -	$ -	$ -	$ -			
204426		K-RAIL BUY							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204427		K-RAIL SALVAGE							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204428		K-RAIL RENT							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
204435		RR SIGNAL FNDNS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204441		BRIDGE BOXES								1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204442		DECK SLABS								1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204481		C-J CONC. BUY ADJ							1432	1434	1436	1440				0	CY	-	$ -	$ -	$ -	$ -	$ -			
204482		C-J CEMENT BUY AD							1432	1434	1436	1440				0	TN	-	$ -	$ -	$ -	$ -	$ -			
204491		STAMPED SIDEWALKS							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204492		STAMPED CROSSWALK							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204493		CONV. SIDEWALK							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204494		24IN CURB & GUTTER							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204495		VALLEY GUTTER							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204500	*	**FORMWORK**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
204502		FORM SALVAGE							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204503		CRANE PADS								1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
204505		TINKERTOY 10K REN							1432	1434	1436					0	CF	-	$ -	$ -	$ -	$ -	$ -			
204511		DIM LUMBER							1432	1434	1436					0	MB	-	$ -	$ -	$ -	$ -	$ -			
204514		PLYFORM 5/8							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204515		PLYFORM 3/4							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204516		PLYFORM HDO							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204518		GOCK SCREEN MATL								1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204521		FORM HARDWARE							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204535		MISC C&G FORMS							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204613		SONO VOID - 7IN							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
204631		INVERT FORM (EFCO)							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204632		TRENCH WALL FORM							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204633		TRENCH RETWALL FO							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204634		TRENCH BARRIER FO							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204635		FORM RENTAL							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204641		CAP BEAM FORM							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204642		BRIDGE RAIL FORM							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
204900	*	**FURNITURE / SPECIALTY**							**1432**	**1434**	**1436**					**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
204911		TRASH RECEPTACLES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204921		BENCHES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
204931		TRANSIT TILE								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
204940		TEMP AMTRAK BUILDING								1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
204941		TEMP AMTRAK BUILD OUT							1432	1434						0	PC	-	$ -	$ -	$ -	$ -	$ -			
205000	*	**STRUCTURAL METALS**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
205001		C6 CHANNEL							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
205021		NEOPRENE BEARING							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
205022		EPOXY COAT BEAMS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205031		LAKE ST BMS/HANGER								1434						0	EA	-	$ -	$ -	$ -	$ -	$ -			
205500	*	**MISCELLANEOUS METALS**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
205508		TREE GUARDS / GRATES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205512		5/8INX18FT STEEL							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205531		REBAR WALL TEMPLATE							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
205532		STREET BOLLARDS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205533		SLAB EDGE TEMPLATE							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
205535		SLOPE FORM TEMPLATE							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
205537		NELSON STUDS							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
205601		SOUND CURTAIN							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
205611		APPROACH SLABS MM							1432	1434	1436					0	LS	-	$ -	$ -	$ -	$ -	$ -			
205621		WET WELL MM							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
205631		ACCESS HATCH (BILCO TYPE							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205633		PUMP STA H-20 COVER							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205635		FLAP GATES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
205641		AMTRAK BLDG MM							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
205651		AWNING MISC MATL							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
205800	*	**POST-TENSIONING**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
205808		PRESTRESS GROUT							1432	1434	1436					0	CF	-	$ -	$ -	$ -	$ -	$ -			
205821		PRESTR BARS / STRD / ANCH							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
205900	*	**REINFORCING STEEL**														**0**	**LB**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
205911		REBAR BLACK							1432	1434	1436					0	LB	-	$ -	$ -	$ -	$ -	$ -			
206000	*	**PIPE**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
206001		MISC PIPE SUPPLIES							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
206003		STORM DRAIN PATCH							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
206004		DRUM SUMPS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206005		AMTRAK BLDG DRAIN							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206006		BARRIER SCUPPERS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206007		CUSTOM GRATE								1434						0	EA	-	$ -	$ -	$ -	$ -	$ -			
206008		PIPE SUPPORTS							1432	1434	1436			1480		0	EA	-	$ -	$ -	$ -	$ -	$ -			
206009		BAY SAVER							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206011		SHORE RENTAL					1422	1424	1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
206012		SHIELD RENTAL					1422	1424	1432	1434	1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
206013		PURCHASE TRENCH PLATES							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
206015		GEOTEXTILE DRAIN BOARD							1432	1434	1436					0	SF	-	$ -	$ -	$ -	$ -	$ -			
206031		SUBDRAINS							1432	1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206044									1432	1434	1436					0		-	$ -	$ -	$ -	$ -	$ -			
206045		WATER PIPE SMALL							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
206066		STL4 GAS							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206067		STL8 GAS							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206112		RCP12							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206115		RCP15							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206118		RCP18 CL3							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
206124		RCP24 CL3							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206130		RCP30								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206136		RCP36								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206148		RCP48								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206149		48" RCP FES								1434						0	EA	-	$ -	$ -	$ -	$ -	$ -			
206154		RCP54							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206160		RCP60							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206166		RCP66								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206184		RCP84							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206196		RCP96							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206201		12-48IN FES								1434						0	EA	-	$ -	$ -	$ -	$ -	$ -			
206301		SCUPPER COVERS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206304		PVC4 SCH 40							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206306		PVC6 SCH40							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206308		PVC8							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206310		PVC10"								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206312		PVC 12"							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206315		PVC 15"							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206318		PVC18							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206324		PVC24							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206330		PVC30"								1434						0	LF	-	$ -	$ -	$ -	$ -	$ -			
206336		36IN SANITARY SEWER							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206401		MH ETC MISC ADJ MATL							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206402		MISC MH CONC. MATL							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206403		RAMNECK							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206411		MH 36IN BARREL							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206412		MH 60IN							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206413		MH RISER RINGS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206421		MH/VLV/VLT TEMP CVR							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206422		MH CASTINGS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206423		MH P/C RING&COVER							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206431		FRAME AND COVERS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206441		CB - DBL BOX - AR							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206442		CB - DBL BOX - CU							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206443		DI/CB - AREA							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206444		DI/CI/CB - CURB							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206445		CB TY4R							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206446		SUR TRAP							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206669		RCB7X6							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206678		RCB5X2							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206682		RCB11X5							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
206856		FIRE HYDRANT							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206857		STAND PIPE								1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
206968		DIP8&14							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
207000	*	**ELECTRICAL**														**0**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
207001		PVC4 SCH 80 CONDUIT							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
207002		RGS4 CONDUIT							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
207011		DETECTION STRIPS							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
207012		MISC MATERIAL/BRK							1432	1434	1436					0	LF	-	$ -	$ -	$ -	$ -	$ -			
207014		SWEEPS							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
207021		PULL BOXES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
207023		TEMP VAULTS 4X4FT							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
207025		PERM VAULT 4X4FT							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
207027		PERM VAULT 3X3FT							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
207031		TELEPHONE POLES							1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
208300	*	**INSTRUMENTATION**														**0**		**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
208301		GEOTECH INSTRUMENT								1434						0	EA	-	$ -	$ -	$ -	$ -	$ -			
208303		PIEZOMETER								1434						0	EA	-	$ -	$ -	$ -	$ -	$ -			
210000	*	**MOISTURE PROTECTION**														**0**		**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
210001		BASEMENT WPRF							1432	1434						0	SF	-	$ -	$ -	$ -	$ -	$ -			
250000	*	******DIRECT******														**1,494,000**	**PC**	**733,000**	**$ 5,555,000**	**$ 3,045,000**	**$ -**	**$ -**	**$ 83,161,000**			
250000		**MOBILIZATION**														**0**		**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
250061		SUPPT OF EXC MOB										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
260000	*	**TRAFFIC CONTROL**														**0**	**MO**	**42,000**	**$ 888,000**	**$ 132,000**	**$ 596,000**	**$ 219,000**	**$ 1,241,000**			
260010	*	**MOT**														**0**	**MO**	**39,000**	**$ 799,000**	**$ 107,000**	**$ 313,000**	**$ 31,000**	**$ 935,000**			
260011		T/C IN/OUT	1412	1414			1422	1424								0		(33)	$ -	$ -	$ 313,000	$ -	$ 313,000			
260013		DAILY MOT	1412	1414			1422	1424								0	WK	20,000	$ 420,000	$ 107,000	$ -	$ -	$ 526,000			
260019		FLAGGING	1412	1414			1422	1424								0	MO	20,000	$ 379,000	$ 550	$ -	$ -	$ 380,000			
260020		RR FLAGGING	1412	1414			1422	1424				1440		1480		0	DA	-	$ -	$ -	$ -	$ 31,000	$ 29,000			
263000	*	**PORTABLE CTB**														**100**	**PC**	**3,000**	**$ 86,000**	**$ 24,000**	**$ 283,000**	**$ -**	**$ 110,000**			
263211		CTB UNLOAD/SET	1412	1414			1422	1424								18,000	LF	2,000	$ 41,000	$ 15,000	$ 282,000	$ -	$ 57,000			
263227		MOVE CTB (TRUCK)	1412	1414			1422	1424								6,000	LF	650	$ 17,000	$ 4,000	$ -	$ -	$ 21,000			
263228		CTB2YARD	1412	1414			1422	1424								13,000	LF	430	$ 13,000	$ 5,000	$ -	$ -	$ 18,000			
263229		GAWK SCREEN	1412	1414			1422	1424								3,000	LF	-	$ 15,000	$ -	$ 780	$ -	$ 15,000			
264000	*	**PAVEMENT MARKERS**														**0**	**PC**	**490**	**$ 570**	**$ -**	**$ -**	**$ 177,000**	**$ 181,000**			
264001		TEMP STRIPES	1412	1414								1440				0	PC	-	$ -	$ -	$ -	$ 109,000	$ 113,000			
264002		GCCO TEMP STRIPE	1412	1414			1422	1424								2,000	LF	20	$ 570	$ -	$ -	$ -	$ 570			
264003		STRIPE ROBB DR										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
264005		REMOVE STRIPES	1412	1414			1422	1424				1440				2,000	LF	-	$ -	$ -	$ -	$ 6,000	$ 6,000			
264011		PERM PVMT MARKING										1440				0	PC	-	$ -	$ -	$ -	$ 61,000	$ 61,000			
266000	*	**SIGNAGE**														**160**	**SF**	**110**	**$ 3,000**	**$ 2,000**	**$ -**	**$ 11,000**	**$ 15,000**			
266001		LOAD LIMIT SIGNS										1440				0	SF	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
266503		PERMANENT SIGNS	1412	1414			1422	1424				1440				160	SF	110	$ 3,000	$ 2,000	$ -	$ -	$ 5,000			
266505		SIGN POSTS										1440				30	EA	-	$ -	$ -	$ -	$ 11,000	$ 11,000			
280000	*	**SITEWORK**														**100**	**PC**	**54,000**	**$ 1,632,000**	**$ 187,000**	**$ 1,365,000**	**$ 1,497,000**	**$ 3,316,000**			
280010	*	**MISCELLANEOUS**														**100**	**PC**	**3,000**	**$ 83,000**	**$ 19,000**	**$ -**	**$ 219,000**	**$ 321,000**			
280051		POTHOLE UTILITIES	1412	1414			1422	1424				1440	1450			90	PC	3,000	$ 83,000	$ 19,000	$ -	$ -	$ 102,000			
280052		POTHOLE UTIL SUB										1440				100	PC	-	$ -	$ -	$ -	$ 219,000	$ 219,000			
281000	*	**EROSION CONTROL**														**40**	**MO**	**5,000**	**$ 116,000**	**$ 21,000**	**$ 38,000**	**$ -**	**$ 137,000**			
281010		EROS CONTROL CREW	1412	1414			1422	1424								40	MO	5,000	$ 116,000	$ 21,000	$ 38,000	$ -	$ 137,000			
285100	*	**CURB & GUTTER**														**100**	**PC**	**15,000**	**$ 470,000**	**$ 52,000**	**$ 287,000**	**$ -**	**$ 522,000**			
285101		GRADE CURB & GUTTER	1412	1414			1422	1424								23,000	LF	1,000	$ 35,000	$ 12,000	$ -	$ -	$ 46,000	Rough Grade for all types of curb and gutter	Cut curb and gutter subgrade with street subgrade	
285102		BACKFILL MEDIAN CURB	1412	1414			1422	1424								7,000	LF	220	$ 7,000	$ 5,000	$ -	$ -	$ 12,000	Backfill curb and curb and gutter not adjacent to sidewalk		Actual quantity 12.9% of budget quantity. High unit cost can be attributed to small actual quantity.
285103		IMPORT/PLACE/FINEGRADE C&G BASE	1412	1414			1422	1424								68,000	SF	4,000	$ 117,000	$ 32,000	$ 268,000	$ -	$ 149,000	Fine Grade Type 2 AB under Curb/Curb & Gutter Areas		Budget quantity of 2500 SF is 4.4% of actual quantity.
285111		HANDSET C&G (TEMP)	1412	1414			1422	1424								2,000	LF	250	$ 7,000	$ 210	$ -	$ -	$ 7,000			
285112		CURB & GUTTER	1412	1414			1422	1424								16,000	LF	8,000	$ 239,000	$ 3,000	$ 19,000	$ -	$ 242,000	Form/Pour/Strip Curb and Gutter	Hand set all but 2380 LF at Dickerson Rd.	
285113		MEDIAN CURB	1412	1414			1422	1424								4,000	LF	2,000	$ 52,000	$ 280	$ -	$ -	$ 52,000	Form/Pour/Strip Median and Post Curb	Hand set	Budget quantity was 19.6% of actual quantity
285115		VALLEY GUTTER	1412	1414			1422	1424								3,000	SF	380	$ 12,000	$ 70	$ 350	$ -	$ 12,000	Form/Pour/Strip Valley Gutter	Hand set	
285117		SLIP TRENCH TROUGH	1412	1414			1422	1424								0	LF	30	$ 940	$ 190	$ -	$ -	$ 1,000			
285200	*	**SIDEWALK / CROSSWALK**														**100**	**PC**	**28,000**	**$ 861,000**	**$ 82,000**	**$ 671,000**	**$ -**	**$ 943,000**			
285201		GRADE SIDEWALK	1412	1414			1422	1424								126,000	SF	2,000	$ 43,000	$ 12,000	$ -	$ -	$ 55,000	Rough Grade for sidewalk/flatwork areas	Cut sidewalk subgrade with street subgrade	
285202		GRADE CROSSWALK	1412	1414			1422	1424								20,000	SF	620	$ 19,000	$ 4,000	$ -	$ -	$ 23,000	Sawcut and remove AC	Sawcut and remove AC	
285204		IMPRT/PLCE/FINEGRD SW/CW BASE	1412	1414			1422	1424								143,000	SF	6,000	$ 175,000	$ 56,000	$ 268,000	$ -	$ 231,000	Import/Place/Fine Grade base for sidewalk and crosswalk.	Rough dump, grade and compact base for sidewalk. Rough dump, grade and compact base and tie steel for crosswalk	Cost includes #4 bar tied for crosswalk areas (14,950 SF)
285205		SIDEWALK SOLDIER COURSE	1412	1414			1422	1424								5,000	SF	3,000	$ 93,000	$ 140	$ 65,000	$ -	$ 94,000	Form/Pour/Strip Sidewalk Soldier Course (8" wide stamped brick pattern with integral color)	Hand set all. Neatline pour to expansion adjacent curb and gutter, backside form.	This was an added cost code to help in tracking the stamped/stained sidewalk unit cost.
285206		CROSSWALK SOLDIER COURSE	1412	1414			1422	1424								5,000	SF	1,000	$ 49,000	$ 770	$ 65,000	$ -	$ 50,000	Neatline pour (16" wide, 12" deep integral color stamped brick pattern) to expansion at sawcut AC, backside form.	Tie steel cage, Hand set	This was an added cost code to differentiate between sidewalk and crosswalk soldier course
285209		TREE GUARD/GRATES	1412	1414			1422	1424								40	EA	50	$ 1,000	$ -	$ -	$ -	$ 1,000			
285211		SIDEWALK	1412	1414			1422	1424								42,000	SF	4,000	$ 124,000	$ 2,000	$ 17,000	$ -	$ 126,000			
285212		STAMPED SIDEWALK	1412	1414			1422	1424								76,000	SF	7,000	$ 216,000	$ 3,000	$ 242,000	$ -	$ 220,000	Form/Pour/Strip 4" sidewalk	Hand set	Unit cost is high due to lack of available quantities. Total quantity broken up into several small areas not available to pour on same day
285213		DICKERSON C&G REPAIR	1412	1414			1422	1424								1,000	LF	400	$ 12,000	$ 2,000	$ -	$ -	$ 15,000			
285214		AMTRAK BLDG SWALK	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -			
285215		CAULK/SEAL STAMPED SW	1412	1414			1422	1424								75,000	SF	2,000	$ 60,000	$ 400	$ -	$ -	$ 61,000	Seal joints with Sikaflex sealant and apply concrete seal to stamped stained concrete areas.	Seal joints with Sikaflex sealant using caulking gun. Apply concrete seal to stamped stained concrete area with airless sprayer	This cost code was added to avoid inaccurate unit cost tracking of Stamped/Stained concrete sidewalk.
285216		CROSSWALKS	1412	1414			1422	1424								14,000	SF	2,000	$ 48,000	$ 1,000	$ 13,000	$ -	$ 49,000	Form/Pour/Strip 8" integral color crosswalk stamped with Ashler Slate pattern.	Hand set	
285217		CAULK/SEAL CROSSWALK	1412	1414			1422	1424								14,000	SF	680	$ 20,000	$ -	$ -	$ -	$ 20,000	Seal joints with Sikaflex sealant and apply concrete seal to stamped stained concrete areas.	Seal joints with Sikaflex sealant using caulking gun. Apply concrete seal to stamped stained concrete area with airless sprayer	This cost code was added to avoid inaccurate unit cost tracking of Stamped/Stained concrete crosswalk.
285220	*	**DRIVEWAYS**														**3,000**	**SF**	**260**	**$ 8,000**	**$ 1,000**	**$ -**	**$ -**	**$ 9,000**			
285222		R/F/P DRIVEWY	1412	1414			1422	1424								3,000	SF	260	$ 8,000	$ 1,000	$ -	$ -	$ 9,000			
286000	*	**FENCING**														**30,000**	**LF**	**3,000**	**$ 70,000**	**$ 7,000**	**$ 73,000**	**$ 1,278,000**	**$ 1,356,000**			
286010		MISC GCCO FENCE	1412	1414			1422	1424								8,000	LF	2,000	$ 49,000	$ 5,000	$ -	$ -	$ 54,000			
286012		YARD FENCE R&R										1440				1	LS	-	$ -	$ -	$ -	$ 12,000	$ 12,000			
286013		CHAIN LINK FENCE/TEMP	1412	1414			1422	1424				1440				24,000	LF	(11)	$ (1)	$ -	$ -	$ 259,000	$ 259,000			
286014												1440				0		-	$ -	$ -	$ -	$ -	$ -			
286015		C/L 12 FT (SOUND)	1412	1414			1422	1424				1440				90	LF	40	$ 1,000	$ -	$ -	$ -	$ 1,000			
286016		C/L 15FT (SOUND)	1412	1414			1422	1424				1440				0	LF	-	$ -	$ -	$ -	$ -	$ -			
286017		SOUND CURTAIN	1412	1414			1422	1424				1440				760	LF	430	$ 13,000	$ 2,000	$ 64,000	$ -	$ 15,000			
286018		SECURE VACANT PRO	1412	1414			1422	1424								40	PC	100	$ 3,000	$ 620	$ -	$ -	$ 4,000			
286019		`										1440				0	LF	-	$ -	$ -	$ -	$ 3,000	$ 3,000			
286021		C/L - TRENCH WALL										1440				9,000	LF	-	$ -	$ -	$ -	$ 362,000	$ 362,000			
286022		C/L - PED ON BRID										1440				0	LF	-	$ -	$ -	$ -	$ -	$ -			
286024												1440				0		-	$ -	$ -	$ -	$ -	$ -			
286036		C/L TEMP WALK GAT										1440				4	EA	-	$ -	$ -	$ -	$ 2,000	$ 2,000			
286037		C/L TEMP DRIVE GA										1440				5	EA	-	$ -	$ -	$ -	$ 12,000	$ 12,000			
286038		C/L MAINT RD GATE										1440				2	EA	-	$ -	$ -	$ -	$ 7,000	$ 7,000			
286039		C/L PUMP STA GATE										1440				1	EA	-	$ -	$ -	$ -	$ 8,000	$ 8,000			
286051		O/I - TRENCH WALL										1440				7,000	LF	-	$ -	$ -	$ -	$ 323,000	$ 323,000			
286052		O/I - PED ON BRID										1440				2,000	LF	-	$ -	$ -	$ -	$ 155,000	$ 155,000			
286071		PED BRIDGE FENCE										1440				0	LF	-	$ -	$ -	$ -	$ -	$ -			
286081		ROW FENCE										1440				0	LF	-	$ -	$ -	$ -	$ 48,000	$ 48,000			
286091		REPLACE PERMANENT FENCE										1440				4	EA	-	$ -	$ -	$ -	$ 85,000	$ 85,000			
286544		STREET BOLLARDS	1412	1414			1422	1424				1440				30	EA	130	$ 4,000	$ -	$ 9,000	$ 2,000	$ 6,000			
288101																0		-	$ -	$ (239)	$ -	$ -	$ (239)			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
289000	*	**TRACKWORK**														**100**	**PC**	**730**	**$ 23,000**	**$ 5,000**	**$ 297,000**	**$ -**	**$ 28,000**			
289010		PLACE ML SUBBAL	1412	1414			1422	1424								13,000	TN	530	$ 18,000	$ 3,000	$ 297,000	$ -	$ 21,000			
289011		F/G ML SUBB	1412	1414			1422	1424								0	SY	-	$ -	$ -	$ -	$ -	$ -			
289030		TRACK REMVL GCCO	1412	1414			1422	1424								950	TN	200	$ 5,000	$ 1,000	$ -	$ -	$ 7,000			
289032		TRACK REMVL SUB										1440				0	TF	-	$ -	$ -	$ -	$ -	$ -			
290000	*	**LANDSCAPE**														**100**	**PC**	**680**	**$ 19,000**	**$ 7,000**	**$ -**	**$ 272,000**	**$ 298,000**			
292513		LANSCAPE ROUGHGRD	1412	1414			1422	1424								51,000	SF	510	$ 15,000	$ 6,000	$ -	$ -	$ 21,000			
293211		SEED GRADED AREAS										1440				20	AC	-	$ -	$ -	$ -	$ 42,000	$ 42,000			
295001		LANDSCAPE TY A										1440				0	PC	-	$ -	$ -	$ 51,000	$ 231,000	$ 231,000			
295004		LANDSCAPE GCCO	1412	1414			1422	1424								0	PC	160	$ 4,000	$ 430	$ -	$ -	$ 5,000			
300000	*	**DEMOLITION**														**100**	**PC**	**21,000**	**$ 599,000**	**$ 495,000**	**$ 17,000**	**$ 937,000**	**$ 2,031,000**			
300010		**DEMO MISC**														**100**	**PC**	**10,000**	**$ 254,000**	**$ 182,000**	**$ 17,000**	**$ 147,000**	**$ 583,000**			
300025		LD/HAUL DEBRIS														2,000	LD	9,000	$ 239,000	$ 181,000	$ 17,000	$ -	$ 419,000			
300050		SAWCUT GCCO	1412	1414			1422	1424								0	LF	310	$ 7,000	$ 460	$ -	$ -	$ 7,000			
300051		SAWCUT SUB										1440				0	LF	-	$ -	$ -	$ -	$ 147,000	$ 147,000			
300052		SAWCUT AC	1412	1414			1422	1424								16,000	LF	(1)	$ 680	$ -	$ -	$ -	$ 680			
300054		DEMO SBC CASING	1412	1414			1422	1424								100	PC	240	$ 8,000	$ 1,000	$ -	$ -	$ 9,000			
300093			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
300130	*	**BUILDING DEMO**														**100**	**PC**	**1,000**	**$ 32,000**	**$ 22,000**	**$ -**	**$ 475,000**	**$ 529,000**			
300132		BLDG DEMO										1440				100	PC	-	$ -	$ -	$ -	$ 475,000	$ 475,000			
300133		BLDG DEMO - GCCO	1412	1414			1422	1424								100	PC	1,000	$ 31,000	$ 12,000	$ -	$ -	$ 43,000			
300134		BAT SURVEY										1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
300141		DEMO AMTRAK TEMP	1412	1414			1422	1424								100	PC	20	$ 850	$ 10,000	$ -	$ -	$ 11,000			
300700	*	**DEMO AC PAVEMENT**														**90**	**PC**	**10,000**	**$ 305,000**	**$ 287,000**	**$ -**	**$ 61,000**	**$ 653,000**			
300711		1.5IN GRIND										1440				26,000	SF	-	$ -	$ -	$ -	$ 13,000	$ 13,000			
300719		GRINDING SUPPORT	1412	1414			1422	1424								26,000	SF	250	$ 7,000	$ 1,000	$ -	$ -	$ 8,000			
300721		DEMO FLAT	1412	1414			1422	1424				1440				35,000	CY	10,000	$ 298,000	$ 286,000	$ -	$ 26,000	$ 609,000			
300722		DEMO FLAT SUB										1440				210	PC	-	$ -	$ -	$ -	$ 22,000	$ 22,000			
301000	*	**BRIDGE DEMO**														**100**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ 255,000**	**$ 255,000**			
301031		WELLS AVE BRIDGE										1440				100	PC	-	$ -	$ -	$ -	$ 120,000	$ 120,000			
301041		2ND AVE BRIDGE										1440				100	PC	-	$ -	$ -	$ -	$ 135,000	$ 135,000			
301051		2ND AVE LIFT STAT										1440				100	PC	-	$ -	$ -	$ -	$ -	$ -			
305200	*	**PIPE DEMO**														**390**	**LF**	**270**	**$ 8,000**	**$ 3,000**	**$ -**	**$ -**	**$ 11,000**			
305211		EXC/REMOVE PIPE	1412	1414			1422	1424								250	LF	190	$ 5,000	$ 2,000	$ -	$ -	$ 8,000			
305212		REMOVE EXISTING MH	1412	1414			1422	1424								1	EA	10	$ 320	$ 70	$ -	$ -	$ 390			
305250		REMOVE EXISTING CB	1412	1414			1422	1424								3	EA	70	$ 2,000	$ 830	$ -	$ -	$ 3,000			
305260		WATER PIPE REMOVAL	1412	1414			1422	1424								150		-	$ -	$ -	$ -	$ -	$ -			
320000	*	**PILING/EXC SUPPORT**														**100**	**PC**	**12,000**	**$ 302,000**	**$ 274,000**	**$ -**	**$ 24,323,000**	**$ 24,905,000**			
320010	*	**MISC PILING**														**100**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ 809,000**	**$ 809,000**			
320012		MINIPILE										1440				100	PC	-	$ -	$ -	$ -	$ 809,000	$ 809,000			
320021		OUTAGE SOE										1440				0	SF	-	$ -	$ -	$ -	$ -	$ -			
320030	*	**SOE TOP 5FT**														**0**	**LF**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**-**			
320031		EXC TOP 5FT	1412	1414			1422	1424								0	CY	-	$ -	$ -	$ -	$ -	$ -			
320032		SET TEMP CTB	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			
320033		BACKFILL CTB	1412	1414			1422	1424								0	CY	-	$ -	$ -	$ -	$ -	$ -			
320034		REMOVE TEMP CTB	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			
320900	*	**UNDERPINNING**														**100**	**PC**	**2,000**	**$ 66,000**	**$ 97,000**	**$ -**	**$ 8,833,000**	**$ 8,996,000**			
320901		UNDERPIN SUPPORT	1412	1414			1422	1424								100	PC	2,000	$ 66,000	$ 97,000	$ -	$ -	$ 163,000			
320911		U/P PKG GARAGE										1440				100	PC	-	$ -	$ -	$ -	$ 6,118,000	$ 6,118,000			
320912		U/P RAINBOW BRDG										1440				100	PC	-	$ -	$ -	$ -	$ 796,000	$ 796,000			
320914		U/P MEN'S CLUB										1440				100	PC	-	$ -	$ -	$ -	$ 1,333,000	$ 1,333,000			
320915		U/P FREIGHT HOUSE										1440				100	PC	-	$ -	$ -	$ -	$ 489,000	$ 489,000			
320916		U/P TEST SECTION										1440				100	PC	-	$ -	$ -	$ -	$ 97,000	$ 97,000			
321000	*	**CIDH**														**100**	**PC**	**7,000**	**$ 176,000**	**$ 170,000**	**$ -**	**$ 12,245,000**	**$ 12,598,000**			
321001			1412	1414			1422	1424								3,000		-	$ -	$ -	$ -	$ -	$ -			
321011		CIDH SUB SUPPT	1412	1414			1422	1424				1440				8,000	CY	7,000	$ 176,000	$ 170,000	$ -	$ 1,000	$ 347,000			
321012			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
321013		CIDH SUB SUPP SUB									1436	1440				8,000	CY	-	$ -	$ -	$ -	$ 70,000	$ 76,000			
321030		CIDH30										1440				0	LF	-	$ -	$ -	$ -	$ -	$ -			
321101		CIDH FULL HT TREN										1440				21,000	SF	-	$ -	$ -	$ -	$ 1,572,000	$ 1,572,000			
321105		CIDH BRIDGE ABUT									1436	1440				44,000	SF	-	$ -	$ -	$ -	$ 4,091,000	$ 4,091,000			
321106		CIDH CUTOFF WALL										1440				37,000	SF	-	$ -	$ -	$ -	$ 5,421,000	$ 5,421,000			
321107		CIDH WET WELL										1440				3,000	SF	-	$ -	$ -	$ -	$ 246,000	$ 246,000			
321108		CIDH VINE ST										1440				5,000	SF	-	$ -	$ -	$ -	$ 845,000	$ 845,000			
321800	*	**TIEBACKS**														**1,000**	**EA**	**-**	**$ -**	**$ -**	**$ -**	**$ 1,992,000**	**$ 1,992,000**			
321815		TIEBACKS F&I										1440				1,000	EA	-	$ -	$ -	$ -	$ 1,992,000	$ 1,992,000			
321900	*	**SOIL NAILS**														**196,000**	**SF**	**-**	**$ -**	**$ -**	**$ -**	**$ 4,625,000**	**$ 4,625,000**			
321915		SOIL NAIL F&I										1440				196,000	SF	-	$ -	$ -	$ -	$ 4,625,000	$ 4,625,000			
321916		SIPHON SOIL NAILING										1440				3,000	SF	-	$ -	$ -	$ -	$ -	$ -			
321930	*	**SHOTCRETE**														**35,000**	**SF**	**3,000**	**$ 60,000**	**$ 7,000**	**$ -**	**$ 444,000**	**$ 511,000**			
321931		SHOTCRETE LAGGING										1440				35,000	SF	-	$ -	$ -	$ -	$ 193,000	$ 193,000			
321933		SC 1SIDE 12" BRIDGEWL										1440				17,000	PC	-	$ -	$ -	$ -	$ 135,000	$ 135,000			
321935		SC 1SIDE 10" UNDRPINWL										1440				12,000	PC	-	$ -	$ -	$ -	$ 100,000	$ 100,000			
321937		SC 1SIDE 18" UNDRPINWL										1440				1,000	PC	-	$ -	$ -	$ -	$ 13,000	$ 13,000			
321939		SC TESTPANEL										1440				100	PC	-	$ -	$ -	$ -	$ 3,000	$ 3,000			
321941		GCCO SHOTCRETE SUPPORT	1412	1414			1422	1424								100	PC	860	$ 22,000	$ -	$ -	$ -	$ 22,000			
321950		GRANITE LAGGING	1412	1414			1422	1424								35,000	SF	2,000	$ 38,000	$ 7,000	$ -	$ -	$ 45,000			
350000	*	**PIPE**														**100**	**PC**	**30,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 992,000**			
350010	*	**MISCELLANEOUS**														**100**	**PC**	**29,000**	**$ 789,000**	**$ 142,000**	**$ 188,000**	**$ -**	**$ 931,000**			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
350021		SUB DRAINS	1412	1414			1422	1424								19,000	LF	5,000	$ 136,000	$ 44,000	$ 86,000	$ -	$ 180,000	Install various sizes of slotted drain SDR35 pipe along the shoofly tracks and on the east and west ends of the trench. Shoofly drainage = 14,531', Trench subdrains = 3,980' - 2,070' of 6"; 1,838' of 8"; 72' of 10" and 19 cleanouts.	The pipe trench was excavated using a backhoe, filter fabric was laid in the trench, the pipe was placed, the trench was backfilled with Class C backfill, then the filter fabric was folded over the top of the backfilled trench.	Gradesetter would come and help lay pipe after the trench was excavated. The loader only worked when the pipe was being backfilled. The spoils from the excavations were mostly lost onsite with the loader, although some of the spoils were off hauled with trucks.
350171		INSTALL HYDRANTS	1412	1414			1422	1424								2	EA	190	$ 5,000	$ 2,000	$ -	$ -	$ 7,000			
350201		BRIDGE GAS CASING	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ 2,000	$ -	$ -			
350203		AMTRAK SUBSTR DRAIN	1412	1414			1422	1424								150	LF	120	$ 3,000	$ 2,000	$ 2,000	$ -	$ 5,000			
350205		PVC18/24 TRNCH DRAIN	1412	1414			1422	1424								16,000	LF	24,000	$ 645,000	$ 94,000	$ 98,000	$ -	$ 739,000	Install various sizes of pipe on the north and south side of the trench for storm drainage. Includes scupper inlet drains along invert and manholes over pipe in the invert. All drainage flows to the Pump Station where it is pumped into the sewer and storm drain.	The pipe was laid and then poured with the inverts. To stop the pipe from floating, the pipe had to be anchored to the seal slab in the downtown area and to a rat slab for areas without seal slab. This was down by wet setting or epoxing all thread into the concrete. A piece of angle was then placed on the all thread below the pipe and above the pipe to hold it at the desired elevation. The pipe was also banded to the anchors and angle to help prevent the pipe from floating. In total, there were the 508 scuppers installed at 20' and 40' spacing, 115 Manholes installed at 200' spacing, and 15,926' of pipe - 7200' of 8", 2100' of 10", 600 ' of 12", 2400' of 18", 3100' of 24", 400' of 30", 80' of 36"	There were several instances where the pipe floated during the invert pour. One picture below shows the demo of the pipe after a section of pipe floated. The associated cost is included in the total. After all the drainage was completed and invert poured, there was a problem with excessive leakage in the trench. Part of the problem was attributed to sections of pipe leaking at the joints. We spent an extra $56,000 in labor to crawl inside the pipe and repair the leaking joints.
350206																0		5	$ -	$ -	$ -	$ -	$ -			
352500	*****	**JACK&BORE**														**160**	**LF**	**350**	**$ 10,000**	**$ 11,000**	**$ -**	**$ 40,000**	**$ 60,000**			
352501		JACK PITS EXC/BFI	1412	1414			1422	1424								2	EA	350	$ 10,000	$ 11,000	$ -	$ -	$ 21,000			
352518		J&B 18IN										1440				160	LF	-	$ -	$ -	$ -	$ 40,000	$ 40,000			
360000		**<Concrete Pipe>**														**0**		**30,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 3,390,000**			
361200	*****	**RCP INSTALL**														**13,000**	**LF**	**13,000**	**$ 383,000**	**$ 429,000**	**$ 1,543,000**	**$ 722,000**	**$ 1,534,000**			
361205		UNLOAD / HANDLE PIPE	1412	1414			1422	1424								7,000	LF	110	$ 3,000	$ 1,000	$ -	$ -	$ 4,000			
361206		TIE-INS	1412	1414			1422	1424								7	EA	240	$ 7,000	$ 1,000	$ -	$ -	$ 8,000			
361207		TEST&PATCH PIPE	1412	1414			1422	1424								0	LF	70	$ 2,000	$ -	$ -	$ -	$ 2,000			
361208		CLEANUP	1412	1414			1422	1424								6,000	LF	120	$ 3,000	$ 350	$ -	$ -	$ 4,000			
361212		RCP12	1412	1414			1422	1424								4,000	LF	4,000	$ 106,000	$ 58,000	$ 513,000	$ -	$ 164,000	Install 12" RCP or SDR35 pipe for the storm drain in the city streets.	Sawcut or demo AC/Concrete as needed, excavate trench, lay pipe and tie into main, manhole, or drain inlet, backfill to roadway cross-section specifications.	Depending on the site conditions and pipe depth, RCP or SDR35 pipe was used. In one instance, SDR35 pipe was used with a slurry backfill. About 15% of the pipe layed required the rental of trench shoring to allow for safe installation.
361213		RCP12 SUB										1440				1,000	LF	-	$ -	$ -	$ -	$ 132,000	$ 132,000			
361218		RCP18	1412	1414			1422	1424				1440				1,000	LF	1,000	$ 30,000	$ 19,000	$ 13,000	$ -	$ 49,000			
361219		RCP18 SUB										1440				0	LF	-	$ -	$ -	$ -	$ 32,000	$ 32,000			
361224		RCP24	1412	1414			1422	1424								170	LF	280	$ 10,000	$ 11,000	$ 15,000	$ -	$ 21,000			
361225		RCP24 SUB										1440				60	LF	-	$ -	$ -	$ -	$ 5,000	$ 5,000			
361230		RCP30 (RELAY)	1412	1414			1422	1424				1440				60	LF	150	$ 5,000	$ 1,000	$ 6,000	$ -	$ 6,000			
361231		RCP30 SUB										1440				2,000	LF	-	$ -	$ -	$ -	$ 492,000	$ 492,000			
361236		RCP36"	1412	1414			1422	1424				1440				610	LF	700	$ 22,000	$ 23,000	$ 289,000	$ -	$ 45,000			
361237		RCP36 SUB										1440				330	LF	-	$ -	$ -	$ -	$ 62,000	$ 62,000			
361242		RCP42"	1412	1414			1422	1424								400	LF	740	$ 21,000	$ 19,000	$ -	$ -	$ 40,000			
361243		SUB-RCP42"										1440				0	LF	-	$ -	$ -	$ -	$ -	$ -			
361248		RCP 48" GCCO	1412	1414			1422	1424								290	LF	360	$ 12,000	$ 5,000	$ 53,000	$ -	$ 17,000			
361254		RCP54(DBL)	1412	1414			1422	1424								0	LF	-	$ -	$ 210	$ -	$ -	$ 210			
361260		RCP60	1412	1414			1422	1424								810	LF	2,000	$ 43,000	$ 63,000	$ 97,000	$ -	$ 106,000			
361284		RCP84	1412	1414			1422	1424								1,000	LF	3,000	$ 91,000	$ 197,000	$ 397,000	$ -	$ 288,000			
361296		RCP96	1412	1414			1422	1424								210	LF	920	$ 27,000	$ 29,000	$ 161,000	$ -	$ 56,000			
362500	*****	**RCB INSTALL**														**320**	**LF**	**1,000**	**$ 36,000**	**$ 12,000**	**$ -**	**$ -**	**$ 47,000**			
362505		UNLOAD/HANDLE RCB	1412	1414			1422	1424								0	LF	(4)	$ -	$ -	$ -	$ -	$ -			
362508		CLEANUP	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			
362617		RCB5X2	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
362618		RCB9X6	1412	1414			1422	1424								320	LF	1,000	$ 36,000	$ 12,000	$ -	$ -	$ 48,000	Excavate, place, set and backfill 305 LF of 9X6 RCB, 13 LF OF 12X4 RCB and corresponding transition structures for a total of 318 LF. Begin box was at a cast-in-place outlet structure at outfalling into the Truckee River and end box was at a cast-in-place transition to an 84" RCP. Cost for the tie-in is in this code.	Pre-cast boxes were chosen for this project because excavation was required under a bridge being utilized by the Union Pacific Railroad. By using pre-cast box sections the amount of time the bridge footings were exposed was limited to less than 5 days. The pre-cast sections were set using several different pieces of equipment. The equipment used was an 385L excavator with the bucket removed, 150 TN crane, 30TN forklift and a 988G loader. The equipment variation was a result of various environmental constraint such as overhead clearance restrictions, adverse slopes and limited room for unloading the box sections.	Included in this labor cost is two days of a 4 man carpenter crew to form and pour the tie-in from the end of the box to the beginning of the 84" pipe.
362619		RCB11X5	1412	1414			1422	1424								0	LF	-	$ -	$ (390)	$ -	$ -	$ (390)			
362800	*	**SANITARY SEWER**														**7,000**	**LF**	**8,000**	**$ 212,000**	**$ 231,000**	**$ 143,000**	**$ 508,000**	**$ 950,000**			
362801		PUMP AROUND	1412	1414			1422	1424								3,000	LF	180	$ 4,000	$ 14,000	$ -	$ -	$ 18,000			
362803		CLEARING & REMOVALS	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			
362805		UNLOAD/HANDLE PIP	1412	1414			1422	1424								3,000	LF	210	$ 6,000	$ 5,000	$ -	$ -	$ 10,000			
362806		TIE-INS	1412	1414			1422	1424								2	EA	210	$ 6,000	$ 2,000	$ -	$ -	$ 8,000			
362807		TEST&PATCH PIPE	1412	1414			1422	1424								3,000	LF	650	$ 16,000	$ 10,000	$ -	$ -	$ 26,000			
362808		CLEANUP	1412	1414			1422	1424								200	LF	50	$ 1,000	$ -	$ -	$ -	$ 1,000			
362811		SS24 SDR-25	1412	1414			1422	1424				1440				3,000	LF	-	$ -	$ -	$ 142,000	$ 477,000	$ 477,000			
362812		SS24 SUPPORT	1412	1414			1422	1424								160	LF	140	$ 4,000	$ 2,000	$ -	$ -	$ 6,000			
362821		SS36 SDR-25	1412	1414			1422	1424								3,000	LF	5,000	$ 129,000	$ 183,000	$ 1,000	$ -	$ 312,000			
362822		SS36 SDR-25 SUB	1412	1414			1422	1424				1440				0	LF	-	$ -	$ -	$ -	$ 30,000	$ 30,000			
362831		SERVICES PIP	1412	1414			1422	1424								720	LF	1,000	$ 34,000	$ 11,000	$ -	$ -	$ 45,000			
362841		SS8-SDR 035	1412	1414			1422	1424								840	LF	390	$ 11,000	$ 4,000	$ -	$ -	$ 15,000			
362851												1440				0		-	$ -	$ -	$ -	$ -	$ -			
362900	*	**VINE ST SIPHON PIP**														**460**	**LF**	**920**	**$ 28,000**	**$ 11,000**	**$ -**	**$ -**	**$ 69,000**			
362901		GRADE SIPHON	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -			
362902		BEDDING	1412	1414			1422	1424								190	TN	50	$ 1,000	$ 610	$ -	$ -	$ 2,000			
362903		LEAN CONC FILL	1412	1414			1422	1424								360	CY	50	$ 1,000	$ 10	$ -	$ -	$ 1,000			
362904		DRAIN ROCK BFILL	1412	1414			1422	1424								0	TN	-	$ -	$ -	$ -	$ -	$ -			
362907		TEST SYSTEM	1412	1414			1422	1424								100	PC	40	$ 850	$ -	$ -	$ -	$ 850			
362909		SIPHON SHORING										1440				100	PC	-	$ -	$ -	$ -	$ -	$ 30,000			
362911		PVC8 INSTALL	1412	1414			1422	1424								0	PC	-	$ -	$ -	$ -	$ -	$ -			
362912		RCP66 INSTALL	1412	1414			1422	1424								460	LF	780	$ 24,000	$ 10,000	$ -	$ -	$ 35,000			
363000	*	**WATER LINE**														**2,000**	**LF**	**7,000**	**$ 197,000**	**$ 104,000**	**$ 362,000**	**$ 488,000**	**$ 789,000**			
363003		HOT TAPS	1412	1414			1422	1424								8	EA	390	$ 11,000	$ 3,000	$ 362,000	$ -	$ 14,000			
363005			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
363006			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
363007			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
363011		del	1412	1414			1422	1424								0		(2)	$ -	$ -	$ -	$ -	$ -			
363021		del	1412	1414			1422	1424				1440				0		9	$ -	$ -	$ -	$ -	$ -			
363031		del	1412	1414			1422	1424				1440				0		-	$ -	$ -	$ -	$ -	$ -			
363032		del										1440				0		-	$ -	$ -	$ -	$ -	$ -			
363035																0		-	$ -	$ -	$ -	$ -	$ -			
363039																0		-	$ (95)	$ 100	$ -	$ -	$ -			
363110		WL PROT MRRL2SPOK	1412	1414			1422	1424								1,000	LF	2,000	$ 59,000	$ 32,000	$ -	$ -	$ 91,000			
363111		WL PROT MRRL2SPOK SUB														1,000	LF	-	$ -	$ -	$ -	$ 27,000	$ 27,000			
363120		W2ND PH2&TIE INS	1412	1414			1422	1424								350	LF	190	$ 4,000	$ -	$ -	$ -	$ 4,000			
363130		RECORD WL RELO	1412	1414			1422	1424								380	LF	2,000	$ 45,000	$ 33,000	$ -	$ -	$ 78,000			
363140		WASH ST WL	1412	1414			1422	1424								200	LF	1,000	$ 30,000	$ 18,000	$ -	$ -	$ 48,000			
363141		WASH ST WL SUB										1440				0	LF	-	$ -	$ -	$ -	$ 20,000	$ 20,000			
363150		SIERRA ST WL	1412	1414			1422	1424								140	LF	470	$ 13,000	$ 4,000	$ -	$ -	$ 17,000			
363151		SIERRA ST WL SUB										1440				0	LF	-	$ -	$ -	$ -	$ 8,000	$ 8,000			
363160		EVANS WL	1412	1414			1422	1424								0	LF	20	$ 880	$ 350	$ -	$ -	$ 1,000			
363170		BURGER KING WL	1412	1414			1422	1424								150	LF	260	$ 8,000	$ 4,000	$ -	$ -	$ 13,000			
363171		HARRAHS FIRE HYDRANT	1412	1414			1422	1424								100	PC	90	$ 2,000	$ 400	$ -	$ -	$ 3,000			
363172		KEYSTONE FIRE SERVICE	1412	1414			1422	1424								100	PC	150	$ 4,000	$ 2,000	$ -	$ -	$ 6,000			
363173		KEYSTONE FIRE HYDRANT	1412	1414			1422	1424								100	PC	40	$ 1,000	$ 310	$ -	$ -	$ 1,000			
363180		WEST ST WL OFFSET	1412	1414			1422	1424								50	PC	130	$ 4,000	$ 3,000	$ -	$ -	$ 7,000			
363181		VINE ST WL	1412	1414			1422	1424								160	LF	130	$ 4,000	$ 670	$ -	$ -	$ 4,000			
363182		AMTRAK FIRE SERVICE	1412	1414			1422	1424								4	LF	370	$ 11,000	$ 3,000	$ -	$ -	$ 14,000			
363201		KEYSTONE WL RELO										1440				120	LF	-	$ -	$ -	$ -	$ 23,000	$ 23,000			
363202		VINE WL ABANDON										1440				100	PC	-	$ -	$ -	$ -	$ 9,000	$ 9,000			
363203		WASHNGTN WL PROT										1440				100	PC	-	$ -	$ -	$ -	$ 18,000	$ 18,000			
363204		WASHNGTN WL SERV										1440				30	LF	-	$ -	$ -	$ -	$ 2,000	$ 2,000			
363205		WAS/DOUG ALY6INWL										1440				150	LF	-	$ -	$ -	$ -	$ 24,000	$ 24,000			
363206		LAKE WL RELO										1440				80	LF	-	$ -	$ -	$ -	$ 34,000	$ 34,000			
363207		WEST ST WL ABANDN										1440				100	PC	-	$ -	$ -	$ -	$ 5,000	$ 5,000			
363208		ARLINGTN WL ABAND										1440				100	PC	-	$ -	$ -	$ -	$ 14,000	$ 14,000			
363209		3RD WL RELO VN2WA										1440				570	LF	-	$ -	$ -	$ -	$ 24,000	$ 24,000			
363210		SIERRA WL RELO&P&										1440				60	LF	-	$ -	$ -	$ -	$ 65,000	$ 65,000			
363211		3RD WLRELO WSH2RA										1440				80	LF	-	$ -	$ -	$ -	$ 71,000	$ 71,000			
363212		W2ND WL RELO PH1										1440				180	LF	-	$ -	$ -	$ -	$ 26,000	$ 26,000			
363213		PARK ST WL ABANDN										1440				100	PC	-	$ -	$ -	$ -	$ 12,000	$ 12,000			

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363214		CNTR WL RELO&PROT										1440				260	LF	-	$ -	$ -	$ -	$ 90,000	$ 90,000			
363215		WL CASE WASTE MAN										1440				60	LF	-	$ -	$ -	$ -	$ 15,000	$ 15,000			
370000	*	**MANHOLES & INLETS**														**100**	**PC**	**9,000**	**$ 255,000**	**$ 53,000**	**$ 639,000**	**$ 98,000**	**$ 406,000**			
370108		ADJ MH/CB/VLT2GRD	1412	1414			1422	1424								420	EA	4,000	$ 106,000	$ 14,000	$ 28,000	$ -	$ 121,000			
370121		MH TY 1 INSTALL	1412	1414			1422	1424								20	EA	550	$ 16,000	$ 4,000	$ 369,000	$ -	$ 20,000			
370122		MH TY 1 SUB										1440				6	EA	-	$ -	$ -	$ -	$ 12,000	$ 12,000			
370123		MH TY 4 INSTALL	1412	1414			1422	1424				1440				20	EA	2,000	$ 47,000	$ 15,000	$ 38,000	$ -	$ 63,000			
370124		MH TY V SUB										1440				20	EA	-	$ -	$ -	$ -	$ 80,000	$ 80,000			
370125		7X7 MH	1412	1414			1422	1424								1	EA	400	$ 12,000	$ 2,000	$ 148,000	$ -	$ 14,000			
370126		9X9 MH	1412	1414			1422	1424								1	EA	590	$ 20,000	$ 3,000	$ 1,000	$ -	$ 23,000			
370131		INLETS / BASINS INSTALL	1412	1414			1422	1424								70	EA	2,000	$ 54,000	$ 14,000	$ 54,000	$ -	$ 68,000			
370132		INLETS /BASINS SUB										1440				4	EA	-	$ -	$ -	$ -	$ 6,000	$ 6,000			
372000	*	**HEADWALLS**														**100**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
372011		F/P/S HEADWALL	1412	1414			1422	1424								830	SF	300	$ 9,000	$ 720	$ 21,000	$ -	$ 10,000			
400000	*	**EARTHWORK**														**1,121,000**	**CY**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
400010	*	**MISCELLANEOUS**														**100**	**PC**	**21,000**	**$ 5,000**	**$ 11,000**	**$ 170,000**	**$ 12,000**	**$ 27,000**			
400022		WATER TRUCK	1412	1414			1422	1424								0	MO	21,000	$ -	$ -	$ -	$ -	$ -			
400041		MISC OG COMPACTN	1412	1414			1422	1424								9,000	SY	150	$ 4,000	$ 11,000	$ -	$ -	$ 15,000			
400060		GEOTECH INSTR	1412	1414			1422	1424				1440				0	EA	-	$ -	$ -	$ 128,000	$ -	$ -			
400061																0		-	$ -	$ -	$ -	$ 12,000	$ 12,000			
400064		PIEZOMETER	1412	1414			1422	1424				1440				0	EA	-	$ -	$ -	$ 780	$ -	$ -			
400073		SETTLMNT PT MONUM	1412	1414			1422	1424				1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
400074		SETTLEMENT PT	1412	1414			1422	1424				1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
400121		GEOFAB PLACE-ROLL	1412	1414			1422	1424								0	LF	20	$ 350	$ -	$ 41,000	$ -	$ 350			
410200			1412	1414			1422	1424								200		-	$ -	$ -	$ -	$ -	$ -			
410211			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
410213			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
410000		**<EARTHWORK EXCAVATION>**														**0**		**86,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 8,622,000**			
411010	*	**TRNCHEXC DRY FAST**														**388,000**	**BC**	**10,000**	**$ 288,000**	**$ 1,821,000**	**$ -**	**$ -**	**$ 2,110,000**	Excavation of the trench prizm in areas that were accessible by the Transystems Double Side Dumps, where the 345 CAT did not have to slow down to digout the trench.	Areas of excavation were first slope staked according to the ReTRAC excavation spreadsheet layout. Most areas of the "Dry Fast Trench Excavation" were open cut areas, laid back at a 1.5:1 slope. These were areas where the excavator did not have to slow down, and its swing was unhindered by close objects, or railroad easements. The primary areas that this work affected was the West & East end approachs. From the West end tie-in to the Ralston St. Bridge, and from the East end tie-in to the Lake St. Bridge areas.	Trucking dictated the cost of this particular item. The easier the access to the ends of the job, the cheaper the cost. The typical cycle time to load a Double Side Dump truck with the 345 CAT was 6 passes (approx 24 CY's) in 83 seconds (1min, 23 sec), with a 10 second max spacing to get a new truck situated under the excavator.
411011		LOAD CAT345	1412	1414			1422	1424								388,000	BC	1,000	$ 43,000	$ 72,000	$ -	$ -	$ 115,000	Actual cost to excavate the Trench & load trucks with the CAT 345 only.	Mass Exc with the CAT 345. Trucks drove alongside excavator, and were top loaded by the 345. The typical cycle time to load a Double Side Dump truck with the 345 CAT was 6 passes (approx 24 CY's) in 83 seconds (1min, 23 sec).	This is only the cost for the CAT 345 on this work only.
411012		LOAD CAT330	1412	1414			1422	1424								388,000	BC	1,000	$ 37,000	$ 42,000	$ -	$ -	$ 79,000	Actual cost to excavate the Trench & load trucks with the CAT 330 only	Mass Exc with the CAT 330. Trucks drove alongside excavator, and were top loaded by the 330. The typical cycle time to load a Double Side Dump truck with the 330 CAT was 12 passes (approx 24 CY's) in 133 seconds (2min, 13 sec).	This is only the cost to excavate & load with the CAT 330 Excavator. This was primarily used on the second ecavation heading when we started diggin. The ideal situation would have been to use another CAT 345 to cut cost, and speed up cycle times. The double side dumps were primarily used witht he CAT 345, and Single Sides & End Dumps were used with the CAT 330.
411013		HAUL 43T DBLSIDE	1412	1414			1422	1424								388,000	BC	2,000	$ 50,000	$ 1,678,000	$ -	$ -	$ 1,728,000	This is the trucking costs for the Fast Dry Trench Exc only.	We were able to get the trucks alongside the excavators to load them out. The biggest problem contorlling this cost was the haul route through downtown city traffic. The easier it was to get in and out of the site, the cheaper the cost. In addition it was obvious that no trial cycle times were run with actual trucks. The re-use site was the same as in the estimate, but no one ran any real truck cycle times when they did the estimate. The average cycle time with a Double Side Dump was between 45 - 53 minutes dependent on the haul route. the average cycle time for end dumps & singel side dumps was 10-12 minutes faster then the double side dumps.	

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411014		LABORERS	1412	1414			1422	1424								388,000	BC	3,000	$ 58,000	$ 1,000	$ -	$ -	$ 60,000	This work is only for the laborers to pin & unpin the double side dumps at the fill site.	3 laborers were involved. The first 2 laborers unpinned the truck beds for the double side dumps to dump. After dumping, Transystems safety regulations involved the driver walking around his rig to make sure no materials were on the fenders that would fall off on the freeway on the way back to the trench site.	No laborers were ever needed in the excavation itself. Due to the excavations linear nature, the trucks had one way in, and one way out. So there was no need for a laborer to stage the trucks. No details from Transystems were asked for, or given, that explained their operating/safety procedures and what the drivers had to do. If we had asked for this information, or it had been given, we might have been able to incorporate this extra cost into the initial estimate for the work.
411015		OPERATOR FOREMAN	1412	1414			1422	1424								388,000	BC	1,000	$ 48,000	$ 100	$ -	$ -	$ 48,000	Operator Foreman costs to supervise the excavation crews.	Layout crews every morning, and assign grade checking assignments.	
411016		GRADE SETTER	1412	1414			1422	1424								388,000	BC	1,000	$ 36,000	$ 270	$ -	$ -	$ 36,000	Surveyors would offset cut stakes 10 ft outside the perimter of the excavation. Grade checkers would set the slope stakes and chase the stakes down into the excavation.	One Grade Checker was required per excavation heading. Surveyors usually laid out an area 2 days before the excavation crew got into an area. Therefore one grade checker could maintain a heading if everything was laid out ahead of time.	
411017		D-6 DOZER	1412	1414			1422	1424								388,000	BC	430	$ 15,000	$ 27,000	$ -	$ -	$ 42,000	Supplemental work to trim up areas in difficult areas. No D6 Dozer was ever used in the excavation of the trench itself. All excavation was done with the CAT 345 & 330, and 710 JD Backhoe was used to trim up areas, and to clean up any small wind rows that were left behind.		
411020	*	**TRNCHEXC DRY SLOW**														**200,000**	**BC**	**22,000**	**$ 655,000**	**$ 1,154,000**	**$ -**	**$ -**	**$ 1,809,000**	Excavation of the trench prizm in areas that were inaccessible for the major haul operations. Primarily these are the areas that required Soil Nail Walls (SNW) to be installed. This cost code also included the trimming of the SNW's, as well as the double handling of materials to make ramps & access.	Areas of excavation were first slope staked according to the ReTRAC excavation spreadsheet layout. Most areas of the "Dry Slow Trench Excavation" were tight SNW areas, laid back at a 1:6 slope. These were areas where the excavator had to slow down, and its swing was hindered by close objects, or railroad easements. The primary areas that this work affected was the Ralston St. to the Wells Ave. Bridge.	Trucking dictated the cost of this particular item. The easier the access to the ends of the job, the cheaper the cost. In addition the total SF of SNW was 195530 SF, which equates to $406,824 of Cost ($2.10 x 193,726 CY) for trimming the SNW. Each SNW lift was 5.0 FT high, which converts this to a LF basis of 39,106 LF of Soil Nailing ==> $10.40/LF or $2.08/SF of SNW
411021		LOAD CAT345	1412	1414			1422	1424								200,000	BC	820	$ 28,000	$ 43,000	$ -	$ -	$ 70,000	Actual cost to excavate the Trench & load trucks with the CAT 345 only.	Mass Exc with the CAT 345. Trucks drove alongside excavator, and were top loaded by the 345. The typical cycle time to load a Single Side Dump truck with the 345 CAT was 3 passes (approx 12 CY's) in 42 seconds (0.70 min).	In the tighter areas the CAT 345 did not leave much room for access through the worksite. The CAT 330 is smaller, and provided easier access.
411022		LOAD CAT330	1412	1414			1422	1424								200,000	BC	3,000	$ 120,000	$ 129,000	$ -	$ -	$ 249,000	Cost to excavate the Trench & load trucks with the CAT 330, trim SNW's, and double handle material to create ramps and access into the trench. These excavator costs a skewed due to the additional work that was incorporated into these cost codes.	Mass Exc with the CAT 330. Trucks drove alongside excavator, and were loaded by the 330. The typical cycle time to load a Single Side Dump truck with the 330 CAT was 6 passes (approx 12 CY's) in 75 seconds (1.25 min).	In the tighter areas the CAT 345 did not leave much room for access through the worksite. The CAT 330 is smaller, and provided easier access.
411023		HAUL 25T SNGLSIDE	1412	1414			1422	1424								200,000	BC	6,000	$ 148,000	$ 879,000	$ -	$ -	$ 1,027,000	This work is for the haul of the material for the Slow Trench Exc only. This cost includes the Slow Exc, trimming the Soil Nail Walls, and the double handling of material for creating Access Ramps into & out of the trench.	Initial expectations were that this haul would be done exclusively with Transystems Single Side Dumps. Unfortunately, with the double heading, Transystems could not supply a sufficient amount of Single Side Dumps to meet out needs. Therefore we used a lot more Owner Operated End Dumps then originally envisioned. The fortunate thing about this is the fact that costs for O/O trucks did not fall under the prevailing wage rates criteria (i.e. Prevailing Rate: $90-$98 per hour, non-prevailing $70-$75 per hour), which meant we saved money on this cost. In addition we supplemented the trucks with our own Granite Trucks.	

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411024		LABORERS	1412	1414			1422	1424								200,000	BC	3,000	$ 72,000	$ 20,000	$ -	$ -	$ 91,000	This work covers 2 primary areas of work; the unpinning of the Transystems Single Side Dumps at the reuse site, and the trimming of the Soil Nail Walls.	Transystem trucking procedures required that the driver unpin his bed so that he could dump his load. A time analysis indicated we could speed up the cycle time of the trucks by having a couple of labores on the ground unpinning the beds, so the drivers could dump quicker. The other portion of work was hand trimming the SNW once the excavator pulled most of the material away from the SNW face. The trimming of the SNW was excluded in the Schanbel proposal, but we did no put an item into our estimate to do this work. so we lost the cost in these codes.	Cost are inflated due to all the other work that was dumped into this code.
411025		OPERATOR FOREMAN	1412	1414			1422	1424								200,000	BC	3,000	$ 109,000	$ 770	$ -	$ -	$ 109,000	Oversaw and supervised operations on a daily basis. Layout work for the Grade Checker and ensure that furture areas are ready to go.		Cost are inflated due to all the other work that was dumped into this code: Cost's are higher due to the fact we had different foremen responsible for the different types work that were placed into these codes. The ideal scenario would have been 1 Foreman for 1/2 the time.
411026		GRADE SETTER	1412	1414			1422	1424								200,000	BC	3,000	$ 89,000	$ 2,000	$ -	$ -	$ 90,000	These cost are for the Grade Setting of the Soil Nail Walls primarily.	Typically only one Grade Setter would have been required for the excavation. The trimming of the soil nail walls required a constant grade setter also. Schnabel needed constant oversight because they would over spray their SNW's, which would push out the bottom of the SNW's as we got down to the bottom. A certain amount of clearance was required to place the cutoff wall below the SNW's, so a Grade Setter was always needed to maintain the grade & slope of the 1:6 SNW's to the bottom of the trench.	Cost are inflated due to all the other work that was dumped into this code. Cost are hight due to the additional Grade Setter placed into this code for the SNW trimming.
411027		973 LOADER	1412	1414			1422	1424								200,000	BC	2,000	$ 62,000	$ 55,000	$ -	$ -	$ 117,000	These 2 cost codes are primarily for the Soil nail Wall trimming.	Originally it was envisioned that the CAT 330 would mass exc 90% of the material for the slow exc, and then the D-6 Dozer & 973 Loader would follow behind and clean up the remaining spoils. Fortunately the 330 uncut the subgrade by 6/10 and no followup crew was required to cleanup the invert subgrade. But a crew was needed to clean the 1:1 material left on the SNW lift excavated.	Cost are inflated due to all the additional work that was dumped into this code. Costs are elevated also due to the nature of the material that was excavated. Cohesive material could be excavated in uniform 5.0 ft lifts. Non-cohesive, granular, sandy material could only be excavated in a checker board pattern. Dig 10 LF, skip 10 LF, dig 10 LF, etc...
411028		D-4 DOZER	1412	1414			1422	1424								200,000	BC	870	$ 29,000	$ 27,000	$ -	$ -	$ 56,000	These 2 cost codes are primarily for the Soil nail Wall trimming.	Originally it was envisioned that the CAT 330 would mass exc 90% of the material for the slow exc, and then the D-6 Dozer & 973 Loader would follow behind and clean up the remaining spoils. Fortunately the 330 uncut the subgrade by 6/10 and no followup crew was required to cleanup the invert subgrade. But a crew was needed to clean the 1:1 material left on the SNW lift excavated.	Cost are inflated due to all the additional work that was dumped into this code. Costs are elevated also due to the nature of the material that was excavated. Cohesive material could be excavated in uniform 5.0 ft lifts. Non-cohesive, granular, sandy material could only be excavated in a checker board pattern. Dig 10 LF, skip 10 LF, dig 10 LF, etc...
411030	*	**TRNCHEXC WET SLOW**														**41,000**	**BC**	**5,000**	**$ 143,000**	**$ 283,000**	**$ -**	**$ -**	**$ 426,000**			
411031		LOAD CAT345	1412	1414			1422	1424								41,000	BC	880	$ 29,000	$ 59,000	$ -	$ -	$ 89,000			
411033		HAUL 25T SNGLSIDE	1412	1414			1422	1424								41,000	BC	2,000	$ 48,000	$ 157,000	$ -	$ -	$ 206,000			
411034		LABORERS	1412	1414			1422	1424								41,000	BC	940	$ 19,000	$ 500	$ -	$ -	$ 20,000			
411035		OPERATOR FOREMAN	1412	1414			1422	1424								41,000	BC	640	$ 24,000	$ -	$ -	$ -	$ 24,000			
411036		GRADE SETTER	1412	1414			1422	1424								41,000	BC	380	$ 12,000	$ -	$ -	$ -	$ 12,000			
411037		LOADER	1412	1414			1422	1424								41,000	BC	370	$ 11,000	$ 13,000	$ -	$ -	$ 25,000			
411038		30 TON TRUCK	1412	1414			1422	1424								41,000	BC	4	$ 100	$ 52,000	$ -	$ -	$ 52,000			
411100	*	**CUT2FILL STREETS**														**8,000**	**BC**	**3,000**	**$ 86,000**	**$ 51,000**	**$ -**	**$ -**	**$ 138,000**			
411101		LOAD CAT330	1412	1414			1422	1424								8,000	BC	1,000	$ 36,000	$ 24,000	$ -	$ -	$ 60,000			
411103		HAUL 25T SNGLSIDE	1412	1414			1422	1424								8,000	BC	390	$ 10,000	$ 13,000	$ -	$ -	$ 23,000			
411104		LABORERS	1412	1414			1422	1424								8,000	BC	620	$ 16,000	$ 550	$ -	$ -	$ 17,000			
411105		OPERATOR FOREMAN	1412	1414			1422	1424								8,000	BC	240	$ 9,000	$ 2,000	$ -	$ -	$ 10,000			
411106		GRADE SETTER	1412	1414			1422	1424								8,000	BC	340	$ 13,000	$ 290	$ -	$ -	$ 13,000			
411107		815 COMPACTOR	1412	1414			1422	1424								8,000	BC	90	$ 3,000	$ 11,000	$ -	$ -	$ 14,000			
411110	*	**DICKERSON AVE EXC**														**4,000**	**BC**	**260**	**$ 9,000**	**$ 11,000**	**$ -**	**$ -**	**$ 21,000**			
411111		LOAD CAT330	1412	1414			1422	1424								4,000	BC	40	$ 1,000	$ 2,000	$ -	$ -	$ 3,000			
411113		HAUL 25T SNGLSIDE	1412	1414			1422	1424								4,000	BC	80	$ 3,000	$ 7,000	$ -	$ -	$ 10,000			
411114		LABORERS	1412	1414			1422	1424								4,000	BC	20	$ 830	$ 2,000	$ -	$ -	$ 3,000			
411115		OPERATOR FOREMAN	1412	1414			1422	1424								4,000	BC	70	$ 3,000	$ 340	$ -	$ -	$ 3,000			

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411116		GRADE SETTER	1412	1414			1422	1424								4,000	BC	40	$ 2,000	$ -	$ -	$ -	$ 2,000			
411150	*	**M/L BALLAST EXC**														**1,000**	**BC**	**180**	**$ 6,000**	**$ 9,000**	**$ -**	**$ -**	**$ 15,000**			
411151		LOAD CAT966	1412	1414			1422	1424								1,000	BC	20	$ 910	$ 5,000	$ -	$ -	$ 6,000			
411153		HAUL 25T SNGLSIDE	1412	1414			1422	1424								1,000	BC	120	$ 4,000	$ 3,000	$ -	$ -	$ 7,000			
411154		LABORERS	1412	1414			1422	1424								1,000	BC	20	$ 1,000	$ 100	$ -	$ -	$ 1,000			
411155		OPERATOR FOREMAN	1412	1414			1422	1424								1,000	BC	20	$ 740	$ -	$ -	$ -	$ 740			
411156		GRADE SETTER	1412	1414			1422	1424								1,000	BC	-	$ -	$ -	$ -	$ -	$ -			
411160	*	**M/L SUBB DBL HANDLE**														**0**	**BC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
411161		LOAD/HAUL CAT631	1412	1414			1422	1424								0	BC	-	$ -	$ -	$ -	$ -	$ -			
411165		OPERATOR FOREMAN	1412	1414			1422	1424								0	BC	-	$ -	$ -	$ -	$ -	$ -			
411166		GRADE SETTER	1412	1414			1422	1424								0	BC	-	$ -	$ -	$ -	$ -	$ -			
411168		CAT 815 COMPACTOR	1412	1414			1422	1424								0	BC	-	$ -	$ -	$ -	$ -	$ -			
411169		CAT D-9R	1412	1414			1422	1424								0	BC	-	$ -	$ -	$ -	$ -	$ -			
411200		**REGULATED MATL EXC**														**148,000**	**BC**	**7,000**	**$ 208,000**	**$ 873,000**	**$ -**	**$ -**	**$ 1,083,000**			
	*																									
411220		**TRENCH HOT SPOTS**														**2,000**	**BC**	**180**	**$ 5,000**	**$ 11,000**	**$ -**	**$ (1,974)**	**$ 17,000**	This work was essentially done over a 2 day period. The cost entails 2 days of making grade on Keystone Ave. to bring it up to grade for the bridge profile.		
411211																0		-	$ 4	$ -	$ -	$ -	$ 4			
411214																0		-	$ -	$ 40	$ -	$ -	$ 40			
411221		LOAD CAT345	1412	1414			1422	1424								2,000	BC	30	$ 1,000	$ 1,000	$ -	$ -	$ 2,000			
411223		HAUL 13T END	1412	1414			1422	1424								2,000	BC	100	$ 3,000	$ 10,000	$ -	$ -	$ 13,000			
411224		LABORER	1412	1414												2,000	BC	20	$ 670	$ -	$ -	$ -	$ 670			
411225		OPERATOR FOREMAN	1412	1414			1422	1424								2,000	BC	30	$ 890	$ -	$ -	$ (1,974)	$ 890			
411226		GRADE SETTER	1412	1414			1422	1424								2,000	BC	10	$ 350	$ -	$ -	$ -	$ 350			
411250	*	**REGULATED MATL EXC**														**146,000**	**BC**	**7,000**	**$ 203,000**	**$ 862,000**	**$ 59,000**	**$ -**	**$ 1,067,000**			
411251		LOAD CAT345	1412	1414			1422	1424								146,000	BC	1,000	$ 49,000	$ 82,000	$ -	$ -	$ 131,000			
411253		HL REGULATED MATL	1412	1414			1422	1424								146,000	BC	3,000	$ 67,000	$ 779,000	$ 59,000	$ -	$ 846,000			
411254		LABORER	1412	1414			1422	1424								146,000	BC	2,000	$ 47,000	$ (742)	$ -	$ -	$ 46,000			
411255		3IN SUBB SLFPRFM	1412	1414			1422	1424				1440				0	BC	70	$ -	$ -	$ -	$ -	$ 2,000			
411256		GRADE SETTER	1412	1414			1422	1424								146,000	BC	280	$ 10,000	$ 920	$ -	$ -	$ 11,000			
411257		OPERATOR FOREMAN	1412	1414			1422	1424								146,000	BC	840	$ 29,000	$ 120	$ -	$ -	$ 29,000			
411300	*	**SHOOFLY EXCAVATION**														**116,000**	**BC**	**17,000**	**$ 505,000**	**$ 988,000**	**$ -**	**$ 213,000**	**$ 1,707,000**			
411310		SHOOFLY CUT TO FILL	1412	1414			1422	1424								93,000	BC	10	$ -	$ -	$ -	$ -	$ -			
411311		LOAD CAT330	1412	1414			1422	1424								93,000	BC	2,000	$ 73,000	$ 42,000	$ -	$ -	$ 115,000			
411313		HAUL 25T SNGLSIDE	1412	1414			1422	1424								93,000	BC	6,000	$ 150,000	$ 328,000	$ -	$ -	$ 478,000			
411314		SUPPORT	1412	1414			1422	1424								93,000	BC	6,000	$ 188,000	$ 525,000	$ -	$ -	$ 713,000			
411321		SCREEN 3IN MINUS	1412	1414			1422	1424								98,000	BC	3,000	$ 95,000	$ 93,000	$ -	$ -	$ 188,000			
411322		3IN MINUS SUB										1440				0	BC	-	$ -	$ -	$ -	$ 213,000	$ 213,000			
411330	*	**REMOVE SHOOFLY**														**24,000**	**BC**	**1,000**	**$ 49,000**	**$ 39,000**	**$ -**	**$ -**	**$ 88,000**			
411331		LOAD CAT330	1412	1414			1422	1424								22,000	BC	460	$ 18,000	$ 21,000	$ -	$ -	$ 39,000			
411333		HAUL 25T SNGLSIDE	1412	1414			1422	1424								5,000	BC	190	$ 5,000	$ 12,000	$ -	$ -	$ 17,000			
411334		SUPPORT	1412	1414												24,000	BC	770	$ 24,000	$ 1,000	$ -	$ -	$ 25,000			
411337		SCRAPER	1412	1414			1422	1424								2,000	BC	50	$ 2,000	$ 4,000	$ -	$ -	$ 6,000			
411500	*	**STRUCTURE EXC**														**27,000**	**BC**	**2,000**	**$ 56,000**	**$ 171,000**	**$ -**	**$ -**	**$ 226,000**			
411510	*	**VINE ST SIPHON**														**2,000**	**BC**	**400**	**$ 12,000**	**$ 16,000**	**$ -**	**$ -**	**$ 29,000**			
411511		LOAD CAT330	1412	1414			1422	1424								2,000	BC	70	$ 2,000	$ 5,000	$ -	$ -	$ 8,000			
411513		HAUL 25T SNGLSIDE	1412	1414			1422	1424								2,000	BC	60	$ 2,000	$ 11,000	$ -	$ -	$ 13,000			
411514		LABORER	1412	1414												2,000	BC	140	$ 4,000	$ -	$ -	$ -	$ 4,000			
411515		GRADE SETTER	1412	1414			1422	1424								2,000	BC	30	$ 1,000	$ -	$ -	$ -	$ 1,000			
411516		OPERATOR FOREMAN	1412	1414			1422	1424								2,000	BC	100	$ 4,000	$ 280	$ -	$ -	$ 4,000			
411520	*	**SIGNAL CASES**														**1,000**	**BC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
411521		LOAD CAT330	1412	1414			1422	1424								0	BC	-	$ -	$ -	$ -	$ -	$ -			
411523		HAUL 25T SNGLSIDE					1422	1424								1,000	BC	-	$ -	$ 5,000	$ -	$ -	$ 5,000			
411524		LABORER	1412	1414												0	BC	-	$ -	$ -	$ -	$ -	$ -			
411525		GRADE SETTER	1412	1414												0	BC	-	$ -	$ -	$ -	$ -	$ -			
411526		OPERATOR FOREMAN	1412	1414												0	BC	-	$ -	$ -	$ -	$ -	$ -			
411530	*	**AMTRAK STATION**														**15,000**	**BC**	**960**	**$ 28,000**	**$ 69,000**	**$ -**	**$ -**	**$ 97,000**			
411531		LOAD CAT330	1412	1414			1422	1424								15,000	BC	220	$ 8,000	$ 8,000	$ -	$ -	$ 16,000			
411533		HAUL 25T SNGLSIDE	1412	1414			1422	1424								15,000	BC	450	$ 11,000	$ 61,000	$ -	$ -	$ 73,000			
411534		LABORER	1412	1414												15,000	BC	100	$ 2,000	$ -	$ -	$ -	$ 2,000			
411535		GRADE SETTER	1412	1414												15,000	BC	20	$ 650	$ -	$ -	$ -	$ 650			
411536		OPERATOR FOREMAN	1412	1414												15,000	BC	170	$ 6,000	$ -	$ -	$ -	$ 6,000			
411540	*	**TRENCH SUMP**														**9,000**	**BC**	**490**	**$ 15,000**	**$ 85,000**	**$ -**	**$ -**	**$ 101,000**			
411541		LOAD CAT330	1412	1414			1422	1424								9,000	BC	150	$ 5,000	$ 52,000	$ -	$ -	$ 58,000			
411543		HAUL 25T SNGLSIDE	1412	1414			1422	1424								9,000	BC	230	$ 6,000	$ 33,000	$ -	$ -	$ 39,000			
411544		LABORER	1412	1414												9,000	BC	20	$ 1,000	$ -	$ -	$ -	$ 1,000			
411545		GRADE SETTER	1412	1414												9,000	BC	40	$ 2,000	$ -	$ -	$ -	$ 2,000			
411546		OPERATOR FOREMAN	1412	1414												9,000	BC	40	$ 1,000	$ -	$ -	$ -	$ 1,000			
412000	*	**PLACE/COMPACT EMBANK**														**28,000**	**BC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
412321		E/W/SHOO/RB SUBBLST	1412	1414			1422	1424								28,000	TN	830	$ 25,000	$ 26,000	$ -	$ -	$ 51,000			
412500	*	**STRUCTURE BACKFILL**														**158,000**	**CY**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
412501		TRENCH WALLS	1412	1414			1422	1424						1480		158,000	CY	17,000	$ 497,000	$ 455,000	$ 809,000	$ -	$ 949,000	Haul place and compact fill material behind trench walls. Fill material is native material excavated from trench, decomposed granite from pit and crushed rock from quarry.	Method 1: directly place material in lifts with end dumps, transfers and bottom dumps, spread with backhoe/ loader or dozer then compact. Method 2: Import material into trench invert, buck into hopper with CAT 950 and move with conveyor belt over trench wall, this method is used in locations where direct access is not possible.	Compactors and JD 710 are rentals, smaller rental trench compactors are necessary. Conveyor belt is a custom built item which is not easily disposed of.
430000	*	**SITE GRADING**														**248,000**	**SY**	**10,000**	**$ 305,000**	**$ 156,000**	**$ -**	**$ -**	**$ 460,000**			
430011		DICKERSON SUBGR	1412	1414			1422	1424								5,000	SY	100	$ 4,000	$ 7,000	$ -	$ -	$ 11,000			
430021		FGRD E/W/SHOO/RB	1412	1414			1422	1424								68,000	SY	3,000	$ 95,000	$ 55,000	$ -	$ -	$ 150,000			
430051		ROUGH/FINEGRD ML	1412	1414			1422	1424								21,000	SY	950	$ 32,000	$ 5,000	$ -	$ -	$ 37,000			
430111			1412	1414			1422	1424								0		-	$ -	$ -	$ -	$ -	$ -			
430121		FGRD SHOOF/SUBB	1412	1414			1422	1424								68,000	SY	2,000	$ 52,000	$ 21,000	$ -	$ -	$ 74,000			
430131		FINEGRADE SUBB ML	1412	1414			1422	1424								21,000	SY	700	$ 21,000	$ 3,000	$ -	$ -	$ 24,000			
430211		CROSS STREETS	1412	1414			1422	1424								42,000	SY	970	$ 31,000	$ 14,000	$ -	$ -	$ 45,000			
430241		PARKING LOTS	1412	1414			1422	1424								25,000	SY	1,000	$ 35,000	$ 14,000	$ -	$ -	$ 49,000			
430250		MAINTAIN HAUL ROADS	1412	1414			1422	1424								40	WK	1,000	$ 35,000	$ 36,000	$ -	$ -	$ 71,000			
500000	*	**CONCRETE STRUCTURES**														**100**	**PC**	**69,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 8,718,000**			
500010	*	**MISCELLANEOUS**														**100**	**PC**	**45,000**	**$ 1,147,000**	**$ 407,000**	**$ 180,000**	**$ 6,167,000**	**$ 7,720,000**			
500011		CONC PUMP CHARGE										1440				91,000	CY	-	$ -	$ -	$ -	$ 667,000	$ 667,000			
500021		WINTER PROTECTION	1412	1414			1422	1424								861,000	SF	9,000	$ 230,000	$ 107,000	$ 62,000	$ -	$ 337,000			
500111		CURE CONCRETE	1412	1414												1,164,000	SF	2,000	$ 45,000	$ -	$ 19,000	$ -	$ 45,000			
500211		POINT&PATCH	1412	1414			1422	1424								288,000	SF	880	$ 22,000	$ 10,000	$ 19,000	$ -	$ 32,000			
500212		POINT&PATCH(EXPOS	1412	1414			1422	1424								484,000	SF	25,000	$ 632,000	$ 42,000	$ 19,000	$ -	$ 674,000			
500213		POINT&PATCH(EXPOS										1440				0	SF	-	$ -	$ -	$ 19,000	$ 6,000	$ 6,000			
500250		SANDBLAST/JT PREP	1412	1414			1422	1424								58,000	SF	3,000	$ 70,000	$ 3,000	$ -	$ -	$ 73,000			
501111		REBAR BLACK F&I										1440				9,290,000	LB	-	$ -	$ -	$ 42,000	$ 5,424,000	$ 5,424,000			
501112		REBAR SUPPORT	1412	1414			1422	1424								4,000	TN	5,000	$ 148,000	$ 245,000	$ -	$ -	$ 393,000			
501113		REBAR GREEN F&I										1440				111,000	LB	-	$ -	$ -	$ -	$ 70,000	$ 70,000			
505100	*	**BRIDGE ABUTMENTS**														**6,000**	**CY**	**14,000**	**$ 411,000**	**$ 76,000**	**$ 816,000**	**$ 35,000**	**$ 522,000**			
505101		EXC ABUTS	1412	1414			1422	1424								3,000	CY	2,000	$ 59,000	$ 23,000	$ -	$ -	$ 82,000			
505102		BFILL ABUTS	1412	1414			1422	1424								2,000	CY	830	$ 23,000	$ 17,000	$ -	$ -	$ 40,000			
505103		FDN PREP (CIDH ETC)	1412	1414			1422	1424								17,000	SF	460	$ 13,000	$ 5,000	$ -	$ -	$ 18,000	Cleaning off Bridge Piles		
505104		FDN PREP (CIDH SUB)	1412													0	SF	-	$ -	$ -	$ -	$ 27,000	$ 27,000	Cleaning off Bridge Piles		
505111		FAB CAPBKWL FORM	1412	1414			1422	1424								260	SF	80	$ 2,000	$ -	$ -	$ -	$ 2,000			
505112		FAB WOODWALL FORM	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -			
505113		STEEL FORM MOD	1412	1414			1422	1424								3	EA	350	$ 10,000	$ -	$ -	$ -	$ 10,000	About 2000 SF		
505121		S&S CAP/BKWALL	1412	1414			1422	1424								20,000	SF	6,000	$ 174,000	$ 4,000	$ -	$ -	$ 178,000			
505122		S&S 2SIDE TRNCHWL	1412	1414			1422	1424								0	SF	(258)	$ (7,849)	$ -	$ 804,000	$ -	$ (7,849)	Need to JCA back into this to 0 out		
505123		S&S 1SIDE TRNCHWL	1412	1414			1422	1424								12,000	SF	3,000	$ 94,000	$ 910	$ -	$ -	$ 94,000			
505124		S&S BULKHEAD	1412	1414			1422	1424								120	SF	200	$ 6,000	$ -	$ -	$ -	$ 6,000			
505131		PLACE CAP CONC	1412	1414												690	CY	740	$ 20,000	$ -	$ -	$ -	$ 20,000			
505132		PLACE TRENCHWALL	1412	1414												430	CY	170	$ 5,000	$ -	$ -	$ -	$ 5,000			
505133		WELD STUDS	1412	1414			1422	1424								6,000	EA	430	$ 13,000	$ 26,000	$ 13,000	$ -	$ 39,000			
505135		WELD STUDS SUB										1440				0	EA	-	$ -	$ -	$ -	$ 8,000	$ 8,000			
507000	*	**BRIDGE DECK**														**10**	**EA**	**8,000**	**$ 222,000**	**$ 179,000**	**$ 1,910,000**	**$ -**	**$ 391,000**			
507101		NEOPRENE INSTALL	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -			
507103		TRUCK CRANE MOVES						1424	1432	1434	1436					0	EA	-	$ -	$ -	$ -	$ -	$ -			
507105		SET SLABS&BOXES	1412	1414			1422	1424						1480		220	EA	2,000	$ 69,000	$ 170,000	$ 1,910,000	$ -	$ 229,000			
507106		WELD CLIPS	1412	1414			1422	1424								1	LB	-	$ -	$ -	$ -	$ -	$ -			
507107		DWL SLAB/GROUTKEY	1412	1414			1422	1424								10	EA	2,000	$ 53,000	$ 7,000	$ -	$ -	$ 60,000			
507109		SET HANDRAILS	1412	1414			1422	1424								10	EA	290	$ 9,000	$ -	$ -	$ -	$ 9,000			
507143		PLACE SIDEWALK 8 IN	1412	1414			1422	1424								11,000	SF	3,000	$ 92,000	$ 1,000	$ -	$ -	$ 93,000			
508100	*	**APPROACH SLABS**														**8**	**EA**	**2,000**	**$ 77,000**	**$ 7,000**	**$ 16,000**	**$ -**	**$ 84,000**			
508101		FINEGRADE APPR	1412	1414			1422	1424								560	SY	110	$ 4,000	$ 400	$ -	$ -	$ 4,000			
508102		EXC BRIDGE APPR	1412	1414			1422	1424								460	CY	120	$ 4,000	$ 2,000	$ -	$ -	$ 6,000			
508103		PED BRG APPR FILL	1412	1414			1422	1424								190	CY	120	$ 4,000	$ 2,000	$ -	$ -	$ 7,000	After the retaining walls of the Ped bridge were stripped, fill would be placed to bring the grade up for the final sidewalks and stairs to be poured.	Placement of fill with a 950 loader and small walk behind compation roller	
508114		F&P PED BR RETWL	1412	1414			1422	1424								290	LF	1,000	$ 48,000	$ 390	$ -	$ -	$ -	Placement of four cast in place type 5 retaining walls to create ramps off the ends of the Sand's Ped Bridge.	These walls varied in height from 0' - 6' with a 5' wide spread footing. Both the footings and walls were formed with ply and dim lumber. Pouring was done with a 28meter concrete pump in order to pour on both sides of the trench.	
508121		PLACE /FINISH APP	1412	1414			1422	1424								230	CY	600	$ 17,000	$ 2,000	$ 16,000	$ -	$ 48,000	Placment of 10' wide approach slabs on 4 bridges.	After the excavation, this item covered setting one out side edge form 3' tall, pour, and finish of 8 approach slabs.	
508122		PED BRIDGE APPR	1412	1414			1422	1424				1440				0	SY	-	$ -	$ -	$ -	$ -	$ 19,000			
510000		**<>**														**0**		**18,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 603,000**			
511500	*	**CIP BARRIER**														**7,000**	**LF**	**15,000**	**$ 456,000**	**$ 46,000**	**$ 24,000**	**$ -**	**$ 502,000**	Not used		
511521		F&P BRIDGE RAIL	1412	1414			1422	1424								1,000	LF	4,000	$ 120,000	$ 6,000	$ 24,000	$ -	$ 126,000			
511531		F&P TRENCH BARRIER	1412	1414			1422	1424								6,000	LF	11,000	$ 313,000	$ 41,000	$ -	$ -	$ 354,000			
511541		F&P BRIDGE PILASTER	1412	1414			1422	1424								40	EA	660	$ 23,000	$ -	$ -	$ -	$ 23,000			
512100	*	**CIP RETAINING WALL**														**100**	**PC**	**3,000**	**$ 93,000**	**$ -**	**$ -**	**$ -**	**$ 101,000**			
512111		EXCAVATE	1412	1414			1422	1424								30	CY	80	$ 2,000	$ 760	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
512113		BACKFILL	1412	1414			1422	1424								0	CY	70	$ 2,000	$ 730	$ -	$ -	$ 3,000			
512115		F/P/S	1412	1414			1422	1424								2,000	SF	200	$ 6,000	$ 580	$ -	$ -	$ 7,000			
512121		PERM RDWY RETWALL	1412	1414			1422	1424				1440				640	LF	3,000	$ 86,000	$ 4,000	$ -	$ -	$ 91,000			
512131		SHOOFLY TEMP REWA	1412	1414			1422	1424				1440				0	SF	-	$ -	$ -	$ -	$ -	$ -			
520000		**<>**														**0**		**209,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 7,277,000**			
523000	*	**CAP BEAMS**														**680**	**CY**	**8,000**	**$ 237,000**	**$ 46,000**	**$ 1,000**	**$ -**	**$ 282,000**			
523011		FINEGRADE&JT PREP	1412	1414			1422	1424								13,000	SF	2,000	$ 48,000	$ 28,000	$ -	$ -	$ 76,000			
523015		BEAM PREP	1412	1414			1422	1424								5,000	LF	740	$ 22,000	$ 13,000	$ -	$ -	$ 35,000			
523021		S&S TRENCH CAP	1412	1414			1422	1424								18,000	SF	5,000	$ 150,000	$ 5,000	$ 1,000	$ -	$ 156,000			
523031		POUR TRENCH CAP	1412	1414			1422	1424								680	CY	650	$ 16,000	$ -	$ -	$ -	$ 16,000			
523100	*	**SEAL SLABS**														**15,000**	**CY**	**6,000**	**$ 160,000**	**$ 10,000**	**$ -**	**$ 500,000**	**$ 670,000**			
523111		TRENCH WATERSTOP	1412	1414												0	LF	-	$ -	$ -	$ -	$ -	$ -			
523113		SEAL SLAB TIEDOWN										1440				30	EA	-	$ -	$ -	$ -	$ 444,000	$ 444,000			
523115		CUTOFF WALL PREP	1412	1414			1422	1424								37,000	SF	410	$ 9,000	$ 5,000	$ -	$ -	$ 14,000			
523116		SUB-CUTOFF WALL PREP										1440				35,000	SF	-	$ -	$ -	$ -	$ 56,000	$ 56,000			
523121		SET CTB BHD	1412	1414			1422	1424								7	EA	210	$ 5,000	$ 80	$ -	$ -	$ 5,000			
523131		TRENCH SEAL CONC	1412	1414			1422	1424								15,000	CY	6,000	$ 147,000	$ 5,000	$ -	$ -	$ 152,000			
523200	*	**TRENCH INVERT**														**41,000**	**CY**	**73,000**	**$ 2,013,000**	**$ 126,000**	**$ 101,000**	**$ -**	**$ 2,139,000**			
523201		FINE GRADE	1412	1414			1422	1424								108,000	SF	2,000	$ 62,000	$ 68,000	$ -	$ -	$ 130,000			
523203		PREP SEAL SLAB	1412	1414			1422	1424								94,000	SF	2,000	$ 61,000	$ 11,000	$ -	$ -	$ 72,000			
523217		SET REBAR TEMPL	1412	1414			1422	1424								1,000	EA	10,000	$ 269,000	$ 7,000	$ -	$ -	$ 275,000			
523218		INSTALL DOWELS	1412	1414			1422	1424								19,000	EA	5,000	$ 118,000	$ 1,000	$ -	$ -	$ 119,000			
523223		S&S BULKHD / WSTOP	1412	1414			1422	1424								12,000	SF	11,000	$ 328,000	$ 6,000	$ -	$ -	$ 333,000			
523224		S&S EDG / STRT / SLPE	1412	1414			1422	1424								45,000	SF	24,000	$ 675,000	$ 30,000	$ -	$ -	$ 705,000			
523227		INSTALL WS	1412	1414												31,000	LF	1,000	$ 39,000	$ -	$ 101,000	$ -	$ 39,000			
523231		SET UP BIDWELL	1412	1414												0	LF	-	$ -	$ -	$ -	$ -	$ -			
523233		PLACE INVERT CONC	1412	1414			1422	1424								41,000	CY	18,000	$ 462,000	$ 4,000	$ -	$ -	$ 466,000			
523300	*	**TRENCH WALL**														**18,000**	**CY**	**85,000**	**$ 2,410,000**	**$ 509,000**	**$ 101,000**	**$ -**	**$ 2,919,000**			
523303		FDN PREP (CIDH ETC)	1412	1414			1422	1424								16,000	SF	920	$ 28,000	$ 10,000	$ -	$ -	$ 38,000	Cleaning up Cut-Off Wall		
523311		FORM FAB / ASSEM	1412	1414			1422	1424								18,000	SF	4,000	$ 123,000	$ 53,000	$ -	$ -	$ 176,000	Q is suspect (low), this cost includes breaking down panels to ship out (rental & bought) - needs research		
523312		MODIFY STL FORM	1412	1414			1422	1424								1	EA	90	$ 3,000	$ 5,000	$ -	$ -	$ 8,000			
523313		RESKIN STL FORM	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -			
523323		S&S BULKHEAD	1412	1414			1422	1424								8,000	SF	9,000	$ 279,000	$ 4,000	$ -	$ -	$ 283,000			
523324		S&S 2 SIDED WALL	1412	1414			1422	1424								605,000	SF	58,000	$ 1,678,000	$ 437,000	$ -	$ -	$ 2,116,000			
523325		S&S 1 SIDED WALL	1412	1414			1422	1424								3,000	SF	580	$ 16,000	$ 100	$ -	$ -	$ 17,000			
523327		INSTALL WS	1412	1414												7,000	LF	720	$ 20,000	$ -	$ 101,000	$ -	$ 20,000			
523333		PLACE WALL CONC	1412	1414												18,000	CY	11,000	$ 262,000	$ -	$ -	$ -	$ 262,000			
523400	*	**TRENCH RETAINING W**														**5,000**	**CY**	**15,000**	**$ 441,000**	**$ 66,000**	**$ 101,000**	**$ -**	**$ 506,000**			
523401		FINEGRADE C/D	1412	1414			1422	1424								27,000	SF	760	$ 27,000	$ 38,000	$ -	$ -	$ 64,000			
523411		FORM FAB/ASSEM	1412	1414			1422	1424								1,000	SF	430	$ 13,000	$ 200	$ -	$ -	$ 13,000			
523412		MODIFY STL FORM	1412	1414			1422	1424								0	EA	-	$ -	$ -	$ -	$ -	$ -			
523423		S&S BULKHEAD	1412	1414			1422	1424								580	SF	560	$ 16,000	$ -	$ -	$ -	$ 16,000			
523424		S&S FOOTER	1412	1414			1422	1424								10,000	SF	3,000	$ 78,000	$ 1,000	$ -	$ -	$ 79,000			
523425		S&S 2 SIDED WALL	1412	1414			1422	1424								91,000	SF	8,000	$ 248,000	$ 27,000	$ -	$ -	$ 275,000			
523427		INSTALL WS	1412	1414												260	LF	5	$ 140	$ -	$ -	$ -	$ 140			
523432		PLACE FTG CONC	1412	1414												2,000	CY	970	$ 24,000	$ -	$ 101,000	$ -	$ 24,000			
523433		PLACE WALL CONC	1412	1414												3,000	CY	1,000	$ 34,000	$ -	$ -	$ -	$ 34,000			
523500	*	**WET WELL**														**810**	**CY**	**8,000**	**$ 230,000**	**$ 86,000**	**$ 107,000**	**$ -**	**$ 316,000**			
523503		INVERT SLAB PREP	1412	1414			1422	1424								2,000	SF	810	$ 18,000	$ 3,000	$ -	$ -	$ 21,000			
523505		OG PREP @ WALL	1412	1414			1422	1424								3,000	SF	460	$ 11,000	$ 25,000	$ -	$ -	$ 36,000			
523511		FORM FAB/ASSEM	1412	1414			1422	1424								4,000	SF	80	$ 3,000	$ -	$ -	$ -	$ 3,000			
523523		S&S BULKHEAD	1412	1414			1422	1424								110	SF	80	$ 3,000	$ -	$ -	$ -	$ 3,000			
523525		S&S 1 SIDED WALL	1412	1414			1422	1424								2,000	SF	2,000	$ 57,000	$ 6,000	$ 3,000	$ -	$ 63,000			
523526		S&S SOFFIT	1412	1414			1422	1424								1,000	SF	2,000	$ 46,000	$ 45,000	$ -	$ -	$ 90,000			
523527		INSTALL WS	1412	1414												380	LF	20	$ 490	$ -	$ 101,000	$ -	$ 490			
523528		S&S 2 SIDED WALL	1412	1414			1422	1424								7,000	SF	3,000	$ 73,000	$ 8,000	$ 3,000	$ -	$ 81,000			
523533		PLACE WETWALL CONC	1412	1414												810	CY	780	$ 19,000	$ -	$ -	$ -	$ 19,000			
523600	*	**SIPHON INLT/OUTLT**														**100**	**PC**	**4,000**	**$ 100,000**	**$ 6,000**	**$ -**	**$ -**	**$ 106,000**			
523601		FINEGRD DRAINROCK	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -			
523602		BACKFILL	1412	1414			1422	1424								2,000	CY	440	$ 13,000	$ 5,000	$ -	$ -	$ 18,000	Backfill the siphon structure with native fill material.	The siphon structure is backfilled in lifts of 12 inches. The material is placed with a Cat 966 loader and compacted with a sheeps foot roller. The Cat 345 excavator is used to feed material to the loader. A laborer is used to handle a small tamping foot compactor around the siphon structure.	
523621		F&P BASE	1412	1414			1422	1424								1,000	SF	600	$ 18,000	$ 60	$ -	$ -	$ 18,000	Form and Pour the Base Foundation for the Siphon Inlet/Outlet Structures.		
523622		F&P WALLS/WEIR	1412	1414			1422	1424								100	CY	2,000	$ 64,000	$ 690	$ -	$ -	$ 65,000	Form and Pour the Siphon Inlet/Outlet structure walls. Openings are formed for the 96in SD, 36in SD, and 10in SD.		
523623		F&P TOP	1412	1414			1422	1424								40	CY	210	$ 5,000	$ -	$ -	$ -	$ 5,000	Form and pour the top section of the siphon structure. Openings are formed for 3 manholes.	After the walls/weir have been formed and poured, the top section of the siphon structure is formed in the same method as the walls/weir.	
523700	*	**RIVER OUTLET STRUCTURE**														**220**	**CY**	**2,000**	**$ 60,000**	**$ 36,000**	**$ -**	**$ -**	**$ 96,000**			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
523701		EXC/FINEGRADE	1412	1414			1422	1424								1,000	CY	220	$ 7,000	$ 14,000	$ -	$ -	$ 21,000			
523702		BACKFILL	1412	1414			1422	1424								670	CY	140	$ 4,000	$ 6,000	$ -	$ -	$ 10,000			
523703		PLACE RIPRAP	1412	1414			1422	1424								90	CY	140	$ 4,000	$ 1,000	$ -	$ -	$ 5,000			
523704		SANDBAG DAM IN/OUT	1412	1414			1422	1424								300	LF	640	$ 17,000	$ 12,000	$ -	$ -	$ 29,000			
523705		RETAINING POND	1412	1414			1422	1424								0	EA	-	$ -	$ -	$ -	$ -	$ -			
523711		FAB FORMS	1412	1414			1422	1424								4,000	SF	10	$ 300	$ -	$ -	$ -	$ 300			
523722		S&S WALL	1412	1414			1422	1424								3,000	SF	650	$ 19,000	$ 2,000	$ -	$ -	$ 21,000			
523723		S&S BLOCKS ETC	1412	1414			1422	1424								180	SF	120	$ 4,000	$ 700	$ -	$ -	$ 4,000			
523732		POUR CUTOFF WALLS	1412	1414			1422	1424								40	CY	4	$ 110	$ -	$ -	$ -	$ 110			
523733		POUR APRON SLAB	1412	1414			1422	1424								130	CY	90	$ 3,000	$ 230	$ -	$ -	$ 3,000			
523734		POUR WALLS	1412	1414			1422	1424								50	CY	40	$ 1,000	$ 80	$ -	$ -	$ 1,000			
523735		POUR DIAPHR/BLOCK	1412	1414			1422	1424								3	CY	20	$ 440	$ -	$ -	$ -	$ 440			
524000	*	**AMTRAK STA SUBSTR**														**100**	**PC**	**3,000**	**$ 90,000**	**$ 22,000**	**$ 101,000**	**$ -**	**$ 112,000**			
524003		INVERT SLAB PREP	1412	1414			1422	1424								500	SF	8	$ 210	$ 140	$ -	$ -	$ 350	Power wash and air blow the invert / sealslab interface.		
524005		OG PREP @ WALL	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -	Did not use		
524007		PIT FORMS	1412	1414			1422	1424								60	CY	250	$ 8,000	$ 2,000	$ -	$ -	$ 10,000	Fabracation and installation on steel forms using small I-Beams and trench plate and then placing them inside the blockouts for the elevator shafts.	We used smaller I-beams W10X32's with 1" trench plate attached to the exterior and then crained them into position for the two elevators and one escalator.	These were very effective, but I recommend more bracing in the center of the forms, they deflect up to 3/8 of an inch.
524011		FORM FAB/ASSEM	1412	1414			1422	1424								4,000	SF	90	$ 2,000	$ 50	$ -	$ -	$ 2,000	Assembly of one sided wall forms for the three trench wall sections. These forms were 26' tall and were broken into 10 ft lengths.	Assembly of Doka one sided frames and pannels on the amtrak station platform.	
524023		S&S BULKHEAD	1412	1414			1422	1424								460	SF	410	$ 11,000	$ 290	$ -	$ -	$ 12,000	Set and remove 4 Ea bulkheads 26' high and 2.5' thick. These bulkheads are on one sided walls.	The bulkheads, were stick built and secured to the one sided forms and them welded to the piles behind them or kicked the full height to the ground.	Just slow and labor consuming work.
524024		S&S EDGE	1412	1414			1422	1424								0	SF	30	$ 1,000	$ -	$ -	$ -	$ 1,000	Set Edge form 3' tall and 123' long.	This operation was combined with a nearby invert and the costs are not useful.	
524025		S&S 2 SIDED WALL	1412	1414			1422	1424								4,000	SF	2,000	$ 48,000	$ 20,000	$ -	$ -	$ 68,000			
524026		S&S SOFFIT	1412	1414			1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -	Did not Use		
524027		INSTALL WS	1412	1414												0	LF	-	$ -	$ -	$ 101,000	$ -	$ -	Did not Use		
524031		POUR/FIN SUBSTR	1412	1414												1,000	CY	740	$ 18,000	$ -	$ -	$ -	$ 18,000			
524033		PLATFORM SLAB					1422	1424								0	SF	-	$ -	$ -	$ -	$ -	$ -	Did not use		
524100	*	**AMTRAK TEMP BLDG**														**100**	**PC**	**4,000**	**$ 112,000**	**$ 19,000**	**$ 86,000**	**$ -**	**$ 131,000**			
524111		INSTALL WALLS	1412	1414			1422	1424								1,000	LF	1,000	$ 40,000	$ 5,000	$ -	$ -	$ 45,000			
524112		BACKFILL	1412	1414			1422	1424								3,000	TN	690	$ 19,000	$ 9,000	$ -	$ -	$ 28,000			
524113		PLATFORM BASE ROCK	1412	1414			1422	1424								0	TN	-	$ -	$ -	$ -	$ -	$ -			
524114		TRANSIT TILE INSTALL	1412	1414			1422	1424								2,000	LF	1,000	$ 41,000	$ 5,000	$ 86,000	$ -	$ 46,000			
524115		GCCO BUILD OUT	1412	1414			1422	1424								100	PC	350	$ 11,000	$ 230	$ -	$ -	$ 11,000			
540000		**<>**														**0**		**370**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
549000	*	**MASONRY STRUCTURE**														**100**	**PC**	**370**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
549100	*	**PUMP STA ACCESS BL**														**100**	**PC**	**370**	**$ 360**	**$ -**	**$ -**	**$ -**	**$ -**			
549111		CMUBUILDING										1440				0	SF	-	$ -	$ -	$ -	$ -	$ -			
549121		DRY WELL ROOF										1440				0	SF	370	$ 360	$ -	$ -	$ -	$ -			
549141		MISC METALS										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
549151		FRAME	1412	1414			1422	1424								0	LF	-	$ -	$ -	$ -	$ -	$ -			
549152		COVER	1412	1414			1422	1424								0	EA	-	$ -	$ -	$ -	$ -	$ -			
550000		**<Steel>**														**0**		**20**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 3,906,000**			
550000	*	STEEL STRUCTURES														100	PC	20	$ -	$ -	$ -	$ -	$ 3,771,000			
550101		AMTRAK BLDG STRUC										1440				100	PC	-	$ -	$ -	$ -	$ 3,732,000	$ 3,732,000			
550111		TEMP AMTRAK BLDG										1440				0	SF	-	$ -	$ -	$ 78,000	$ -	$ -			
550121		AWNING R & R	1412	1414			1422	1424								70	PC	-	$ 11,000	$ 2,000	$ 260	$ -	$ 13,000			
550131		LAKE ST TEMP BRDG	1412	1414			1422	1424								1	EA	20	$ 550	$ 3,000	$ -	$ -	$ 4,000			
550135		LAKE ST TMP BRDG										1440				1	EA	-	$ -	$ -	$ -	$ 22,000	$ 22,000			
552000	*	**MISC METALS**														**40**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 135,000**			
552011		SIGNAL CASE MM	1412	1414			1422	1424								0	LB	-	$ -	$ -	$ -	$ -	$ -			
552021		WET WELL MM	1412	1414			1422	1424				1440				0	PC	-	$ -	$ -	$ -	$ 135,000	$ 135,000			
552031		AMTRAK SUBSTR MM	1412	1414			1422	1424								0	LB	-	$ -	$ -	$ 27,000	$ -	$ -			
560000	*	**POST-TENSIONING**														**20**	**EA**	**200**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 30,000**			
560111		TRANSVERSE PT - DECKS	1412	1414			1422	1424								20	EA	200	$ 6,000	$ -	$ -	$ -	$ 6,000			
560112		TRANSVERSE PT - DECKS SUB										1440				20	EA	-	$ -	$ -	$ -	$ 24,000	$ 24,000			
590000		**<>**														**0**		**250**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 1,747,000**			
590000	*	**PAINTING**														**43,000**	**SF**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 30,000**			
590111		ANTI-GRAFFITI PAINT										1440				43,000	SF	-	$ -	$ -	$ -	$ 20,000	$ 6,000			
590113		K-RAIL PAINTING										1440				3,000		-	$ -	$ -	$ -	$ 2,000	$ 24,000			
597000	*	**FURNITURE/SPECIALTY**														**0**	**EA**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**			
597011		TRASH RECEPTACLES	1412	1414												0	EA	-	$ -	$ -	$ -	$ -	$ -			
597013		BENCHES	1412	1414												0	EA	-	$ -	$ -	$ -	$ -	$ -			
598000	*	**WINDOWS & GLASS**														**100**	**PC**	**100**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 1,708,000**			
598011		CUSTOM GLAZING										1440				100	PC	-	$ -	$ -	$ -	$ 1,705,000	$ 1,705,000			
598021		SOLID CORE DOORS										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
598031		PUMP STA DOORS										1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
598032		AMTRAK MODS EAST	1412	1414			1422	1424								100	PC	100	$ 3,000	$ 130	$ -	$ -	$ 3,000			
599000	*	**MOISTURE PROTECTION**														**0**	**SF**	**150**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 9,000**			
599011		BENTONITE PANEL WPRF										1440				0	SF	-	$ -	$ -	$ -	$ -	$ -			
599012		BASEMENT WPRF	1412	1414			1422	1424								0	SF	150	$ 4,000	$ 4,000	$ 5,000	$ -	$ 9,000			
600000	*	*****MECHANICAL*****														**100**	**PC**	**-**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 569,000**			
600051		TRENCH FIRE SYSTE										1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
600061		OWS INSTALL	1412	1414			1422	1424								0	PC	-	$ -	$ -	$ -	$ -	$ -			
600071		VINE ST SIPHON MECH										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
600081		WET WELL MECH										1440				100	PC	-	$ -	$ -	$ -	$ 568,000	$ 568,000			
600091		RVR OUTLT FLAPGATE	1412	1414			1422	1424								2	EA	30	$ 1,000	$ -	$ -	$ -	$ 1,000			
650000	*	**ELECTRICAL**														**90**	**PC**	**6,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 3,466,000**			
650010	*	**BASIC ELECTRICAL**														**100**	**PC**	**180**	**$ 6,000**	**$ 870**	**$ 69,000**	**$ 3,266,000**	**$ 3,272,000**			
650011		MAINTAIN STREETS										1440				100	PC	-	$ -	$ -	$ -	$ 248,000	$ 248,000			
650012		MAINTAIN STREETS SUPPORT	1412	1414			1422	1424								90	PC	180	$ 6,000	$ 870	$ -	$ -	$ 6,000			
650013		MODIFY ROBB DR INTERSECT										1440				100	PC	-	$ -	$ -	$ -	$ -	$ -			
650021		TRENCH ELECTRICAL										1440				0	PC	-	$ -	$ -	$ 69,000	$ 598,000	$ 598,000			
650031		PERM STREET LIGHT										1440				100	PC	-	$ -	$ -	$ -	$ 1,762,000	$ 1,762,000			
650041		PERM TRAFFIC SIGN										1440				100	PC	-	$ -	$ -	$ -	$ 31,000	$ 31,000			
650051		CONDUIT IN TRENCH	1412	1414			1422	1424								100	LF	-	$ -	$ -	$ -	$ -	$ -			
650061		RR SIGNAL ELEC										1440				100	PC	-	$ -	$ -	$ -	$ 61,000	$ 61,000			
650071		VINE ST SIPHON ELEC										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
650081		WET WELL CONTROLS										1440				100	PC	-	$ -	$ -	$ -	$ 48,000	$ 48,000			
650091		TEMP ATRKSTN RAMP										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
650093		PWR TO PUMPSTN										1440				100	PC	-	$ -	$ -	$ -	$ 182,000	$ 182,000			
650094		PUMPSTATION ELEC										1440				0	PC	-	$ -	$ -	$ -	$ -	$ -			
650095		TEMP PWR2SFLY WGH										1440				100	PC	-	$ -	$ -	$ -	$ 8,000	$ 8,000			
650097		ELECT DESIGN										1440				100	PC	-	$ -	$ -	$ -	$ 9,000	$ 9,000			
650098		MCI QUEST CONDUIT										1440				100	PC	-	$ -	$ -	$ -	$ 242,000	$ 242,000			
650099		SANDS PED BRIDGE ELEC.										1440				100	PC	-	$ -	$ -	$ -	$ 77,000	$ 77,000			
650200	*	**BURIED CONDUIT & BOX**														**12,000**	**LF**	**6,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 194,000**			
650221		EXC / GRADE DITCH	1412	1414			1422	1424								13,000	LF	6,000	$ 161,000	$ 33,000	$ -	$ -	$ 194,000			
650231																0		-	$ -	$ -	$ -	$ -	$ -			
700000	*	**PAVEMENT BASE**														**100**	**PC**	**6,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 255,000**			
700321		SPR/CMP PERM BASE	1412	1414			1422	1424								5,000	TN	-	$ -	$ 510	$ -	$ -	$ 510			
700411		FINISH TEMP PAVEMENT	1412	1414			1422	1424								3,000	SY	490	$ 13,000	$ 2,000	$ -	$ -	$ 16,000			
700421		SPR/CMP/FINISH PERM BASE	1412	1414			1422	1424								72,000	SY	5,000	$ 160,000	$ 79,000	$ 268,000	$ -	$ 239,000	Asphalt roadway base course.	Typically imported in triple transfers and spread with skip loader and backhoe.	
720000	*	**AC PAVE**														**35,000**	**TN**	**13,000**	**$ 361,000**	**$ 217,000**	**$ 1,265,000**	**$ 149,000**	**$ 728,000**			
720021		HAUL TRIPLE TRANS														17,000	TN	1,000	$ 37,000	$ 61,000	$ -	$ -	$ 98,000	Haul AC from Lockwood hot plant to project, typically Granite trucks.		
720090		TEMP AC PATCH	1412	1414			1422	1424								5,000	TN	6,000	$ 147,000	$ 65,000	$ 119,000	$ -	$ 212,000			
720091		TEMP AC PATCH SUB										1440				0	TN	-	$ -	$ -	$ -	$ 129,000	$ 129,000			
720126		SLURRY SEAL										1440				0	SF	-	$ -	$ -	$ -	$ -	$ -			
720130		AC PAVE	1412	1414			1422	1424								28,000	TN	6,000	$ 169,000	$ 85,000	$ 1,147,000	$ -	$ 253,000		Granite Reno Branch AC crew.	
720131		AMTRAK TEMP FACILITY	1412	1414			1422	1424								1,000	TN	220	$ 8,000	$ 7,000	$ -	$ -	$ 15,000			
720132		TEMP SHOOFLY XING SUB										1440				0	TN	-	$ -	$ -	$ -	$ 20,000	$ 20,000			
820000	*	**CONCRETE PLANT**														**89,000**	**CY**	**40,000**	**$ 1,078,000**	**$ 1,244,000**	**$ -**	**$ -**	**$ 2,599,000**			
821100	*	**FEED & OPERATE**														**89,000**	**CY**	**35,000**	**$ 910,000**	**$ 947,000**	**$ -**	**$ -**	**$ 1,960,000**			
821101		PLANT RENT-#86-36	1412	1414			1422	1424	1432	1434	1436					89,000	CY	-	$ -	$ 213,000	$ -	$ -	$ 213,000			
821103		LAND RENT							1432	1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 48,000			
821121		GUPPY RENT					1422	1424								10	PC	-	$ -	$ 16,000	$ -	$ -	$ 16,000			
821131																0		-	$ -	#VALUE!	$ -	$ -	$ 10,000			
821301		POWER					1422	1424	1432	1434	1436					89,000	CY	-	$ -	$ 26,000	$ -	$ -	$ 27,000			
821451		HEATER FUEL							1432	1434	1436					89,000	CY	-	$ -	$ -	$ -	$ -	$ 27,000			
821501		UNLD/HAUL RAILAGG	1412	1414			1422	1424								1,000	TN	30	$ 670	$ 2,000	$ -	$ -	$ 2,000			
821510		STKPILE SAND / AGG	1412	1414			1422	1424								89,000	CY	3,000	$ 108,000	$ 136,000	$ -	$ -	$ 244,000			
821601		HAUL W/T-MIX	1412	1414			1422	1424								89,000	CY	20,000	$ 489,000	$ 538,000	$ -	$ -	$ 1,027,000			
821801		FEED&OPERATE	1412	1414			1422	1424								89,000	CY	7,000	$ 235,000	$ 15,000	$ -	$ -	$ 250,000			
821851		QC LAB TECH	1412	1414												20	MO	4,000	$ 78,000	$ -	$ -	$ -	$ 78,000			
821852		QC AGG TEST								1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 18,000			
821900	*	**PLANT UP/DOWN**														**100**	**PC**	**5,000**	**$ 168,000**	**$ 297,000**	**$ -**	**$ 41,000**	**$ 639,000**			
821901		DEVELOP SITE	1412	1414			1422	1424								100	CY	3,000	$ 102,000	$ 157,000	$ -	$ -	$ 259,000			
821902		SUB-DVLP STE & PRMT										1440				0	CY	-	$ -	$ -	$ -	$ 35,000	$ 35,000			
821904		CONDITIONAL USE PRMT							1432	1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 24,000			
821905		AIR QUALITY PERMIT							1432	1434	1436					0	PC	-	$ -	$ -	$ -	$ -	$ -			
821921		SET UP PLANT	1412	1414			1422	1424								100	PC	1,000	$ 36,000	$ 113,000	$ -	$ -	$ 149,000			
821933		ELECTRIC HOOKUP										1440				1	EA	-	$ -	$ -	$ -	$ 5,000	$ 5,000			
821935		INSTL WTR LINE	1412	1414			1422	1424								2,000	LF	500	$ 16,000	$ 9,000	$ -	$ -	$ 25,000			
821936		WATER LINE & FITTINGS							1432	1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 32,000			
821941		PLANT SET MISC MATL							1432	1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 76,000			
821961		CERTIFY SCALES							1432	1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 1,000			
821971		TEAR DOWN PLANT	1412	1414			1422	1424								100	PC	440	$ 15,000	$ 18,000	$ -	$ -	$ 33,000			
821972		ELEC DISCONNECT										1440				0	EA	-	$ -	$ -	$ -	$ -	$ -			
840000	*	**AGGR PIT / PLANT**														**100**	**PC**	**50,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 5,980,000**			
840100	*	**ROBB DR DUMP**														**100**	**PC**	**38,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 2,890,000**			
840101		CONDITIONAL USE PRMT							1432	1434	1436	1440				100	PC	-	$ -	$ -	$ -	$ 12,000	$ 68,000			
840102		NDEP CERT(ROBB DR							1432	1434	1436					100	PC	-	$ -	$ -	$ -	$ -	$ 34,000			
840103		TRANSYSTEM MOB										1440				100	PC	-	$ -	$ -	$ -	$ 37,000	$ 37,000			
840104		REES IMPACT & DELAYS										1440				100	PC	-	$ -	$ -	$ -	$ -	$ 100,000			
840105		WATER ROYALTY							1432	1434	1436					53,000	MG	-	$ -	$ -	$ -	$ -	$ 155,000			
840106		GRIZZLY MOD/DEMOB	1412	1414			1422	1424								2	EA	100	$ 3,000	$ 1,000	$ -	$ -	$ 4,000			
840107		GRIZZLY FEED & OPER	1412	1414			1422	1424								23,000	TN	750	$ 25,000	$ 32,000	$ -	$ -	$ 57,000			
840111		WATER SYS IN/OUT	1412	1414			1422	1424								100	PC	200	$ 5,000	$ 16,000	$ -	$ -	$ 21,000			
840112		WATER SETUP										1440		1480		0	PC	-	$ -	$ -	$ -	$ 2,000	$ 2,000			
840113		PUMPMASTER					1422	1424								0	EA	-	$ -	$ -	$ -	$ -	$ -			
840114		4IN SUBMERSIBLE PUMP					1422	1424								0	EA	-	$ -	$ -	$ -	$ -	$ -			
840115		PIPES & PARTS							1432	1434	1436					300	LF	-	$ -	$ -	$ -	$ -	$ 9,000			

Account	HEADER I/0	Description	REGULAR LABOR	PREMIUM LABOR	PAYROLL BURDEN	KEYPUNCH ERROR	INTERNAL EQUIPMENT	EXTERNAL EQUIPMENT	INTERNAL MATERIAL	EXTERNAL M.ATERIAL	FEES & SERVICES	SUBCONTRACTOR	HAULING	REVENUE	MATERIAL ONHAND	Quantity	Unit	Lab Total Man-Hour	Labor Cost	Equip Cost	Material Cost	Subcontract Cost	Total Cost	Scope of Work:	Method:	Notes:
840116		CLEAN POND	1412	1414			1422	1424								84,000	CY	800	$ 23,000	$ 140,000	$ -	$ -	$ 163,000			
840117		VISQUEEN DISPOSAL							1432	1434	1436					0	LD	-	$ -	$ -	$ -	$ -	$ -			
840118		POND LINER								1434						36,000	SF	-	$ -	$ -	$ -	$ -	$ 29,000			
840119		INST POND LINER	1412	1414			1422	1424								36,000	SF	340	$ 8,000	$ 760	$ -	$ -	$ 8,000			
840120																0		-	$ -	$ -	$ -	$ 13,000	$ 13,000			
840121		BUILD HAUL ROAD FROM	1412	1414			1422	1424								100	PC	330	$ 10,000	$ 13,000	$ -	$ -	$ 23,000			
840122		RESTORE SITE	1412	1414			1422	1424								100	PC	170	$ 6,000	$ 5,000	$ -	$ -	$ 12,000			
840131		OG COMPACTION	1412	1414			1422	1424								1,000	SY	50	$ 1,000	$ 6,000	$ -	$ -	$ 7,000			
840141		D&C INCOMING MATL	1412	1414			1422	1424						1480		613,000	BC	13,000	$ 413,000	$ 608,000	$ -	$ -	$ 1,017,000			
840144		WATER TANKER	1412	1414			1422	1424								613,000	BC	90	$ 2,000	$ 113,000	$ -	$ -	$ 116,000			
840151		LOAD OUT MATERIAL	1412	1414			1422	1424								223,000	BC	3,000	$ 117,000	$ 109,000	$ -	$ -	$ 226,000	Generic code for on-site hauling of stockpiles.	General dumping code for on-site hauls.	General dumping code for on-site hauls.
840153		HAUL BACKFILL	1412	1414			1422	1424								223,000	BC	7,000	$ 186,000	$ 604,000	$ -	$ -	$ 790,000	Backfill along trench walls.	typically end dumps and 10 wheelers.	
840154																0		-	$ -	$ (7)	$ -	$ -	$ (7)			
840200	*	AGGREGATE IMPORT														313,000	TN	12,000	$ -	$ -	$ -	$ -	$ 1,503,000			
840254		HAUL TRIPLE TRANS														314,000	TN	12,000	$ 307,000	$ 1,196,000	$ -	$ -	$ 1,503,000			
840300	*	CRUSHING SUB														369,000	TN	-	$ -	$ -	$ -	$ -	$ 1,587,000			
840301		MOB TO CEMETERY										1440				100	PC	-	$ -	$ -	$ -	$ 77,000	$ 77,000			
840302		MOB CONC AGGS										1440				100	PC	-	$ -	$ -	$ -	$ 59,000	$ 59,000			
840303		3IN MINUS										1440				240,000	TN	-	$ -	$ -	$ -	$ 312,000	$ 312,000			
840304		AGG BASE										1440				20,000	TN	-	$ -	$ -	$ -	$ 59,000	$ 59,000			
840305		DRAIN ROCK										1440				10,000	TN	-	$ -	$ -	$ -	$ 39,000	$ 39,000			
840306		CONC AGG NO 67										1440				56,000	TN	-	$ -	$ -	$ -	$ 331,000	$ 331,000			
840307		CONC SAND										1440				43,000	TN	-	$ -	$ -	$ -	$ 228,000	$ 228,000			
840311		SORT UNCRSHBLE										1440				100	PC	-	$ -	$ -	$ -	$ 140,000	$ 140,000			
840312		CRSH SORTED MTL										1440				100	PC	-	$ -	$ -	$ -	$ 342,000	$ 342,000			
860000	*	*****EXTRA WORK*****														50	MO	14,000	$ 370,000	$ 333,000	259,000	503,000	$ 1,600,000			
860001		BOWL STADIUM FIRE	1412	1414			1422	1424	1432	1434	1436	1440				100	PC	-	$ -	$ -	$ -	$ -	$ 9,000			
860002		BOWL STADIUM ELEC	1412	1414			1422	1424	1432	1434	1436	1440				100	PC	-	$ -	$ -	$ -	$ 3,000	$ 3,000			
860003		SANDS PARKLOT LIG	1412	1414			1422	1424	1432	1434	1436	1440				100	PC	-	$ -	$ -	$ -	$ 22,000	$ 22,000			
870000	*	****BACKCHARGES****														50	MO	$ 12,761	$ 331,530	$ 240,120	$ 991,060	$ 430,370	$ 2,042,530			
870001		TW CNSTRCTN BACKCHARGE	1412	1414			1422	1424	1432	1434	1436	1440				100	PC	380	$ 10,000	$ 2,000	$ 570	$ 152,000	$ 165,000			
870002		TW CNSTRCTN RECOVERY												1480		60	PC	-	$ -	$ -	$ -	$ -	$ -			
870003		CONDON JOHNSON B/C	1412	1414			1422	1424	1432	1434	1436	1440				100	PC	240	$ 7,000	$ 29,000	$ 912,000	$ -	$ 950,000			
870004		CONDON JOHNSON REC										1440		1480		100	PC	-	$ -	$ -	$ -	$ -	$ -			
870005		CITY/KEYSTONE PROFILE	1412	1414			1422	1424	1432	1434	1436	1440				100	PC	4	$ 310	$ -	$ 130	$ -	$ 440			
870006		CITY/KEYSTONE RECOVERY												1480		0	PC	-	$ -	$ -	$ -	$ -	$ -			
880000	*	****INSURANCE****														40	MO	-	$ -	$ -	$ -	$ -	$ -			
880001			1412	1414			1422	1424	1432	1434	1436	1440		1480		100	PC	-	$ -	$ -	$ -	$ -	$ -			
880002			1412	1414			1422	1424	1432	1434	1436	1440		1480		100	PC	-	$ -	$ -	$ -	$ -	$ -			
880003			1412	1414			1422	1424	1432	1434	1436	1440		1480		100	PC	-	$ -	$ -	$ -	$ -	$ -			
890000	*	****PAYROLL BURDEN****														0	MO	-	$ -	$ -	$ -	$ -	$ -			
892000	*	PAYROLL TAXES			1416											0	M$	-	$ -	$ -	$ -	$ -	$ -			
894000	*	SALARY BENEFITS			1416						1436					0	MO	-	$ -	$ -	$ -	$ -	$ -			
894100		SALARY BENEFITS			1416											0	M$	-	$ -	$ -	$ -	$ -	$ -			
895000	*	OTHER BENEFITS			1416											0	QM	-	$ -	$ -	$ -	$ -	$ -			
895100		OTHER BENEFITS			1416											0	M$	-	$ -	$ -	$ -	$ -	$ -			
896000	*	PUBLIC LIABILITY			1416											0	M$	-	$ -	$ -	$ -	$ -	$ -			
896100					1416											0		-	$ -	$ -	$ -	$ -	$ -			
897000	*	EE DEVELOPMENT			1416											0	MH	-	$ -	$ -	$ -	$ -	$ -			
898000	*	BUILDERS RISK PRE			1416											0	M$	-	$ -	$ -	$ -	$ -	$ -			
899000	*	WORKERS COMP PREM			1416											0	M$	-	$ -	$ -	$ -	$ -	$ -			
899100					1416											0		-	$ -	$ -	$ -	$ -	$ -			

9.16 Appendix P: Survey Results

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Model-based quantity collection and control

1. Introduction

This survey is part of research conducted by Professor Martin Fischer investigating model-based quantity collection and control. Prior to becoming a research assistant, I was a field engineer on large civil projects for two years and prior to that a highway laborer for four years. During this time as a laborer and then field engineer, I developed an interest in both improving field working conditions and improving accuracy and precision in the collection process of actual progress measurements. I believe these two topics are closely related.

This survey validates the results of a previous questionnaire through a larger sample size and one additional question regarding cost coding. If you are interested in the results of the prior study, please contact me for the draft publication.

This topic can be controversial due to resistance to innovation, historical project data confidentiality and general protection of professional knowledge. I understand and respect these issues.

With your input, you will help to create a more accurate and precise quantities collection process that will benefit you with better information for your decision-making. Please forward this survey to others you know who have expertise or an interest in this topic.

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Model-based quantity collection and control

2. Company Information:

1. Company name (optional)

[ ]

2. Industry type (select option that best fits with your experience)

- [ ] Building
- [ ] Heavy and Light Industrial
- [ ] Heavy Civil / Infrastructure
- [ ] Mechanical/Electrical/Plumbing
- [ ] Recycle/Waste Management
- [ ] Mining
- [ ] Timber
- [ ] Agriculture
- [ ] Commercial Airline Mfg.
- [ ] Ship Building
- [ ] Medical Care (i.e., nursing)
- [ ] Process Manufacturing
- [ ] Petroleum Extraction
- [ ] Railroad
- [ ] Software
- [ ] Engineering
- [ ] Government
- [ ] Utilities
- [ ] Facilities Maintenance

Other (please specify)

[ ]

3. What type of company is this (select all that apply)

- [ ] Academic / Research
- [ ] Designer (classify in comment box)
- [ ] Consultant (classify in comment box)
- [ ] Owner
- [ ] Construction Manager
- [ ] General Contractor
- [ ] General Engineering
- [ ] Subcontractor / Self-Performed Work

Other (please specify)

[ ]

4. Your professional background

- [ ] Trades
- [ ] Engineer
- [ ] Technician
- [ ] Professional Degree

Other (please specify)

5. Additional background information, e.g., years of experience

6. Your role in the organization

- [ ] Employee
- [ ] Management
- [ ] Senior Management

Title

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Model-based quantity collection and control

3. Quantity Tracking Methods:

1. Data collection methods: standard procedure or as best suits data collector

2. Commercial software you use to collect either field production or project planning quantities (check all that apply, if you select a generic software tool at bottom of list then give software name in comment box)

- [ ] ABB
- [ ] Rockwell
- [ ] SAP
- [ ] HCSS
- [ ] Oracle JD Edwards
- [ ] Computer Guidance
- [ ] Excel
- [ ] Trimble
- [ ] Honeywell
- [ ] IbisTRAD
- [ ] CMiC
- [ ] Amer. Cont.
- [ ] BMC
- [ ] Epic
- [ ] WinCan
- [ ] Meridian Proliance
- [ ] Prolog
- [ ] Sokkia
- [ ] Maximo
- [ ] On-screen Takeoff (OST)
- [ ] SimVision
- [ ] GoLabor
- [ ] Sharpe
- [ ] OSISoft
- [ ] Statistica
- [ ] Surfer
- [ ] ArcView
- [ ] MineSight
- [ ] Downhole Explore
- [ ] MapInfo
- [ ] Primavera Expedition
- [ ] MINCOM ellipse
- [ ] Penta
- [ ] Digital Project (CATIA)
- [ ] Delmia
- [ ] CoGo
- [ ] Google earth
- [ ] Leica Geosystems Cyclone
- [ ] LPile
- [ ] Slope/W
- [ ] Vela Systems
- [ ] Primavera P3/5/6
- [ ] Innovaya
- [ ] Tocoman
- [ ] AGTEK
- [ ] MC2
- [ ] Sage-Timberline
- [ ] Hummingbird
- [ ] RSMeans
- [ ] Vico Control
- [ ] Microsoft Project
- [ ] Building Explorer
- [ ] Vico 5D
- [ ] Oracle Project
- [ ] Bentley Construct Sim
- [ ] CommonPoint
- [ ] Navisworks
- [ ] Product model software tool (not listed above)
- [ ] Scope software tool (not listed above)
- [ ] Cost software tool (not listed above)
- [ ] Time software tool (not listed above)
- [ ] Quality software tool (not listed above)
- [ ] 4D model software tool
- [ ] Integration software tool (not listed above)
- [ ] Automation Software Tool (not listed above)
- [ ] Enterprise Resource Management (ERM) (not listed above)
- [ ] Electronic Data Interchange (EDI) (not listed above)
- [ ] none

Other (please specify)

3. Custom or in-house software you use, name and short description

4. Electronic methods of collection (check all that apply)

- ☐ Global Positioning System (GPS)
- ☐ Radio-frequency Identification (RFID)
- ☐ 3D-imaging (LADAR or Digital Imaging)
- ☐ Electronic Invoice
- ☐ On-board Sensors (OBS)
- ☐ Optical Character Recognition (OCR)
- ☐ Hand Held Computer (HHC), e.g., laptop
- ☐ Barcode
- ☐ Building Information Model (BIM) or (PIM)
- ☐ Total station
- ☐ Recipe Formulas
- ☐ none
- ☐ other sensors (describe below)

Other (please specify)

5. Manual methods of collection (check all that apply)

- ☐ Sight
- ☐ Tape
- ☐ Wheel
- ☐ Plan take-off
- ☐ Invoice
- ☐ Foreman diary
- ☐ Scale
- ☐ Count
- ☐ Calculator
- ☐ Load count
- ☐ Survey

Other (please specify)

6. Electronic methods of recording (check all that apply)

- ☐ Automated System
- ☐ Data-logger
- ☐ Digital file
- ☐ Manual key

Other (please specify)

7. Paper-based methods of recording (check all that apply)

- [ ] Paper notepad
- [ ] Temporary forms (created to meet specific need, might not be reused)
- [ ] Standard form

Other (please specify)

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4. Data Collection:

1. Reason for data collection (check all that apply)

- [ ] Billing
- [ ] Cost forecast
- [ ] Resource forecast
- [ ] Production
- [ ] Mass balance
- [ ] Quality control
- [ ] Community impact
- [ ] Historical library
- [ ] Maintenance
- [ ] Schedule forecast
- [ ] Government regulation
- [ ] Earned Value Management (EVM)

Other (please specify)

2. What is quantified (check all that apply)

- [ ] unit
- [ ] volume
- [ ] type
- [ ] location
- [ ] length
- [ ] cash / cost
- [ ] time
- [ ] area
- [ ] weight
- [ ] labor

Other (please specify)

3. Number of individual items quantified

- [ ] 0
- [ ] 1-10
- [ ] 10's
- [ ] 100's
- [ ] 1,000's
- [ ] unknown
- [ ] na

Other (please specify), if it varies check best answer and define the independent variable, i.e., what it depend on

4. what are your units of measurement and are these consistent between measured and reported

5. Scale of quantities, approximate monthly total

- [ ] 0
- [ ] 10's
- [ ] 100's
- [ ] 1,000's
- [ ] 100,000's
- [ ] unknown
- [ ] na

Other (please specify), if it varies check best answer and define the independent variable, i.e., what it depend on

6. Number of staff required to track the above quantities

- [ ] 0
- [ ] 1-3
- [ ] 4-6
- [ ] 7-10
- [ ] 10's
- [ ] unknown
- [ ] na

Other (please specify), if it varies check best answer and define the independent variable, i.e., what it depend on

7. Importance placed on accuracy

☐ Low ☐ Medium ☐ High

☐ Very high

Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on

8. Level of detail in acquisition

☐ Low ☐ Medium ☐ High

☐ na

Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on

9. Number of items quantity is typically / sometimes estimated

☐ 0 ☐ 10% ☐ 25% ☐ 50% ☐ 75% ☐ unknown

☐ na

Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on. Also, provide the method used to estimate the quantity, e.g., unit cost, % of time, % of cost, guess

10. Percent accuracy in any typical data set

☐ +/- 50% ☐ +/- 40% ☐ +/- 30% ☐ +/- 20% ☐ +/- 10% ☐ unknown

☐ na

Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on

11. What is the source of classification miscodes

- [ ] random type errors
- [ ] knowledge of codes
- [ ] complexity of codes
- [ ] insufficient labor resources
- [ ] missing contextual information for classification

Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on

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5. What Can be Done Better:

1. Areas you think need improvement

2. Your vision for the role of technology or improved methods in your field

3. What is your view of activity codes and cost codes (in general any classification / identification code) accuracy, i.e., miscodes

Q1 Company name (optional)

Answered: 111 Skipped: 64

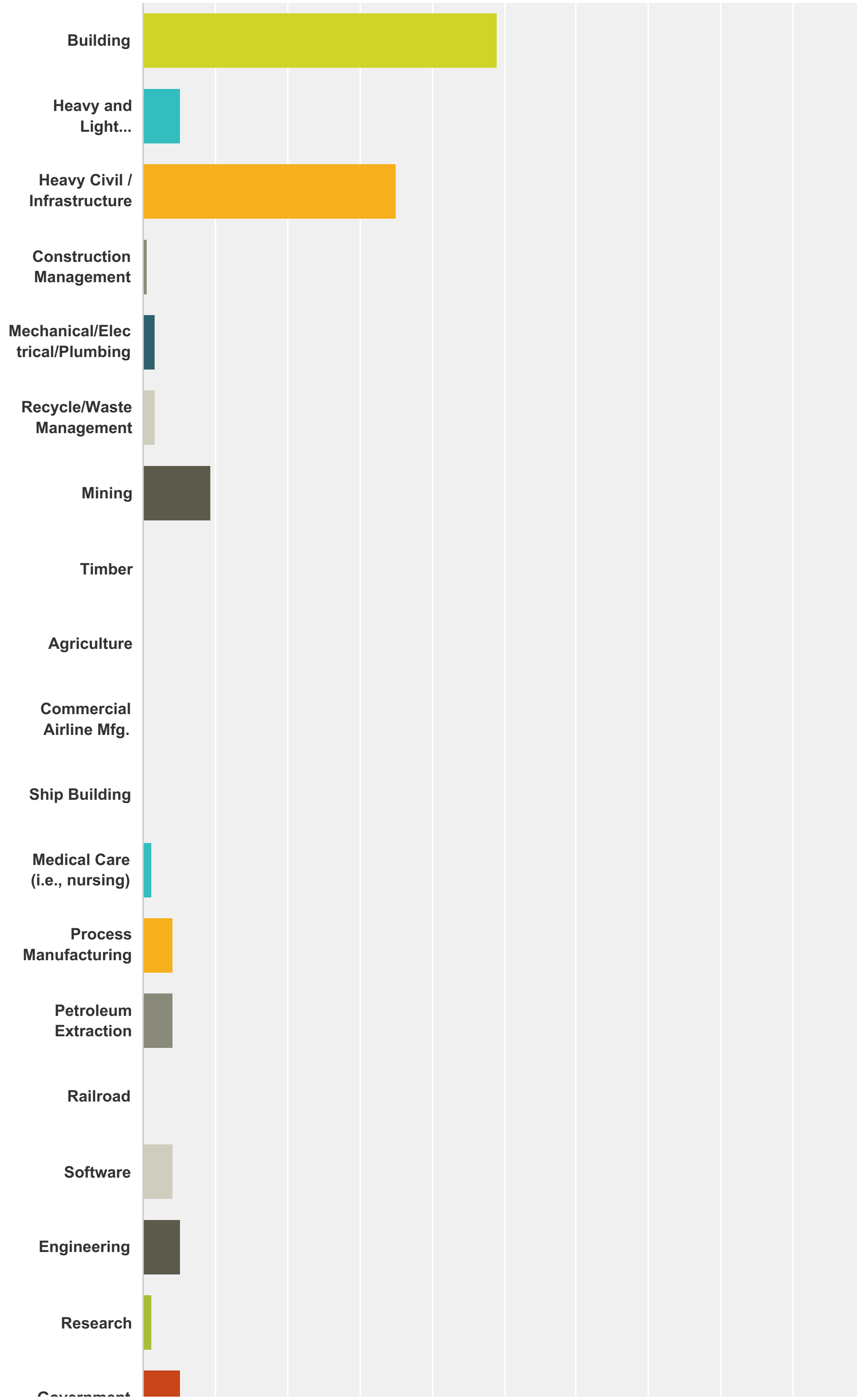
#	Responses	Date
1	Silicon Valley Land Surveying, Inc.	3/12/2009 12:07 PM
2	Vegter Excavating	3/3/2009 8:04 PM
3	Icomas	1/30/2009 5:15 PM
4	Kiewit Mining Group	1/30/2009 5:05 PM
5	Teck Cominco Ltd	1/30/2009 5:04 PM
6	Teck Cominco Ltd	1/30/2009 5:03 PM
7	DPR Construction	1/30/2009 3:05 PM
8	Anovation International	1/30/2009 3:05 PM
9	Cobb, Fendley & Associates	1/30/2009 3:05 PM
10	Teck Cominco Limited	1/30/2009 3:05 PM
11	Granite Construction	1/30/2009 3:04 PM
12	PCL Construction	1/30/2009 3:04 PM
13	Golden Gate Recycling & Disposal, Sunset Scavenger / NorCal Waste Inc.	1/30/2009 3:03 PM
14	Granite Rock	1/30/2009 3:03 PM
15	Aera Energy, LLC	1/30/2009 3:03 PM
16	Aviles Engineering Corp.	1/30/2009 3:03 PM
17	Fluor	1/30/2009 3:02 PM
18	UCSF	1/30/2009 3:02 PM
19	Integral Vision	1/30/2009 3:02 PM
20	Hensel Phelps Construction Co.	1/30/2009 3:02 PM
21	bentley management group	1/30/2009 3:01 PM
22	adroitec Information systems Limited	1/30/2009 3:01 PM
23	Bechtel Corporation	1/30/2009 3:01 PM
24	City of Pueblo	1/30/2009 3:01 PM
25	Stanford University	1/30/2009 3:00 PM
26	Burken Ltd	1/30/2009 3:00 PM
27	Mortenson Construction	1/30/2009 3:00 PM
28	County Sanitation Districts of Los Angeles County	1/30/2009 3:00 PM
29	Gehry Technolgies - GT Asia Limited Hong Kong	1/30/2009 3:00 PM
30	Walbridge	1/30/2009 2:59 PM
31	Skanska USA Building	1/30/2009 2:59 PM
32	Fluor Corporation	1/30/2009 2:59 PM
33	Skanska	1/30/2009 2:59 PM
34	Senate Properties	1/30/2009 2:58 PM
35	Consulting Engineering Company in Construction management	1/30/2009 2:58 PM

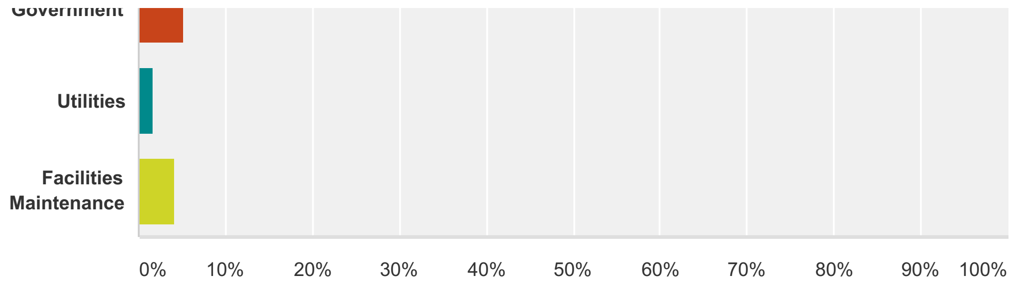
36	Traylor Bros., Inc	1/30/2009 2:58 PM
37	Huntington's Disease Society of America, Inc.	1/30/2009 2:32 PM
38	Werner engineering	1/30/2009 2:31 PM
39	Digital Alchemy, Inc.	1/30/2009 2:31 PM
40	Reed Construction Data - RS Means	1/30/2009 2:31 PM
41	Vela Systems	1/30/2009 2:30 PM
42	Cyon Research Corporation	1/30/2009 2:30 PM
43	Reed Construction Data	1/30/2009 2:30 PM
44	McCarthy Building Companies, Inc.	1/30/2009 2:27 PM
45	Stanford National Accelerator Laboratory	1/30/2009 2:26 PM
46	DPR Construction, Inc.	1/30/2009 2:26 PM
47	URS Corp	1/30/2009 2:25 PM
48	Slavenburg	1/30/2009 2:25 PM
49	Swinerton	1/30/2009 2:24 PM
50	URS-Washington Division	1/30/2009 2:24 PM
51	Plant Constrcution Company	1/30/2009 2:24 PM
52	Rudolph and Sletten, Inc.	1/30/2009 2:23 PM
53	gkkworks	1/30/2009 2:22 PM
54	Fluor	1/30/2009 2:22 PM
55	Arup	1/30/2009 2:21 PM
56	RQ Construction	1/30/2009 2:21 PM
57	Webcor Builders	1/30/2009 2:20 PM
58	US Coast Guard	1/30/2009 2:20 PM
59	CH2M Hill	1/30/2009 2:19 PM
60	Thiess Pty Ltd	1/30/2009 2:12 PM
61	Mortenson Construction	1/30/2009 2:12 PM
62	NCC Construction Sverige AB	1/30/2009 2:09 PM
63	City and County of San Francisco	1/30/2009 2:06 PM
64	Tampere University Hospital, Finland, Europe	1/30/2009 2:06 PM
65	Swinerton Builders	1/30/2009 2:05 PM
66	Shaw Group	1/30/2009 2:04 PM
67	Hunt Construction Group Inc.	1/30/2009 2:03 PM
68	Webcor	1/30/2009 2:02 PM
69	CH2M Hill	1/30/2009 1:59 PM
70	Sundt Construction, Inc.	1/30/2009 1:58 PM
71	Butler County Water and Sewer	1/22/2009 5:26 PM
72	Optira, Inc.	1/22/2009 5:23 PM
73	Legg, Inc.	1/22/2009 4:51 PM
74	The Herrick Corporation	1/22/2009 4:50 PM
75	Critchfield Mechanical Inc	1/22/2009 4:37 PM
76	GRANITE CONSTRUCTION	1/11/2009 12:08 PM

77	Walt Disney Imagineering	1/10/2009 5:40 PM
78	Colorado Department of Transportation, Staff Bridge Design	1/10/2009 5:34 PM
79	VECOVICA Venezuelan Housing Construction C.A	1/10/2009 5:20 PM
80	GSA	1/10/2009 5:19 PM
81	CCC	1/10/2009 5:09 PM
82	J.F. Shea construction, Inc.	1/10/2009 4:46 PM
83	Carillion Plc	1/10/2009 4:40 PM
84	Ferrovial	1/10/2009 4:34 PM
85	Graniterock	1/10/2009 4:33 PM
86	Granite Construction Company	1/10/2009 4:32 PM
87	Shimmick Construction Company, Inc	1/10/2009 4:32 PM
88	William P. Young Construction, Inc.	1/10/2009 4:31 PM
89	Russell G. Clough Co.	1/10/2009 4:31 PM
90	Granite Construction	1/10/2009 4:22 PM
91	Traylor Bros	1/10/2009 4:04 PM
92	Stanford	1/8/2009 7:03 PM
93	Elcometer Limited	1/8/2009 6:36 PM
94	decline	1/8/2009 6:35 PM
95	Teck Cominco	1/8/2009 6:28 PM
96	J. W. Ebert Corp.-small underground contractor	1/8/2009 6:26 PM
97	City of Reno	1/8/2009 6:15 PM
98	NovaGold Resources Inc.	1/8/2009 5:56 PM
99	Charles Pankow Builders LTD.	1/8/2009 5:02 PM
100	Swinerton Builders	1/8/2009 4:35 PM
101	GreenVolts	1/8/2009 4:16 PM
102	STV Inc	1/8/2009 4:11 PM
103	Walbridge	1/8/2009 3:24 PM
104	CobbFendley	1/8/2009 3:15 PM
105	HUGHSON NUT,INC	1/8/2009 3:13 PM
106	Elting Northwest, Inc.	1/8/2009 3:04 PM
107	DCStrategies	1/8/2009 2:37 PM
108	a Chinese GC	1/8/2009 2:19 PM
109	Bill Maddex	1/8/2009 2:18 PM
110	Farnsworth Group, Inc.	1/8/2009 2:12 PM
111	Sundt Construction	1/8/2009 2:06 PM

Q2 Industry type (select option that best fits with your experience)

Answered: 171 Skipped: 4





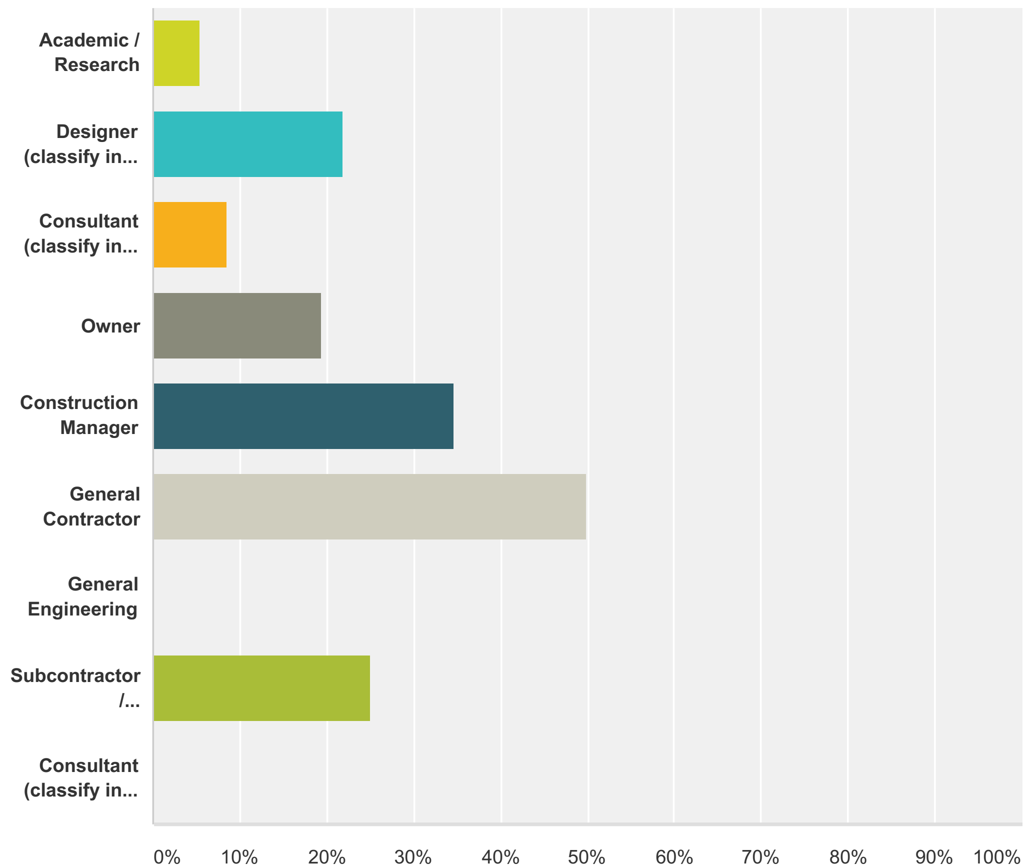
Answer Choices	Responses	
Building	**49.12%**	84
Heavy and Light Industrial	**5.26%**	9
Heavy Civil / Infrastructure	**35.09%**	60
Construction Management	**0.58%**	1
Mechanical/Electrical/Plumbing	**1.75%**	3
Recycle/Waste Management	**1.75%**	3
Mining	**9.36%**	16
Timber	**0.00%**	0
Agriculture	**0.00%**	0
Commercial Airline Mfg.	**0.00%**	0
Ship Building	**0.00%**	0
Medical Care (i.e., nursing)	**1.17%**	2
Process Manufacturing	**4.09%**	7
Petroleum Extraction	**4.09%**	7
Railroad	**0.00%**	0
Software	**4.09%**	7
Engineering	**5.26%**	9
Research	**1.17%**	2
Government	**5.26%**	9
Utilities	**1.75%**	3
Facilities Maintenance	**4.09%**	7
Total Respondents: 171		

#	Other (please specify)	Date
1	land and engineering surveys for design and as-built	3/12/2009 12:07 PM
2	Mining Facilities (FP)	1/30/2009 5:04 PM
3	Chemicals, Energy, Metals, BioPharma (FP)	1/30/2009 3:02 PM
4	Power Petroleum facilities (FP)	1/30/2009 3:01 PM
5	Petroleum and mining facilities (FP)	1/30/2009 3:01 PM

6	Roads and bridges (FP)	1/30/2009 3:00 PM
7	finance	1/30/2009 2:31 PM
8	petroleum and mining facilities (FP)	1/30/2009 2:24 PM
9	medical and manufacturing facilities (FP)	1/30/2009 2:23 PM
10	Education, government and healtchare facilities (FP)	1/30/2009 2:22 PM
11	petroleum and mining facilities (FP)	1/30/2009 2:22 PM
12	medical facilities (FP)	1/30/2009 2:20 PM
13	Medical Facilities (FP)	1/30/2009 2:18 PM
14	representing a transportation department on its highway, rail and facilities projects (FP)	1/30/2009 2:14 PM
15	Medical Facilities (FP)	1/30/2009 2:06 PM
16	Safety	1/22/2009 5:28 PM
17	Water and Sewer (FP)	1/22/2009 5:26 PM
18	3D imaging as-builds (FP)	1/22/2009 5:23 PM
19	transportation (FP)	1/22/2009 4:51 PM
20	Detention Equipment Contractor (FP)	1/22/2009 4:51 PM
21	Structural Steel Fabrication and Erection (FP)	1/22/2009 4:50 PM
22	Entertainment	1/10/2009 5:40 PM
23	Petroleum and mining facilities (FP)	1/10/2009 5:09 PM

Q3 What type of company is this (select all that apply)

Answered: 164 Skipped: 11



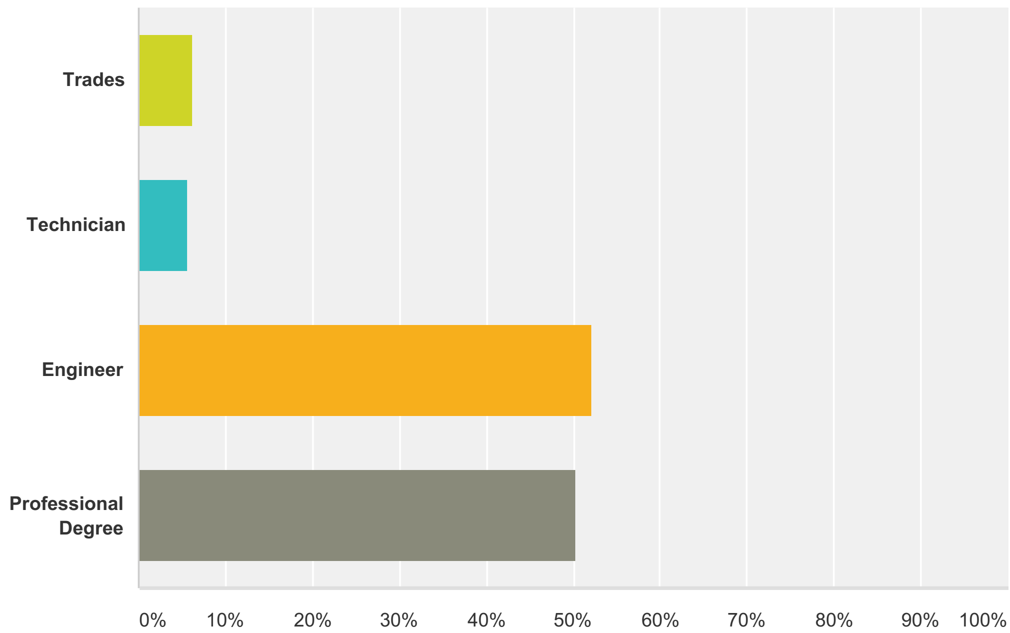
Answer Choices	Responses	
Academic / Research	**5.49%**	9
Designer (classify in comment box)	**21.95%**	36
Consultant (classify in comment box)	**8.54%**	14
Owner	**19.51%**	32
Construction Manager	**34.76%**	57
General Contractor	**50.00%**	82
General Engineering	**0.00%**	0
Subcontractor / Self-Performed Work	**25.00%**	41
Consultant (classify in comment box)	**0.00%**	0
Total Respondents: 164		

#	Other (please specify)	Date
1	engineering surveying are ofetn classified as both consulting and subcontractor	3/12/2009 12:07 PM

2	survey	1/30/2009 3:05 PM
3	Procurement	1/30/2009 3:02 PM
4	engineering and KPO for BIM	1/30/2009 3:01 PM
5	Building Information Model (BIM)	1/30/2009 3:00 PM
6	We provide EPCM services	1/30/2009 2:59 PM
7	Engineering - Construction Management	1/30/2009 2:58 PM
8	Non-Profit	1/30/2009 2:32 PM
9	North American construction industry Cost Data	1/30/2009 2:31 PM
10	strategy	1/30/2009 2:30 PM
11	Mobile field software	1/30/2009 2:30 PM
12	software and strategy	1/30/2009 2:30 PM
13	data and software	1/30/2009 2:30 PM
14	Construction-specific software	1/30/2009 2:30 PM
15	Design / Build	1/30/2009 2:19 PM
16	University hospital	1/30/2009 2:06 PM
17	Design/Build	1/30/2009 1:59 PM
18	Hospital	1/10/2009 5:41 PM
19	Project Management	1/10/2009 5:40 PM
20	Technology	1/10/2009 5:38 PM
21	State Highways	1/10/2009 5:34 PM

Q4 Your professional background

Answered: 159 Skipped: 16



Answer Choices	Responses	
Trades	**6.29%**	10
Technician	**5.66%**	9
Engineer	**52.20%**	83
Professional Degree	**50.31%**	80
Total Respondents: 159		

#	Other (please specify)	Date
1	Licensed Land Surveyor/Geomatic Engineer	3/12/2009 12:07 PM
2	MS Construction Institute Stanford	1/30/2009 3:02 PM
3	Project Manager	1/30/2009 2:59 PM
4	Development	1/30/2009 2:32 PM
5	a BS	1/30/2009 2:31 PM
6	Non-Engineering College Degree, Construction Technology background	1/30/2009 2:26 PM
7	Financial Planning	1/30/2009 2:21 PM
8	Developer of project controls solutions	1/30/2009 2:19 PM
9	Economist	1/30/2009 2:08 PM
10	Masters Materials Engineering	1/30/2009 2:06 PM
11	Bachelor's	1/22/2009 5:28 PM
12	Construction Management	1/22/2009 4:51 PM
13	Professional Engineer.	1/22/2009 4:37 PM

14	Registered Nurse	1/10/2009 5:41 PM
15	Architect	1/10/2009 5:38 PM
16	architect	1/10/2009 5:19 PM
17	Student	1/8/2009 4:10 PM
18	What is a professional degree? I have two degrees, one Bachelors and one doctorate	1/8/2009 3:00 PM
19	intern	1/8/2009 2:19 PM
20	Architect	1/8/2009 2:11 PM
21	Mechanical engineer - originally concentration was in aerospace.	1/8/2009 2:08 PM
22	MSME, PE	1/8/2009 2:06 PM

Q5 Additional background information, e.g., years of experience

Answered: 131 Skipped: 44

#	Responses	Date
1	20+	3/12/2009 12:07 PM
2	2 3 Month Internships	3/3/2009 8:04 PM
3	12	2/6/2009 6:02 AM
4	18 years construction experience 11 years academic experience	1/30/2009 5:15 PM
5	Project Development, Technical Management	1/30/2009 5:04 PM
6	Project Development, Technical Management	1/30/2009 5:03 PM
7	16 years experience with Professional Engineering License	1/30/2009 3:05 PM
8	34 years	1/30/2009 3:05 PM
9	-Field Engineer on multiple reconstructs & underground jobs <$5 millions -Project engineer on $90 million site development -Project engineer on $100 million airport design build (current)	1/30/2009 3:04 PM
10	10 years	1/30/2009 3:04 PM
11	35 years	1/30/2009 3:04 PM
12	BA mathematics/computer science; MBA Stanford	1/30/2009 3:03 PM
13	24 years	1/30/2009 3:03 PM
14	25+	1/30/2009 3:02 PM
15	33+ years	1/30/2009 3:02 PM
16	20 years	1/30/2009 3:02 PM
17	CCE, CCM, PMP, LEED ap	1/30/2009 3:01 PM
18	18 years	1/30/2009 3:01 PM
19	10 yrs	1/30/2009 3:01 PM
20	36 years experience	1/30/2009 3:01 PM
21	+25 years	1/30/2009 3:01 PM
22	15	1/30/2009 3:01 PM
23	6-7 relevant years of experience in the Credit Card Industry, Financial Institution and Consulting	1/30/2009 3:00 PM
24	15 years in electrical engineering, 5 years in civil engineering	1/30/2009 3:00 PM
25	15 years of experience 10 years of experience with VDC	1/30/2009 3:00 PM
26	28 yrs experience	1/30/2009 3:00 PM
27	25 years	1/30/2009 3:00 PM
28	30+	1/30/2009 2:59 PM
29	20 year construction	1/30/2009 2:59 PM
30	35	1/30/2009 2:59 PM
31	15 years	1/30/2009 2:59 PM
32	42	1/30/2009 2:58 PM
33	11	1/30/2009 2:58 PM
34	Fifteen years working with development, membership, education and fundraising.	1/30/2009 2:32 PM

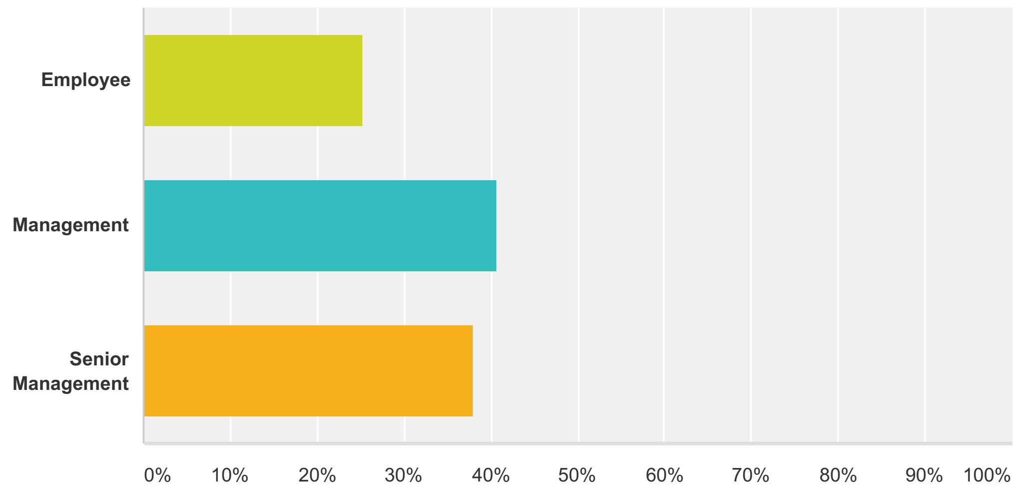
35	8 yrs	1/30/2009 2:31 PM
36	Forty-five years of hands-on field and office engineering and consulting to primarily construction companies; registered civil, structural and geotechnical engineer, incl. many other states besides Calif.	1/30/2009 2:31 PM
37	30 years	1/30/2009 2:31 PM
38	35+ years experience	1/30/2009 2:30 PM
39	B.Arch Cornell, MDES PM Harvard	1/30/2009 2:30 PM
40	Extensive	1/30/2009 2:30 PM
41	In AEC? 7	1/30/2009 2:30 PM
42	30 years construction software experience	1/30/2009 2:30 PM
43	8 months	1/30/2009 2:27 PM
44	6 years in design and construction of heavy civil construction.	1/30/2009 2:26 PM
45	16 years	1/30/2009 2:26 PM
46	30 years	1/30/2009 2:25 PM
47	4 years	1/30/2009 2:25 PM
48	30 years	1/30/2009 2:24 PM
49	29 years	1/30/2009 2:24 PM
50	40	1/30/2009 2:24 PM
51	12 years	1/30/2009 2:23 PM
52	32 years experience in construction and construction management.	1/30/2009 2:23 PM
53	20 years in the design and construction industry.	1/30/2009 2:22 PM
54	12 yrs EPC Experience	1/30/2009 2:22 PM
55	15	1/30/2009 2:21 PM
56	26 Years in the construction business as President and CEO	1/30/2009 2:21 PM
57	30 years of Construction Managment	1/30/2009 2:20 PM
58	18 years of professional experience	1/30/2009 2:20 PM
59	10 years	1/30/2009 2:18 PM
60	10 years of experience as academia.	1/30/2009 2:16 PM
61	BS in Civil Engineering from UC Berkeley, MS in CEM from Stanford. 7 years experience as a construction superintendent/PM, and 13 years experience in CM industry, starting with a software firm and progressing to project controls manager.	1/30/2009 2:14 PM
62	23 years experience	1/30/2009 2:13 PM
63	8	1/30/2009 2:12 PM
64	12 years experience in Architectural and Construction Industry. VDC process lead in company - Denver VDC team leader	1/30/2009 2:12 PM
65	I graduated in 1973 and have been working in industry and academia ever since	1/30/2009 2:10 PM
66	14 yearsw of experience; Phd in construction engineering	1/30/2009 2:09 PM
67	Research background in construction management	1/30/2009 2:08 PM
68	35 yrs in construction industry LEED AP	1/30/2009 2:06 PM
69	15 years in hospital FM and constructing.	1/30/2009 2:06 PM
70	34 year experience in construction	1/30/2009 2:04 PM
71	26	1/30/2009 2:03 PM
72	5	1/30/2009 2:02 PM

73	10 years	1/30/2009 2:00 PM
74	16 years consulting, planning and developing project control solutions	1/30/2009 1:59 PM
75	12 years in commercial construction.	1/22/2009 5:28 PM
76	20 years of exp in project management	1/22/2009 5:26 PM
77	10+ years in 3D imaging and laser scanning	1/22/2009 5:23 PM
78	15 years in Commercial, Residential, Detention and Industrial Construction	1/22/2009 4:51 PM
79	20+ years	1/22/2009 4:50 PM
80	4 years experience	1/10/2009 5:41 PM
81	28 years of experience in this particular industry	1/10/2009 5:40 PM
82	25	1/10/2009 5:38 PM
83	30	1/10/2009 5:19 PM
84	20 years	1/10/2009 5:09 PM
85	18 years construction	1/10/2009 4:48 PM
86	15 years	1/10/2009 4:47 PM
87	34 years in tunnel construction in North America	1/10/2009 4:46 PM
88	25	1/10/2009 4:40 PM
89	2 years	1/10/2009 4:34 PM
90	17 years in construction industry	1/10/2009 4:32 PM
91	None prior	1/10/2009 4:32 PM
92	Been working for General Contractors for 26 years	1/10/2009 4:25 PM
93	20+ years	1/10/2009 4:25 PM
94	24 years bridge construction experience	1/10/2009 4:24 PM
95	10 years	1/10/2009 4:22 PM
96	11 yrs Mining and Tunneling	1/10/2009 4:04 PM
97	25+	1/9/2009 10:51 AM
98	20+ years	1/8/2009 7:03 PM
99	26 years in coatings and coating inspection and test	1/8/2009 6:36 PM
100	38 Years in forestry & aggregate, aphalt industry 14 years forestry, 24 years Sand, gravel & asphalt.	1/8/2009 6:35 PM
101	20 years experience	1/8/2009 6:28 PM
102	exp. 29	1/8/2009 6:26 PM
103	32 years	1/8/2009 6:15 PM
104	30 years experience	1/8/2009 5:56 PM
105	MS Construction Management	1/8/2009 4:35 PM
106	10+	1/8/2009 4:27 PM
107	1 Yr experience	1/8/2009 4:16 PM
108	38 years	1/8/2009 4:11 PM
109	18	1/8/2009 3:43 PM
110	18	1/8/2009 3:25 PM
111	25	1/8/2009 3:24 PM
112	40	1/8/2009 3:24 PM
113	24 years	1/8/2009 3:15 PM

114	26 years experience in the construction field, from estimating to project management, public and private, hospital, industrial, commericial, institutional	1/8/2009 3:12 PM
115	23 yrs	1/8/2009 3:04 PM
116	2 yrs in engineering field, 1 yr in academic field	1/8/2009 3:02 PM
117	20	1/8/2009 3:02 PM
118	Experience of what?	1/8/2009 3:00 PM
119	15 Years Experience	1/8/2009 2:54 PM
120	25	1/8/2009 2:46 PM
121	20	1/8/2009 2:37 PM
122	2-month field experience	1/8/2009 2:19 PM
123	30 years construction all types heavy civil. Presently with international engineering consultancy.	1/8/2009 2:18 PM
124	10 years experience	1/8/2009 2:12 PM
125	0ver 40 years combined	1/8/2009 2:10 PM
126	5 years of experience	1/8/2009 2:08 PM
127	17 years	1/8/2009 2:07 PM
128	25 years of CM & General Contracting	1/8/2009 2:06 PM
129	30 years	1/8/2009 2:06 PM
130	37	1/8/2009 2:05 PM
131	34	1/8/2009 2:03 PM

Q6 Your role in the organization

Answered: 174 Skipped: 1



Answer Choices	Responses	
Employee	25.29%	44
Management	40.80%	71
Senior Management	37.93%	66
Total Respondents: 174		

#	Title	Date
1	Principal	3/12/2009 12:07 PM
2	Intern	3/3/2009 8:04 PM
3	Supervisor Assistant	2/5/2009 2:02 PM
4	Supervisor Assistant	2/5/2009 12:35 PM
5	Associate partner	1/30/2009 5:15 PM
6	Area Manager	1/30/2009 5:05 PM
7	Sr. Manager - Projects	1/30/2009 5:04 PM
8	Sr. Manager - Projects	1/30/2009 5:03 PM
9	Executive Vice President	1/30/2009 3:05 PM
10	Vice President, Department Manager Utility Solutions	1/30/2009 3:05 PM
11	General Manager, Projects	1/30/2009 3:05 PM
12	Project Engineer	1/30/2009 3:04 PM
13	Project Manager	1/30/2009 3:04 PM
14	Construction Manager	1/30/2009 3:04 PM
15	Outside Sales Account Rep-Debris Box specific-Construction & Demo	1/30/2009 3:03 PM
16	President & CEO	1/30/2009 3:03 PM
17	Chief Engineer	1/30/2009 3:03 PM
18	Project Information Manager/Integrator	1/30/2009 3:02 PM

19	Assistant Vice Chancellor and Campus Architect	1/30/2009 3:02 PM
20	President & CEO	1/30/2009 3:02 PM
21	Project Manager	1/30/2009 3:02 PM
22	president	1/30/2009 3:01 PM
23	Director	1/30/2009 3:01 PM
24	Field Eng Manager	1/30/2009 3:01 PM
25	Construction Engineer	1/30/2009 3:01 PM
26	CEO	1/30/2009 3:00 PM
27	Director	1/30/2009 3:00 PM
28	Superintendent	1/30/2009 3:00 PM
29	Managing Director	1/30/2009 3:00 PM
30	Electrical and Control Systems product director	1/30/2009 2:59 PM
31	Manager, Project Controls	1/30/2009 2:59 PM
32	Executive Vice president - Area General Manger	1/30/2009 2:59 PM
33	Proejct Director	1/30/2009 2:59 PM
34	Design/VDC Manager	1/30/2009 2:59 PM
35	R&D Director	1/30/2009 2:58 PM
36	Past President	1/30/2009 2:58 PM
37	President	1/30/2009 2:58 PM
38	Development Director, Northern and Central CA, Northern NV.	1/30/2009 2:32 PM
39	Owner and chief engineer (P.E. Lic.)	1/30/2009 2:31 PM
40	Managing Director	1/30/2009 2:31 PM
41	Senior Engineer	1/30/2009 2:31 PM
42	Principal	1/30/2009 2:30 PM
43	Co-Founder	1/30/2009 2:30 PM
44	President & CEO	1/30/2009 2:30 PM
45	VP	1/30/2009 2:30 PM
46	Project Engineer	1/30/2009 2:27 PM
47	Associate Project Director for Civil Construction	1/30/2009 2:26 PM
48	Director of Preconstruction Technologies	1/30/2009 2:26 PM
49	VP	1/30/2009 2:25 PM
50	Head of R&D	1/30/2009 2:25 PM
51	Corp. Mgr. VD&C	1/30/2009 2:24 PM
52	V.P. - Infrastructure	1/30/2009 2:24 PM
53	Project Manager	1/30/2009 2:24 PM
54	VP,	1/30/2009 2:23 PM
55	Sr. VP Chief Estimator	1/30/2009 2:23 PM
56	constuction management group leader	1/30/2009 2:23 PM
57	Director of Business Development	1/30/2009 2:22 PM
58	Project Manager - Construction	1/30/2009 2:22 PM
59	Principal	1/30/2009 2:21 PM

60	President and CEO	1/30/2009 2:21 PM
61	Sr Vice President	1/30/2009 2:20 PM
62	software architect	1/30/2009 2:19 PM
63	Sr. Construction Manager	1/30/2009 2:18 PM
64	Deputy Program Manager - Program Controls	1/30/2009 2:14 PM
65	Senior Associate	1/30/2009 2:13 PM
66	CAD Manager	1/30/2009 2:12 PM
67	Integrated Construction Manager	1/30/2009 2:12 PM
68	Assistant Dean (Teaching and Learning)	1/30/2009 2:10 PM
69	Associate professor	1/30/2009 2:08 PM
70	Vice President	1/30/2009 2:07 PM
71	Green Building Coordinator	1/30/2009 2:06 PM
72	Constructor engineer	1/30/2009 2:06 PM
73	Mechanical / Electrical Superintendent	1/30/2009 2:05 PM
74	construction manager	1/30/2009 2:04 PM
75	Regional Manager	1/30/2009 2:03 PM
76	Project Manager	1/30/2009 2:02 PM
77	Software Architect	1/30/2009 1:59 PM
78	Safety Manager	1/22/2009 5:28 PM
79	Engineering and Construction Manager	1/22/2009 5:26 PM
80	Executive VP	1/22/2009 5:23 PM
81	Project Manager	1/22/2009 4:51 PM
82	Vice President	1/22/2009 4:37 PM
83	Est./Project Manager	1/11/2009 12:08 PM
84	Staff Nurse, RN	1/10/2009 5:41 PM
85	Chief Design and Project Delivery Executive	1/10/2009 5:40 PM
86	VP	1/10/2009 5:38 PM
87	Director	1/10/2009 5:20 PM
88	architect	1/10/2009 5:19 PM
89	Manager Coordination and Technical Studies Civil	1/10/2009 5:09 PM
90	Estimating Manager	1/10/2009 4:48 PM
91	District Engineer	1/10/2009 4:47 PM
92	Vice President/Chief Engineer	1/10/2009 4:46 PM
93	Project and Bid Manager	1/10/2009 4:40 PM
94	Station chief	1/10/2009 4:34 PM
95	President & CEO	1/10/2009 4:33 PM
96	Project manager for large design build projects	1/10/2009 4:32 PM
97	Intern – Project Engineer	1/10/2009 4:32 PM
98	Division President	1/10/2009 4:25 PM
99	President	1/10/2009 4:24 PM
100	Project Engineer	1/10/2009 4:04 PM

101	Project manager	1/8/2009 7:03 PM
102	Technical Support Manager	1/8/2009 6:36 PM
103	Chief Operating Officer	1/8/2009 6:28 PM
104	president	1/8/2009 6:26 PM
105	Sr. Civil Engineer	1/8/2009 6:15 PM
106	Operations Manager	1/8/2009 5:02 PM
107	Corporate Sustainability Manager	1/8/2009 4:35 PM
108	Communication manager	1/8/2009 4:27 PM
109	Project & Systems Engineer	1/8/2009 4:16 PM
110	Sr. Vice President	1/8/2009 4:11 PM
111	Research Assistant	1/8/2009 4:10 PM
112	Bus. Development	1/8/2009 3:25 PM
113	CFO	1/8/2009 3:24 PM
114	Sr. VP	1/8/2009 3:24 PM
115	Project Manager Supervisor	1/8/2009 3:12 PM
116	President	1/8/2009 3:04 PM
117	lecturer	1/8/2009 3:02 PM
118	Head of School	1/8/2009 3:00 PM
119	VP Operatrions	1/8/2009 2:54 PM
120	Director	1/8/2009 2:37 PM
121	assistant field engineer	1/8/2009 2:19 PM
122	Leader Construction Services Americas Region	1/8/2009 2:18 PM
123	Section Manager	1/8/2009 2:12 PM
124	Operations Engineer	1/8/2009 2:10 PM
125	Quality Control Manager	1/8/2009 2:07 PM
126	Area Manager	1/8/2009 2:06 PM
127	CEO, Retired	1/8/2009 2:06 PM
128	PROJECT MANAGER ESTIMATOR SURVEYOR	1/8/2009 2:05 PM
129	Project Manager	1/8/2009 2:02 PM

Q7 Data collection methods: standard procedure or as best suits data collector

Answered: 99 Skipped: 76

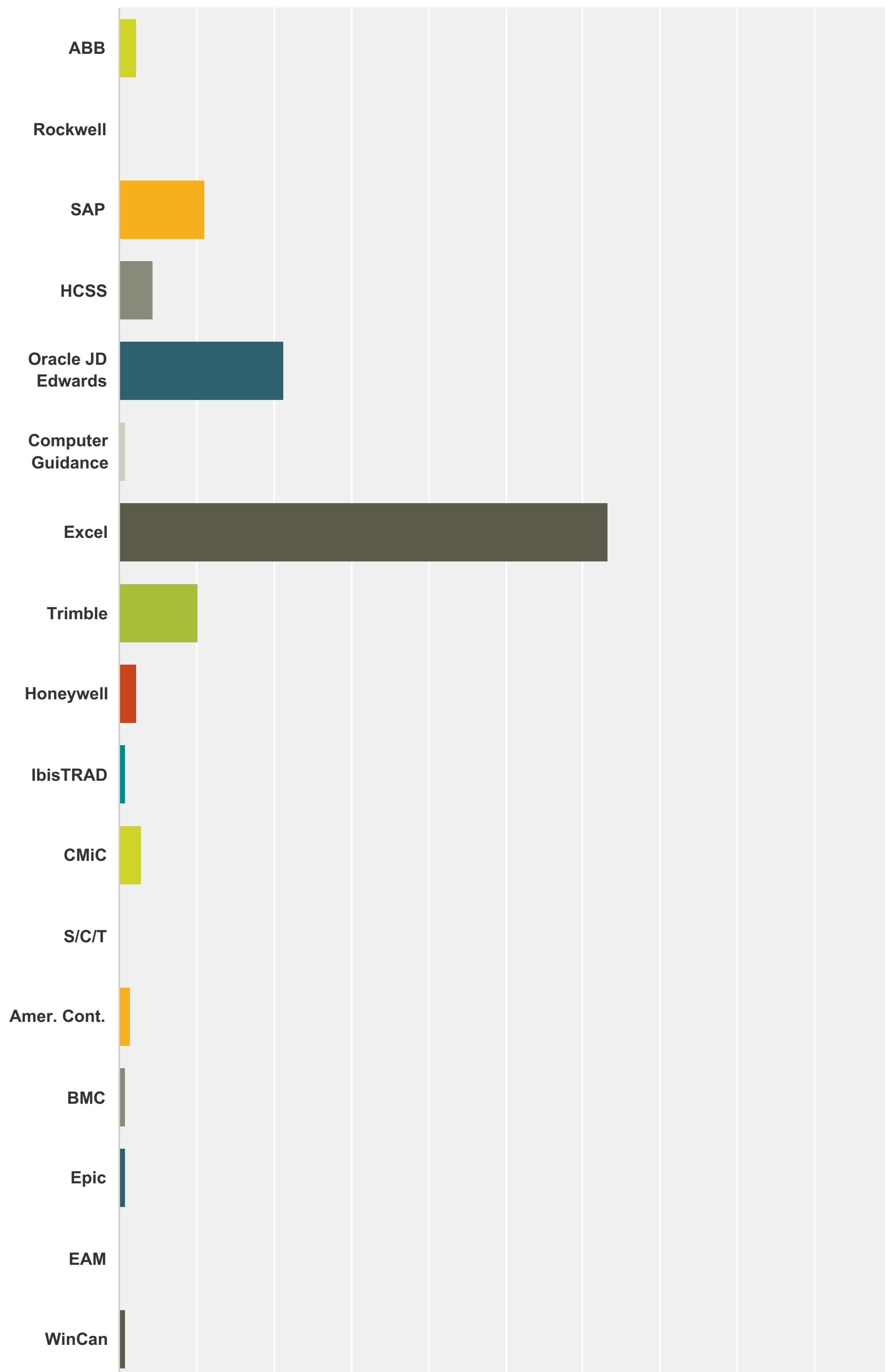
#	Responses	Date
1	various methods depending on the material and improvements to be quantified. Clients preferences may influence methods used. traditional total station, GPS and 3D laser scanners are all part of or usuall tool set.	3/12/2009 12:15 PM
2	Manual tickets along with Foundation software	3/3/2009 8:05 PM
3	Contractor was presenting the data to the owner, or the supervisor on behalf of the owner was attending the field, e.g. counting the rebar or inspecting the work.	2/5/2009 12:39 PM
4	standard procedure	1/30/2009 5:15 PM
5	Standard process	1/30/2009 3:05 PM
6	end user interviews	1/30/2009 3:05 PM
7	We have field survey data collection by field crews and we obtain aerial surveys from consultants.	1/30/2009 3:05 PM
8	On large projects, the procedure depends on the EPC or EPCM contractor's methodology. On smaller projects, Teck or its subsidiary company will resort to ad hoc methodology depending on the type of project and the execution methodology. For mine production, each operation develops its collection methodology for each unit production center. Quantity tracking in the mine, process plant and product sales have distinctly different needs.	1/30/2009 3:05 PM
9	Best suits data collector – different types of data collection needed depending on the type of work being quanitified	1/30/2009 3:04 PM
10	standard procedures	1/30/2009 3:04 PM
11	Standard procedure	1/30/2009 3:03 PM
12	Software, Databases, Spreadsheets	1/30/2009 3:03 PM
13	standard procedures	1/30/2009 3:03 PM
14	standard procedure in most cases	1/30/2009 3:02 PM
15	Handheld: Electromic Data Collection (EDC)	1/30/2009 3:02 PM
16	Engineers walk to observe progress and record quantity of work completed.	1/30/2009 3:02 PM
17	industry best practices	1/30/2009 3:02 PM
18	data collector	1/30/2009 3:01 PM
19	best suits data collector	1/30/2009 3:01 PM
20	Standardized based on commodity type code of accounts	1/30/2009 3:01 PM
21	standard procedures	1/30/2009 3:01 PM
22	Surveying	1/30/2009 3:01 PM
23	System software, use of spreadsheets, analytics from the areas	1/30/2009 3:00 PM
24	3D scanning from ground from air.	1/30/2009 3:00 PM
25	Varies by project	1/30/2009 3:00 PM
26	sewer inspection with CCTV. Sewer flow recorder by meter and down loaded to proprietary software. Other data collected manual and entered into EAM (Oracle JD Edwards)	1/30/2009 3:00 PM
27	as best suits data collector	1/30/2009 3:00 PM
28	standard procedures	1/30/2009 2:59 PM
29	best suits data collector	1/30/2009 2:59 PM
30	Standard practice	1/30/2009 2:59 PM
31	as best suits data collector	1/30/2009 2:59 PM

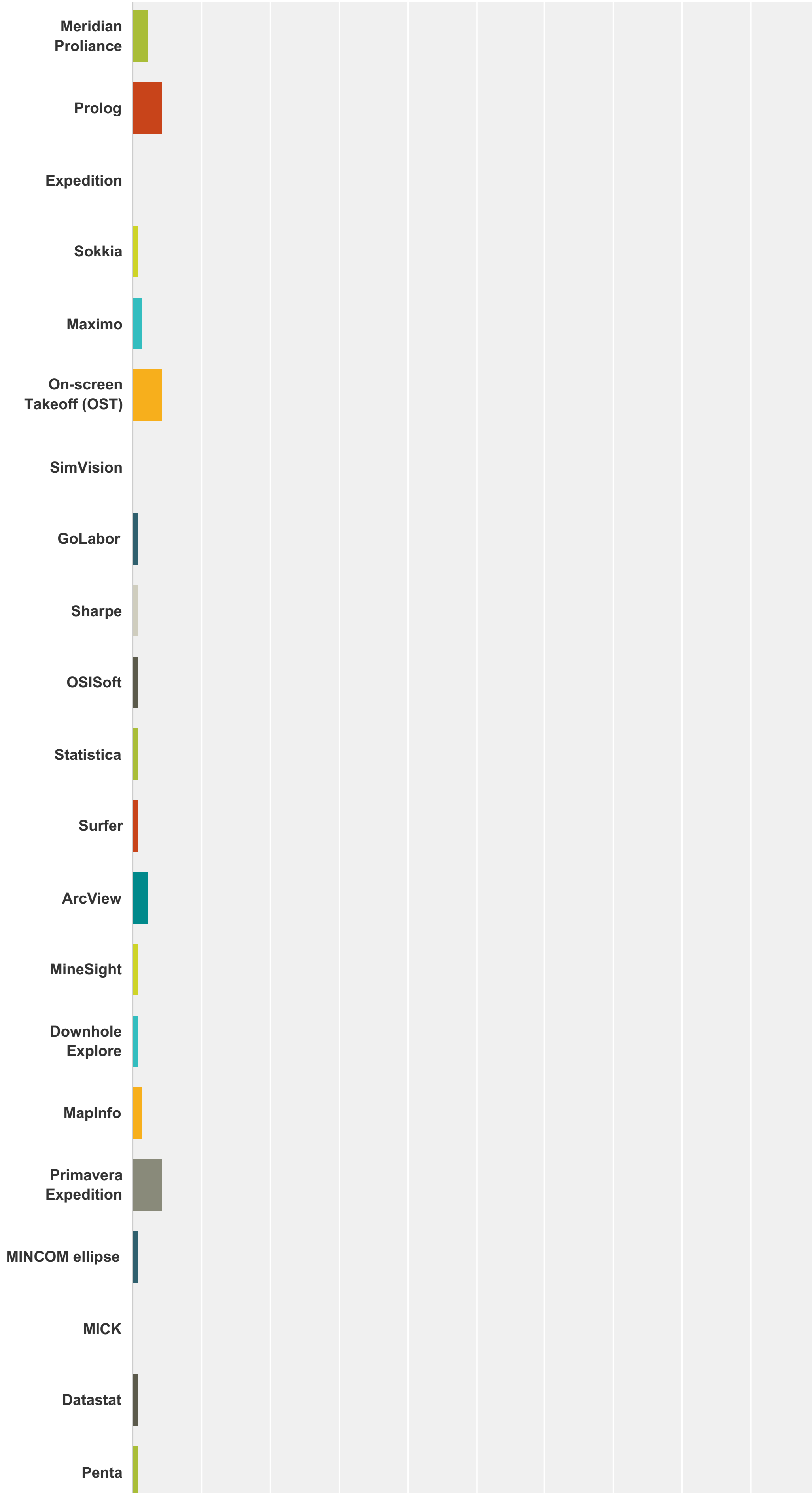
32	Field engineer tracks field quantities through field observations and spreadsheets. Data is input into our data processing system weekly and monthly depending on the quantity being tracked.	1/30/2009 2:58 PM
33	Direct Mail, Newsletters, Conferences	1/30/2009 2:32 PM
34	best suits	1/30/2009 2:31 PM
35	Visual observation, photographs, and manual as well as electronic survey data collection	1/30/2009 2:31 PM
36	Standard procedures	1/30/2009 2:31 PM
37	standard	1/30/2009 2:30 PM
38	Not applicable	1/30/2009 2:30 PM
39	I don't collect data	1/30/2009 2:30 PM
40	Some job site computers either with dedicated or intermittant connectivity, some handheld mobile devices.	1/30/2009 2:30 PM
41	Various - physical % complete is with P3 status of activities. financial data is based on the P3 status, processed with Oracle. Accounting and procurement are Peoplesoft based.	1/30/2009 2:26 PM
42	Specifically in regards to Model Based Quantity Collection	1/30/2009 2:26 PM
43	Budget vs Actual costs in ERP system (no very accurate)	1/30/2009 2:25 PM
44	Model based estimating	1/30/2009 2:25 PM
45	Use inspections in field	1/30/2009 2:24 PM
46	uncertain	1/30/2009 2:24 PM
47	both	1/30/2009 2:22 PM
48	standard procedures	1/30/2009 2:22 PM
49	Standard procedure	1/30/2009 2:21 PM
50	Standard cost code template is used to classify items of work. Propriatary tracking tool developed to track cost in field.	1/30/2009 2:19 PM
51	Construction inspectors measure and negotiate earned quantities on a monthly basis.	1/30/2009 2:14 PM
52	Survey, Issued from Deisgners and Planners	1/30/2009 2:12 PM
53	Outside research student from various Universities to collect metrics on use of VDC. Individual VDC team members track hours, conflicts found/resolved virtually, VDC integration duration along project timeline, productivity metrics on VDC based construction services vs. non-VDC projects	1/30/2009 2:12 PM
54	as best suits data collector	1/30/2009 2:05 PM
55	Company developed software (Shawtrac)	1/30/2009 2:04 PM
56	Standard procedure but adjust to client requirements	1/30/2009 2:03 PM
57	We use both methods depending on what type of data is being collected.	1/30/2009 2:02 PM
58	as best suits	1/30/2009 2:00 PM
59	Export quantities from models through Innovaya to MC2 or use OST to capture quantities to MC2. Upload MC2 estimate through Excel to JD Edwards. Field measure in place quantities and input into JD Edwards and Prolog.	1/30/2009 1:58 PM
60	Pen and paper. Input into laptop computer.	1/22/2009 5:28 PM
61	3D imaging - Laser scanning	1/22/2009 5:23 PM
62	surveyor subcontractor	1/22/2009 4:51 PM
63	Field Input	1/22/2009 4:51 PM
64	Standard procedure	1/22/2009 4:37 PM
65	non standard	1/11/2009 12:08 PM
66	standard procedure	1/10/2009 5:43 PM
67	Migrating over the next nine months to a standard procedure	1/10/2009 5:40 PM
68	We calculate quantities for design-bid-build contracts and include these approximate quantity estimates on the contract documents.	1/10/2009 5:34 PM

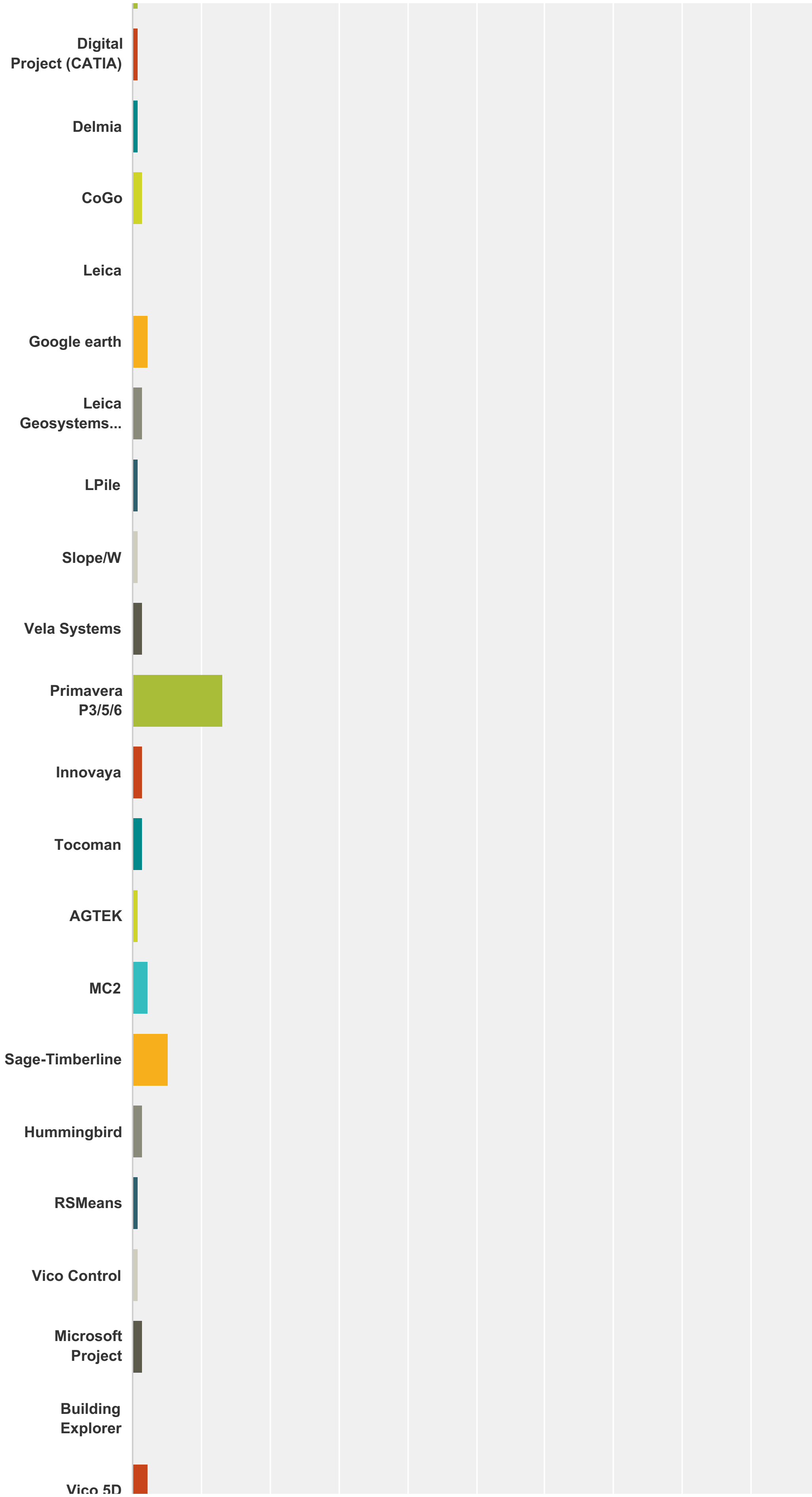
69	Spreadsheet schedule, spreadsheet cost control	1/10/2009 5:20 PM
70	?	1/10/2009 5:19 PM
71	projects provided and audits	1/10/2009 5:09 PM
72	Best Suits	1/10/2009 4:48 PM
73	Surveys, data loggers, PLC	1/10/2009 4:46 PM
74	Standard company procedures	1/10/2009 4:40 PM
75	Data collected by topographer (Theodolite and GPS)	1/10/2009 4:34 PM
76	Materials are tracked through a purchase order system. When items are received, the quantity received is checked vs. the purchase order. Because the price is already in the purchase order, receipt of materials stimulates recognition of cost applied to the project. Daily time records are tracked using wireless laptop computer software. Equipment used on the site (along with equipment hourly rates) and hours worked for each employee working on the project are tracked. Information is uploaded into the computer. We are beginning now to get accurate daily job cost reports.	1/10/2009 4:33 PM
77	Standard procedure, units for tracking were outlined in estimate	1/10/2009 4:32 PM
78	Done manually.	1/10/2009 4:32 PM
79	best suits collector	1/10/2009 4:22 PM
80	Tally sheet and electronic data collectors	1/8/2009 6:37 PM
81	standard procedure	1/8/2009 6:35 PM
82	Best suits	1/8/2009 6:29 PM
83	standard proceedure	1/8/2009 6:28 PM
84	combination -- types and quantities of data, and collection methodologies, are communicated to field crews; application of guidelines is based on field conditions. Initiative to modify collection approach based on field conditions is encouraged.	1/8/2009 5:57 PM
85	We rely on our waste service providers to track and provide excel spreadsheet of waste diversion and landfill material from our jobsites	1/8/2009 4:37 PM
86	Daily reports from Foreman. Camera for some tasks (e.g. how many devices are installed etc.)	1/8/2009 4:17 PM
87	refer to previous project costs to establish new project budgets; contractor's schedule of values - inspector's observation of work complete	1/8/2009 3:12 PM
88	load tickets, field measurement	1/8/2009 3:04 PM
89	standard	1/8/2009 3:03 PM
90	I don't understand the question	1/8/2009 3:00 PM
91	traditional method, including manual takeoffs based on drawings	1/8/2009 2:19 PM
92	Ad Hoc	1/8/2009 2:19 PM
93	Propreitary asset model	1/8/2009 2:12 PM
94	?	1/8/2009 2:12 PM
95	Daily Reports	1/8/2009 2:10 PM
96	Weekly work plans Constraint anaylsis P6 Man power projections vs actual Look ahead schedules	1/8/2009 2:08 PM
97	Data Imput	1/8/2009 2:08 PM
98	Varies per job site, usually manual collection	1/8/2009 2:06 PM
99	Digitizing - input data in spreadsheet	12/12/2008 7:58 AM

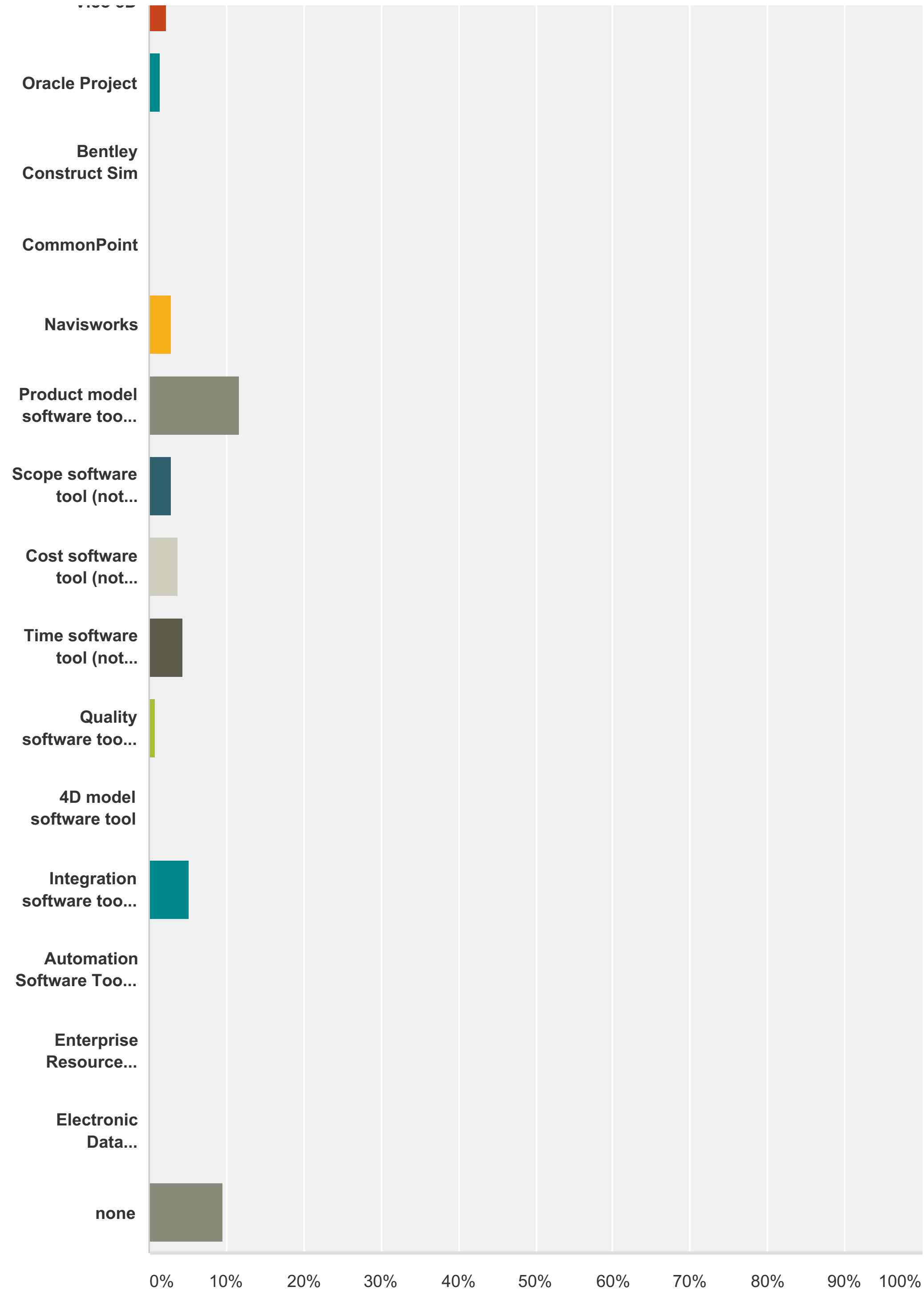
Q8 Commercial software you use to collect either field production or project planning quantities (check all that apply, if you select a generic software tool at bottom of list then give software name in comment box)

Answered: 136 Skipped: 39




Meridian Proliance
Prolog
Expedition
Sokkia
Maximo
On-screen Takeoff (OST)
SimVision
GoLabor
Sharpe
OSISoft
Statistica
Surfer
ArcView
MineSight
Downhole Explore
MapInfo
Primavera Expedition
MINCOM ellipse
MICK
Datastat
Penta


Digital Project (CATIA)
Delmia
CoGo
Leica
Google earth
Leica Geosystems...
LPile
Slope/W
Vela Systems
Primavera P3/5/6
Innovaya
Tocoman
AGTEK
MC2
Sage-Timberline
Hummingbird
RSMeans
Vico Control
Microsoft Project
Building Explorer
Vico 5D



Answer Choices	Responses	
ABB	**2.21%**	3
Rockwell	**0.00%**	0
SAP	**11.03%**	15
HCSS	**4.41%**	6
Oracle JD Edwards	**21.32%**	29

Computer Guidance	**0.74%**	1
Excel	**63.24%**	86
Trimble	**10.29%**	14
Honeywell	**2.21%**	3
IbisTRAD	**0.74%**	1
CMiC	**2.94%**	4
S/C/T	**0.00%**	0
Amer. Cont.	**1.47%**	2
BMC	**0.74%**	1
Epic	**0.74%**	1
EAM	**0.00%**	0
WinCan	**0.74%**	1
Meridian Proliance	**2.21%**	3
Prolog	**4.41%**	6
Expedition	**0.00%**	0
Sokkia	**0.74%**	1
Maximo	**1.47%**	2
On-screen Takeoff (OST)	**4.41%**	6
SimVision	**0.00%**	0
GoLabor	**0.74%**	1
Sharpe	**0.74%**	1
OSISoft	**0.74%**	1
Statistica	**0.74%**	1
Surfer	**0.74%**	1
ArcView	**2.21%**	3
MineSight	**0.74%**	1
Downhole Explore	**0.74%**	1
MapInfo	**1.47%**	2
Primavera Expedition	**4.41%**	6
MINCOM ellipse	**0.74%**	1
MICK	**0.00%**	0
Datastat	**0.74%**	1
Penta	**0.74%**	1
Digital Project (CATIA)	**0.74%**	1
Delmia	**0.74%**	1

CoGo	**1.47%**	2
Leica	**0.00%**	0
Google earth	**2.21%**	3
Leica Geosystems Cyclone	**1.47%**	2
LPile	**0.74%**	1
Slope/W	**0.74%**	1
Vela Systems	**1.47%**	2
Primavera P3/5/6	**13.24%**	18
Innovaya	**1.47%**	2
Tocoman	**1.47%**	2
AGTEK	**0.74%**	1
MC2	**2.21%**	3
Sage-Timberline	**5.15%**	7
Hummingbird	**1.47%**	2
RSMeans	**0.74%**	1
Vico Control	**0.74%**	1
Microsoft Project	**1.47%**	2
Building Explorer	**0.00%**	0
Vico 5D	**2.21%**	3
Oracle Project	**1.47%**	2
Bentley Construct Sim	**0.00%**	0
CommonPoint	**0.00%**	0
Navisworks	**2.94%**	4
Product model software tool (not listed above)	**11.76%**	16
Scope software tool (not listed above)	**2.94%**	4
Cost software tool (not listed above)	**3.68%**	5
Time software tool (not listed above)	**4.41%**	6
Quality software tool (not listed above)	**0.74%**	1
4D model software tool	**0.00%**	0
Integration software tool (not listed above)	**5.15%**	7
Automation Software Tool (not listed above)	**0.00%**	0
Enterprise Resource Management (ERM) (not listed above)	**0.00%**	0
Electronic Data Interchange (EDI) (not listed above)	**0.00%**	0
none	**9.56%**	13
Total Respondents: 136		

#	Other (please specify)	Date
1	various CAD packages depending on integration requirements of the project and client, also use Leica Cloudworx, Leica Cyclone Topo II, and Leica Trueview	3/12/2009 12:15 PM
2	Foundations	3/3/2009 8:05 PM
3	Some are moving to business platforms such as SAP. Suppliers, such as steel fabricators use purchased software for material tracking that can be linked to project material management systems. I don't know the names.	1/30/2009 5:04 PM
4	PLC data collection may be through a distributed control system such as ABB or Honeywell. Smaller operations tend to use networked PLCs. use of Project Information (PI) system OSISoft as a historian and report generator is increasing. increasing linkage with business platforms such as SAP and Oracle JD Edwards.	1/30/2009 5:04 PM
5	surveycraft	1/30/2009 3:05 PM
6	AutoCAD MicroStation other software not associated with field survey	1/30/2009 3:05 PM
7	AutoCAD Field Information system (FIS) HCSS + Excel GPS data collector – downloaded into AutoCAD	1/30/2009 3:04 PM
8	p3/p6 PLC	1/30/2009 3:04 PM
9	WYSE Thin Clients (old system)	1/30/2009 3:03 PM
10	IHS PI/Dwights well db	1/30/2009 3:03 PM
11	Microsoft Office AutoCad Micro Station	1/30/2009 3:03 PM
12	Our own Integrated System: PMIV	1/30/2009 3:02 PM
13	TEAMWorks - construction work packaging and statusing Setroute - electrical material tracking and statusing ePCWorks - progress & performance measurement	1/30/2009 3:01 PM
14	Icarus Plant Design System - PDS (3D)	1/30/2009 2:59 PM
15	Logica, Granlund, Buildercom, Basware, Personec, Hyperion	1/30/2009 2:58 PM
16	these are what our clients require	1/30/2009 2:58 PM
17	Quantity Take Off by Autodesk	1/30/2009 2:58 PM
18	used by consulting clients of this firm	1/30/2009 2:30 PM
19	P3 PeopleSoft	1/30/2009 2:26 PM
20	piloting DProfiler integrated Revit -> Innovaya -> Sage Timberline	1/30/2009 2:26 PM
21	ArchiCAD AutoCAD	1/30/2009 2:20 PM
22	Primavera Contract Manager (aka Expedition) linked to SAP	1/30/2009 2:14 PM
23	AutoCAD Rhino 3DS Max Terramodel ArchiCAD	1/30/2009 2:12 PM
24	QTO and Revit model takeoff quantities as a double check of our estimators.	1/30/2009 2:12 PM
25	I do not know the software used--many departments w/ own systems	1/30/2009 2:06 PM
26	For handling (costs, timing, resurses) investment projects 'ProConcept' by Artemis (http://fi.aisc.com/Product/8), this application only in Finland. For buildingcosts calculating 'TAKU' by Haahtela Group (http://www.haahtela.fi/index_tuot.html), mainly in Finland. For FM (realestate registers and rentcalcutations) we use 'VIA-FM' by Ramboll (http://www.ramboll.fi/services/buildings/operation%20and%20maintenance/kiinteistotietojarjestelma.aspx), only in Finland For FM (drawings etc.) 'AutoManager Meridian' by Cyco. For FM (maintenance management) 'RYHTI' by Granlund (http://www.granlund.fi/granlund_eng/frameset_tiedonhallinta.htm), only(?) in Finland.	1/30/2009 2:06 PM
27	presently investigating Vela Systems	1/30/2009 2:05 PM
28	P3	1/30/2009 2:03 PM
29	Use CAD (Microstation) to determine some areas and then use these areas in Excel.	1/10/2009 5:34 PM
30	CAD	1/10/2009 4:34 PM
31	Field Information System (FIS) = HCSS + Excel	1/10/2009 4:33 PM
32	AutoCAD	1/10/2009 4:22 PM
33	Microsoft (under implementation)	1/8/2009 6:29 PM

34	Hard Dollar - feeds estimated quantities to American Contractor	1/8/2009 6:28 PM
35	AutoCAD	1/8/2009 5:57 PM
36	SPIK - estimation, tender, cost control	1/8/2009 2:12 PM
37	P6	1/8/2009 2:08 PM
38	outlook	1/8/2009 2:08 PM

Q9 Custom or in-house software you use, name and short description

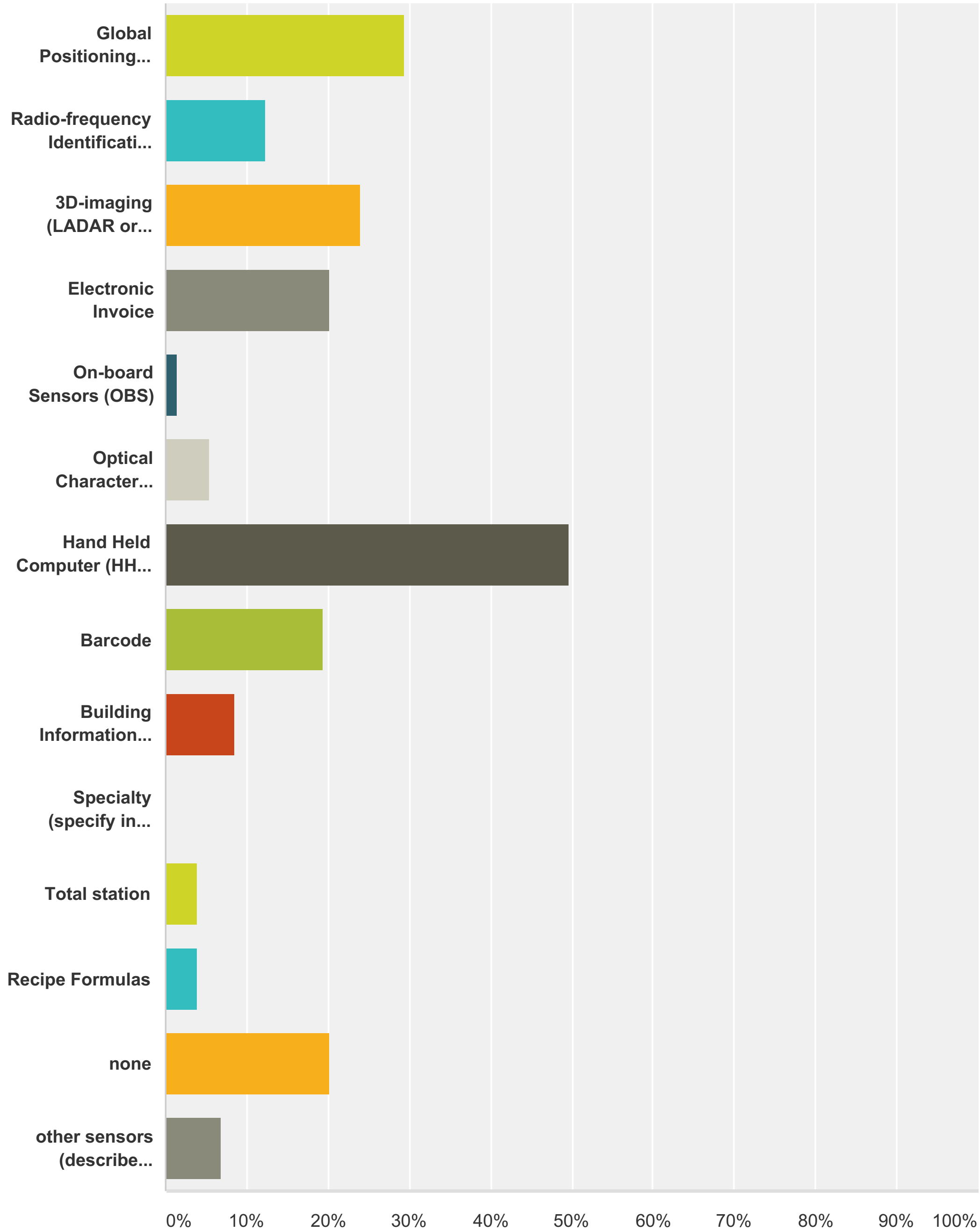
Answered: 36 Skipped: 139

#	Responses	Date
1	Own software ICE - international cost estimation (icomas) MIS - management information system (icomas)	1/30/2009 5:15 PM
2	MICK	1/30/2009 5:05 PM
3	Historically, depending on the company, construction companies develop in-house software for quantity tracking of bulk material purchased and installing in field construction.	1/30/2009 5:04 PM
4	Historical Estimating database	1/30/2009 3:05 PM
5	Electronic Timecard	1/30/2009 3:04 PM
6	PLC inhouse designed software	1/30/2009 3:04 PM
7	GraniteXpress2(TM)	1/30/2009 3:03 PM
8	Material Manager (Procument, Warehousing)	1/30/2009 3:03 PM
9	Our own Integrated System: PMIV	1/30/2009 3:02 PM
10	serveral intergrated internally developed systems	1/30/2009 3:02 PM
11	In house reports that forecasts based on progress to date	1/30/2009 3:02 PM
12	In-house developed tools	1/30/2009 3:01 PM
13	Oracle based	1/30/2009 3:01 PM
14	Flow recoding, custom data bases	1/30/2009 3:00 PM
15	In-house software	1/30/2009 2:59 PM
16	Icarus, PDS, MatMan (Material Management System)	1/30/2009 2:59 PM
17	artra - model based inventory manager	1/30/2009 2:59 PM
18	Optimaze.net, Investment Project Mgmt, R&D project Mgmt, Customer mgmt, Web-survey,…	1/30/2009 2:58 PM
19	yes	1/30/2009 2:58 PM
20	none	1/30/2009 2:31 PM
21	Milemarker - quantity, milestone tracking tool Invision - 3D model status InSequence - 4D model	1/30/2009 2:22 PM
22	Sub-Vendor Progress & EAC Tool - an application that tracks subcontractor and vendor billings as well as forecast earned value.	1/30/2009 2:19 PM
23	Shawtrac	1/30/2009 2:04 PM
24	Microsoft Excel	1/22/2009 4:51 PM
25	Excel spreadsheets	1/22/2009 4:37 PM
26	Bids 2	1/11/2009 12:08 PM
27	excel templates	1/10/2009 5:20 PM
28	?	1/10/2009 5:19 PM
29	CMS - content management system	1/10/2009 4:47 PM
30	Various Microsoft packages	1/10/2009 4:40 PM
31	People and Equipment Dispatch System	1/10/2009 4:33 PM
32	Various, especially for safety	1/8/2009 6:29 PM
33	NA	1/8/2009 5:57 PM

34	spss, amos, SD modeling	1/8/2009 3:03 PM
35	CxTool, asset trackign tool for commissioning services	1/8/2009 2:12 PM
36	Developed inhouse	1/8/2009 2:12 PM

Q10 Electronic methods of collection (check all that apply)

Answered: 129 Skipped: 46



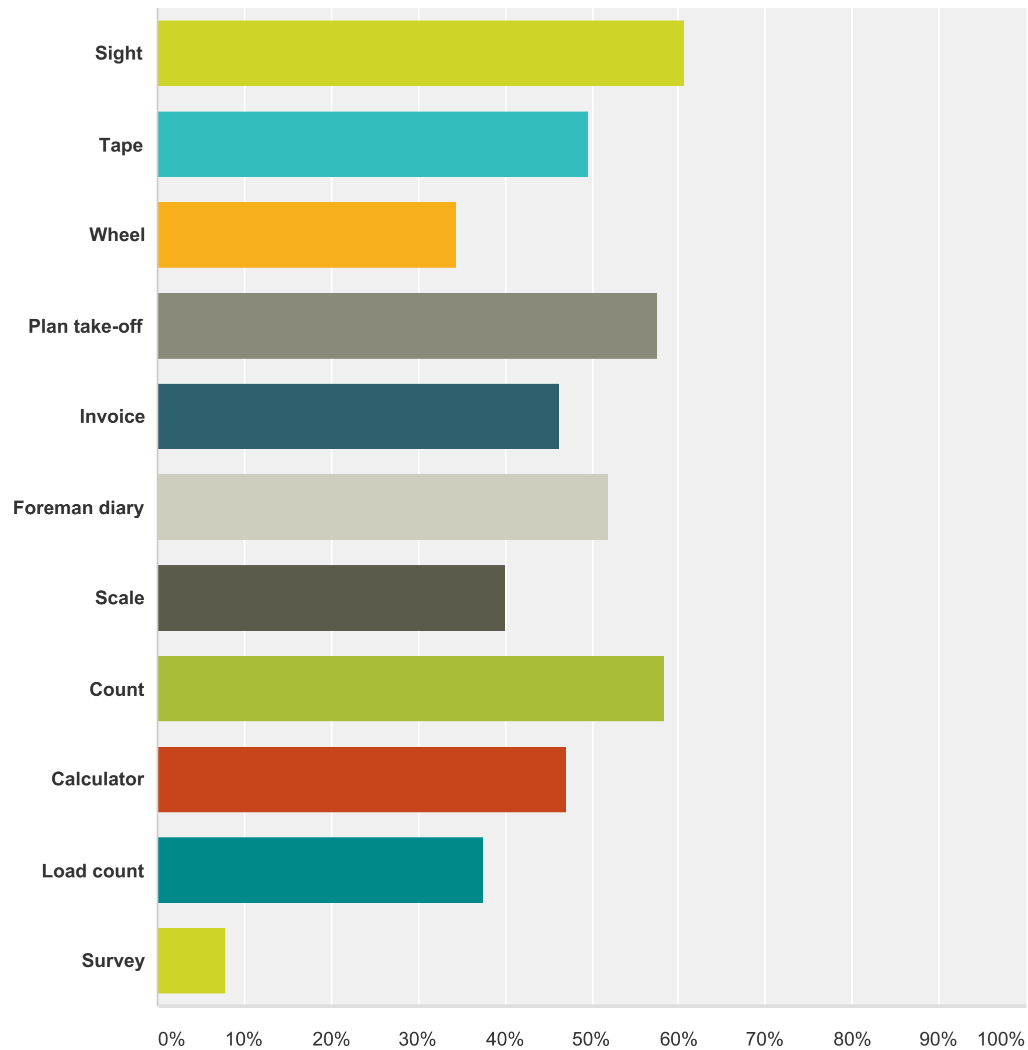
Answer Choices	Responses	
Global Positioning System (GPS)	**29.46%**	38
Radio-frequency Identification (RFID)	**12.40%**	16
3D-imaging (LADAR or Digital Imaging)	**24.03%**	31
Electronic Invoice	**20.16%**	26

On-board Sensors (OBS)	**1.55%**	2
Optical Character Recognition (OCR)	**5.43%**	7
Hand Held Computer (HHC), e.g., laptop	**49.61%**	64
Barcode	**19.38%**	25
Building Information Model (BIM) or (PIM)	**8.53%**	11
Specialty (specify in comment box)	**0.00%**	0
Total station	**3.88%**	5
Recipe Formulas	**3.88%**	5
none	**20.16%**	26
other sensors (describe below)	**6.98%**	9
Total Respondents: 129		

#	Other (please specify)	Date
1	steel is tracked by piece and bar-coded for scanned entry Bulk shipment is commonly bar-coded by batches	1/30/2009 5:04 PM
2	online web surveys	1/30/2009 3:05 PM
3	Depends on contractor and suppliers	1/30/2009 3:05 PM
4	thermal sensor on equipment bearings CAT haul trucks OBS: loads per shift and tonnage per haul 3D imaging: automatic contour maps and volumes RFID on customer aggregate haul trucks for ID loadout system: automatically loaded and ticketed. Truck cycle times (for contractor trucks) stored in data base and daily volumes and cycle times reports provided to customers	1/30/2009 3:03 PM
5	Mobile Phone	1/30/2009 2:58 PM
6	camera	1/30/2009 2:31 PM
7	Pulse oximetry, thermometer, blood pressure/heart rate machine, Pixis, intravenous infusions machine, others depending on acuity of patient	1/10/2009 5:43 PM
8	PLC	1/10/2009 4:46 PM
9	Hand held GPS rovers	1/10/2009 4:33 PM
10	Haul truck barcode ID cards for quarry scale	1/10/2009 4:22 PM
11	Flowmeters	1/10/2009 4:04 PM
12	Dataputer data collectors	1/8/2009 6:37 PM
13	camera for later sight count	1/8/2009 4:17 PM
14	Reporting into the system	1/8/2009 2:12 PM

Q11 Manual methods of collection (check all that apply)

Answered: 125 Skipped: 50



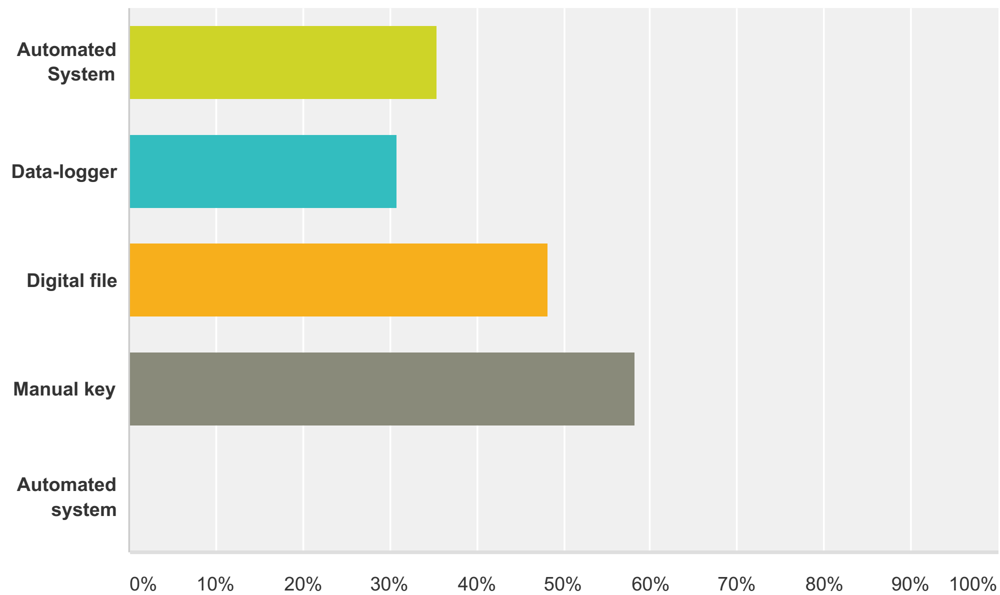
Answer Choices	Responses	
Sight	**60.80%**	76
Tape	**49.60%**	62
Wheel	**34.40%**	43
Plan take-off	**57.60%**	72
Invoice	**46.40%**	58
Foreman diary	**52.00%**	65
Scale	**40.00%**	50
Count	**58.40%**	73
Calculator	**47.20%**	59

Load count	**37.60%**	47
Survey	**8.00%**	10
Total Respondents: 125		

#	Other (please specify)	Date
1	face to face surveys	1/30/2009 3:05 PM
2	Depends on activity, contractor and suppliers.	1/30/2009 3:05 PM
3	Appeals	1/30/2009 2:32 PM
4	extensometer or tilt meter Strain gauges	1/30/2009 2:31 PM
5	phone email web search	1/30/2009 2:31 PM
6	sub-contractors submit the progress billing quantities superintendent's review the billing quantities owner's inspectors (IOR's) approve quantities	1/30/2009 2:27 PM
7	timecards	1/30/2009 2:24 PM
8	auscultation, palpation, sensation, verbal subjective data	1/10/2009 5:43 PM
9	provided by consultants/contractors/team	1/8/2009 7:03 PM
10	supervisor report	1/8/2009 2:12 PM

Q12 Electronic methods of recording (check all that apply)

Answered: 110 Skipped: 65



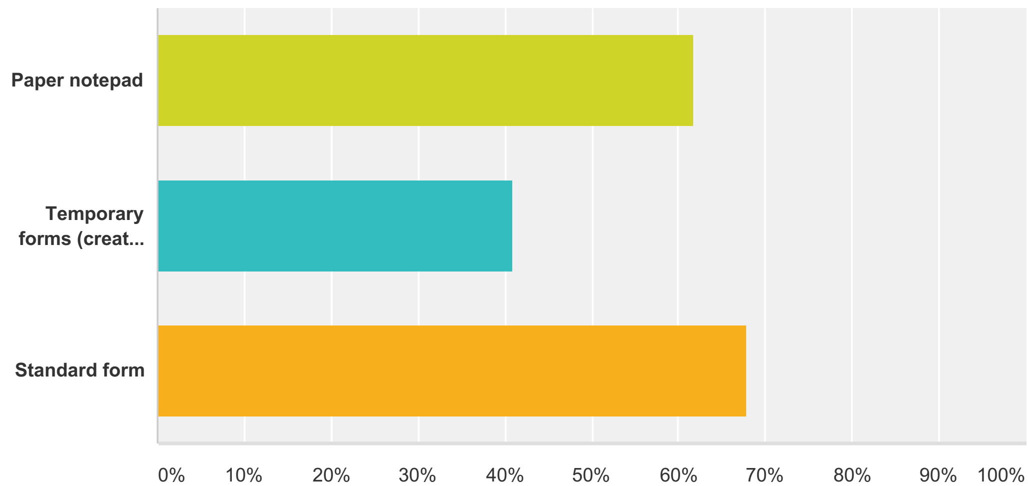
Answer Choices	Responses	
Automated System	35.45%	39
Data-logger	30.91%	34
Digital file	48.18%	53
Manual key	58.18%	64
Automated system	0.00%	0
Total Respondents: 110		

#	Other (please specify)	Date
1	Manual entry of visually-collected data. Automatic entry of scanned data.	1/30/2009 5:04 PM
2	web-based	1/30/2009 3:05 PM
3	excel file	1/30/2009 3:05 PM
4	Contractors and suppliers use a variety of systems.	1/30/2009 3:05 PM
5	Microsoft Excel (for a quantity book)	1/30/2009 3:04 PM
6	order generated from system then keyed in at end of the day to record things like weight	1/30/2009 3:03 PM
7	some manual some automated	1/30/2009 3:02 PM
8	email - client to server messages via web services	1/30/2009 2:31 PM
9	Enter dates from the physical progress in an Excel file	1/10/2009 5:20 PM
10	grey matter	1/10/2009 5:19 PM
11	Final entry placed in excel field reports	1/10/2009 4:32 PM
12	File transfer to spreadsheet	1/8/2009 6:37 PM

13	OST	1/8/2009 2:47 PM

Q13 Paper-based methods of recording (check all that apply)

Answered: 115 Skipped: 60

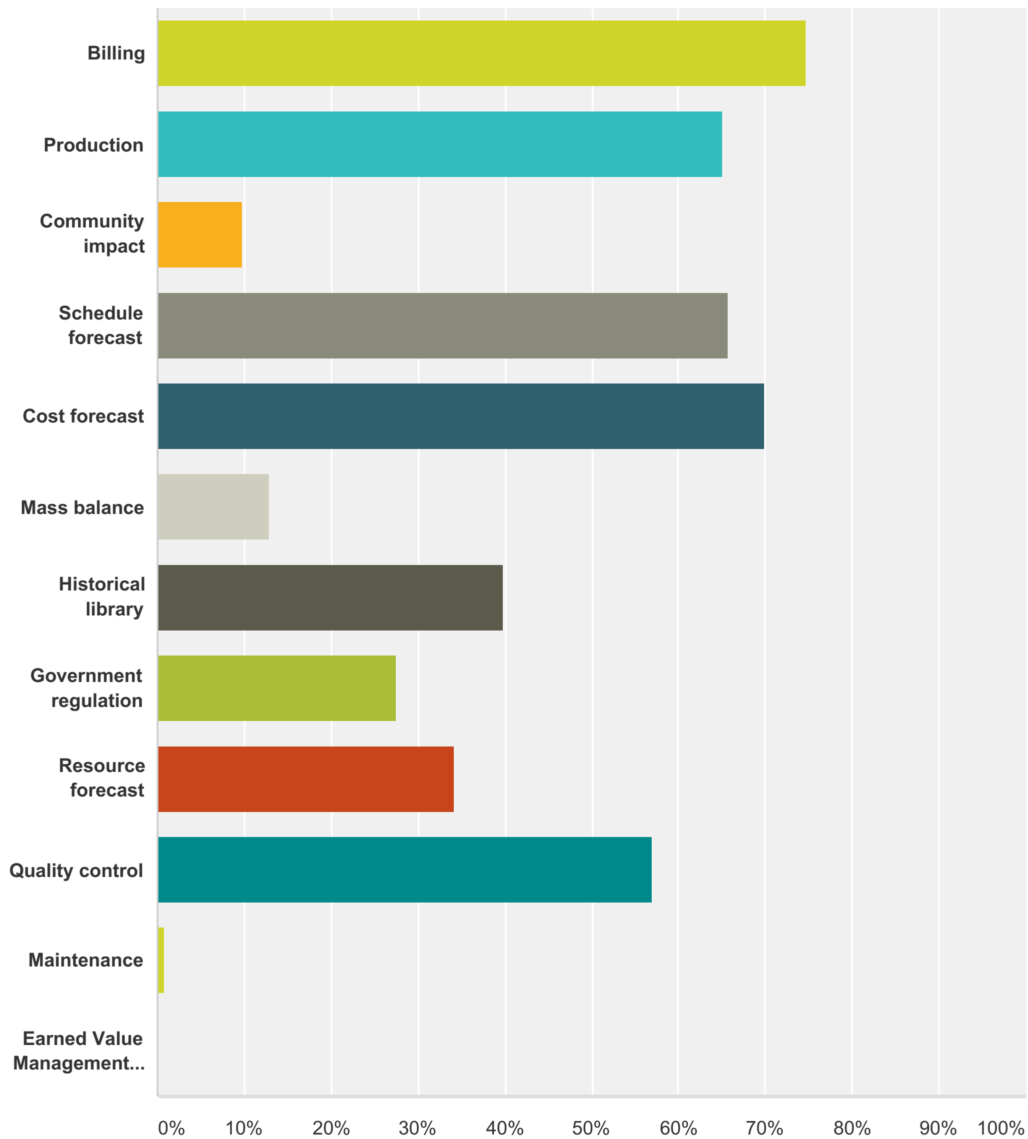


Answer Choices	Responses	
Paper notepad	**61.74%**	71
Temporary forms (created to meet specific need, might not be reused)	**40.87%**	47
Standard form	**67.83%**	78
Total Respondents: 115		

#	Other (please specify)	Date
1	traditional surveyors field books are still employed to record the key elements of the survey and for making journal type entries, compliments and validates the digital data. There's no substitute for sound surveying best practices.	3/12/2009 12:15 PM
2	Much quantity tracking is done manually and recorded on paper / personal computer applications.	1/30/2009 5:04 PM
3	Contractors and suppliers use a variety of systems.	1/30/2009 3:05 PM
4	timecards field notebooks	1/30/2009 3:04 PM
5	we are 100% paperless	1/30/2009 3:00 PM
6	Since I am not in construction N/A.	1/10/2009 5:34 PM
7	Initial recordings placed in paper field journals	1/10/2009 4:32 PM
8	Job specific time sheets	1/8/2009 6:28 PM

Q14 Reason for data collection (check all that apply)

Answered: 123 Skipped: 52



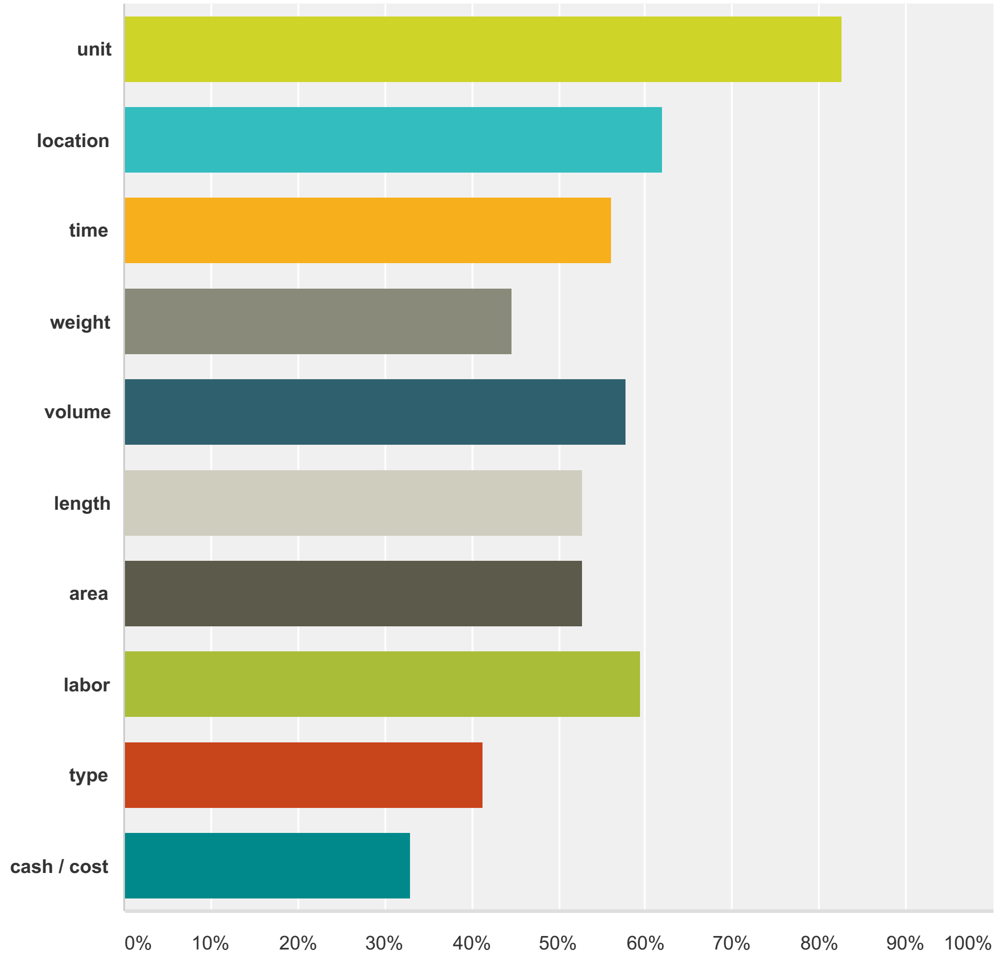
Answer Choices	Responses	
Billing	**74.80%**	92
Production	**65.04%**	80
Community impact	**9.76%**	12
Schedule forecast	**65.85%**	81
Cost forecast	**69.92%**	86
Mass balance	**13.01%**	16
Historical library	**39.84%**	49

Government regulation	**27.64%**	34
Resource forecast	**34.15%**	42
Quality control	**56.91%**	70
Maintenance	**0.81%**	1
Earned Value Management (EVM)	**0.00%**	0
Total Respondents: 123		

#	Other (please specify)	Date
1	strategic management	1/30/2009 3:05 PM
2	reporting to city and state	1/30/2009 3:03 PM
3	maintenance	1/30/2009 3:03 PM
4	engineering design/analysis	1/30/2009 3:03 PM
5	mostly cost management	1/30/2009 3:00 PM
6	Research and development	1/30/2009 2:33 PM
7	design criteria evaluation horizons and quantities production effect on adjacent property.	1/30/2009 2:31 PM
8	material cost labor cost equipment cost	1/30/2009 2:31 PM
9	Value of VDC, cost avoidance estimation	1/30/2009 2:12 PM
10	liability	1/22/2009 5:28 PM
11	patient health monitoring, to ensure proactive and reactive treatment for patient health recovery/maintenance.	1/10/2009 5:43 PM
12	Decision making forecasting cash flow projected profitability calculating sales prices in light of rising costs	1/10/2009 5:20 PM
13	payroll accuracy and timeliness	1/10/2009 4:34 PM
14	as-built	1/10/2009 4:32 PM
15	TPS - Continuous improvement	1/8/2009 6:37 PM
16	research - mineral occurrence location	1/8/2009 5:58 PM
17	for field jobsite labor management	1/8/2009 5:03 PM
18	To lessen project environmental impact and reduce landfill tipping fees, we divert construction waste	1/8/2009 4:39 PM
19	Research	1/8/2009 3:01 PM

Q15 What is quantified (check all that apply)

Answered: 121 Skipped: 54

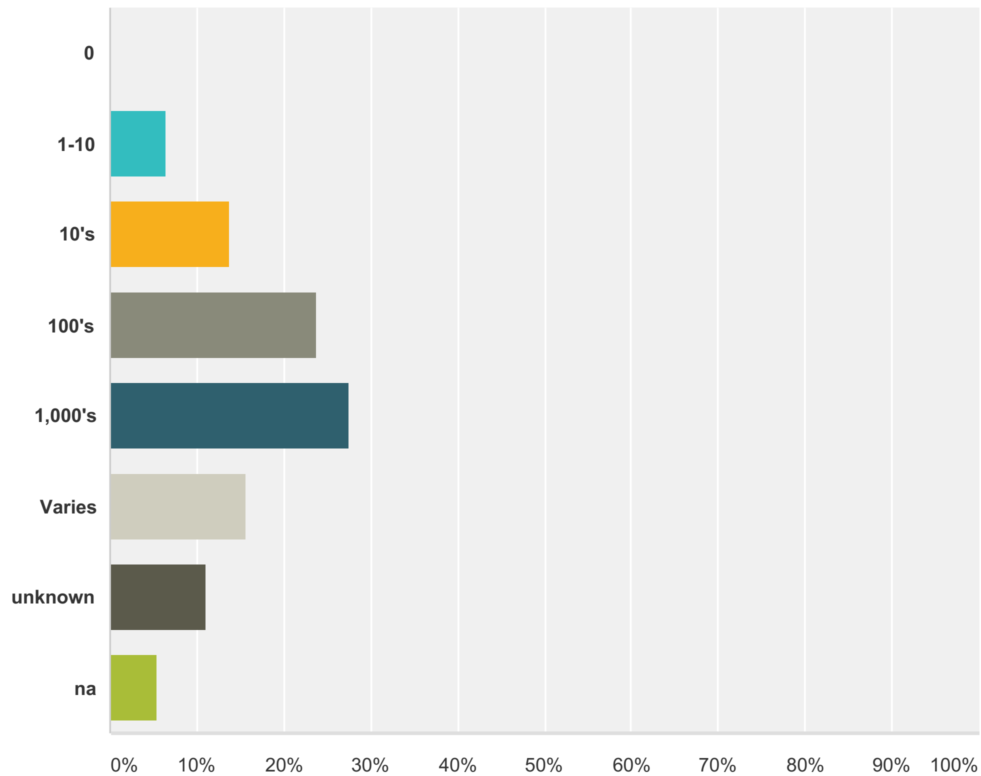


Answer Choices	Responses	
unit	**82.64%**	100
location	**61.98%**	75
time	**56.20%**	68
weight	**44.63%**	54
volume	**57.85%**	70
length	**52.89%**	64
area	**52.89%**	64
labor	**59.50%**	72
type	**41.32%**	50
cash / cost	**33.06%**	40
Total Respondents: 121		

#	Other (please specify)	Date
1	elevation, heigth	3/12/2009 12:35 PM
2	Labor (hours), pipe and cable (lineal) earthwork and concrete (volume) steel (tons)	1/30/2009 5:04 PM
3	multiple	1/30/2009 3:05 PM
4	Mining operations record tons and volumes. Process operations record tons input and output. All operations need to record data for mass balance and reconciliations with resource statements, financial statements. Capital projects will quantify the usual items encountered in construction trades.	1/30/2009 3:05 PM
5	equipment	1/30/2009 3:04 PM
6	volumetric flow density delivered material input materials input energy process efficiency recovery efficiency	1/30/2009 3:04 PM
7	Tonnage, units (ie: containers qty and size)	1/30/2009 3:03 PM
8	This varies widely	1/30/2009 3:02 PM
9	the intent is to quantify all aspects of the project	1/30/2009 3:00 PM
10	Pressures deflection deformation settlement elongation creep	1/30/2009 2:31 PM
11	whatever is required for our consulting business related to project costs	1/30/2009 2:31 PM
12	code compliance	1/30/2009 2:22 PM
13	Pour records, QC clearance	1/30/2009 2:22 PM
14	steel members (tonage), concrete (cu yd), enclosure (sf), doors(count), windows(count), linear ft of walls	1/30/2009 2:12 PM
15	Man hours per project each week	1/22/2009 4:37 PM
16	Each game has its own unit, then turns into money Earned Value Analysis: 1) progress to date 2) average monthly cost performance 3) cost of work payables 4) distributed on cash flow as the monthly performance of each activity	1/10/2009 5:20 PM
17	Units placed Time records materials are purchased using a purchase order and are electronic move-in hours move-in costs actual production numbers for each type of work, e.g., paving, earthwork, underground by type of work	1/10/2009 4:34 PM
18	as-built location	1/10/2009 4:32 PM
19	Fault analysis	1/8/2009 6:37 PM
20	I don't think this applies to me	1/8/2009 3:01 PM

Q16 Number of individual items quantified

Answered: 109 Skipped: 66



Answer Choices	Responses	
0	**0.00%**	0
1-10	**6.42%**	7
10's	**13.76%**	15
100's	**23.85%**	26
1,000's	**27.52%**	30
Varies	**15.60%**	17
unknown	**11.01%**	12
na	**5.50%**	6
Total Respondents: 109		

#	Other (please specify), if it varies check best answer and define the independent variable, i.e., what it depend on	Date
1	Basically just counting truckloads. but need to phase them. Hundreds of phase codes depending on what work is being performed.	3/3/2009 8:08 PM
2	1,300 cost codes	1/30/2009 3:04 PM
3	by project	1/30/2009 3:04 PM
4	Depends on the size on the project. It can be in the 100,000's of items	1/30/2009 3:03 PM

5	we have around 150-200 capital projects underway at any one time.	1/30/2009 3:02 PM
6	Again, this varies widely	1/30/2009 3:02 PM
7	meteric	1/30/2009 3:01 PM
8	tens of thousands per project	1/30/2009 3:00 PM
9	We do projects from serveral $mm to serveral billions in value.	1/30/2009 2:59 PM
10	3 - 300	1/30/2009 2:31 PM
11	costs on 100,000 +/- materials cost on 45 trades around US cost on 1500 pieces of construction equipment	1/30/2009 2:31 PM
12	100,000s +	1/30/2009 2:30 PM
13	Approx 100	1/22/2009 4:37 PM
14	depending on acuity of patient	1/10/2009 5:43 PM
15	44 items	1/10/2009 5:20 PM
16	It depends on what are you measuring. For example volumes of soils in m3, but locations are established with a precission of 1 mm. But they are usually consistent for measuring the same elements.	1/10/2009 4:34 PM
17	by size of project by type of project	1/10/2009 4:33 PM
18	Depends on the size of project. Not less than 20 items	1/10/2009 4:32 PM
19	Depends on project type & size, approx. 50-200 items	1/8/2009 5:03 PM

Q17 what are your units of measurement and are these consistent between measured and reported

Answered: 84 Skipped: 91

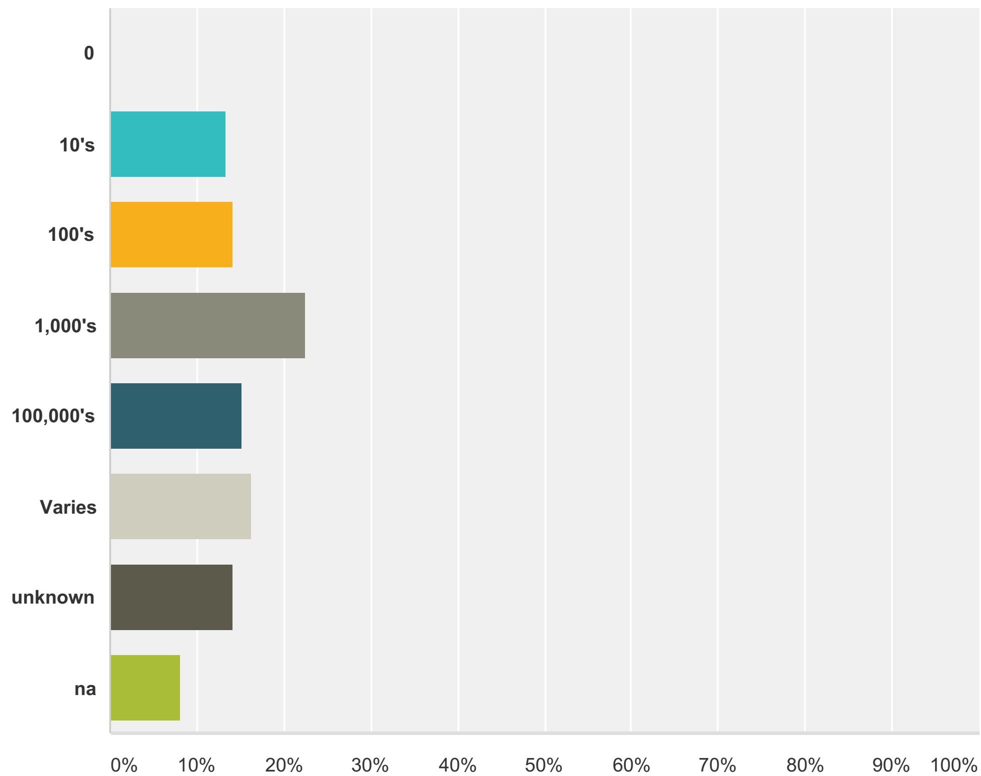
#	Responses	Date
1	units vary as required by client of situation. Both decimal feet and metric units are used for lengths, volumes and for areas. Other units include sq yards, acres, chains, varas. Some measurements are collected in the same units as reported and other are not. Many tools use metric as the native machine coding then convert to feet. location may be measured in Lat/Lon then converted to State Plane coordinates and in both feet and meetrrs depending on whether federal client of state client	3/12/2009 12:35 PM
2	Usually tons, but sometimes use loads	3/3/2009 8:08 PM
3	Units in the metric system and labor hours.	2/5/2009 2:04 PM
4	Mining units are generally consistent world wide. Construction units are becoming more consistent but there is still a "US-block" versus a "European-block" of industries that divide the world of standard units into two.	1/30/2009 3:05 PM
5	LF, Ton, CY, SF, %, Days, Months, Lump Sum, EA, Loads, Hours, (metric for Caltrans work)	1/30/2009 3:04 PM
6	no	1/30/2009 3:04 PM
7	Weight, volumetric flow, density measurements	1/30/2009 3:04 PM
8	yes	1/30/2009 3:03 PM
9	They are appropriate for the item purchased, installed and or check out.	1/30/2009 3:03 PM
10	not consistent enough	1/30/2009 3:02 PM
11	Should be. Our system allows a LS to be broken down in physical quantities	1/30/2009 3:02 PM
12	ywa	1/30/2009 3:02 PM
13	yes, they must be or the data is meaningless.	1/30/2009 3:02 PM
14	depends but usually	1/30/2009 3:02 PM
15	Standardized	1/30/2009 3:01 PM
16	yes	1/30/2009 3:01 PM
17	yes	1/30/2009 3:01 PM
18	Metrics and Performance of the volume worked by the areas	1/30/2009 3:00 PM
19	yes	1/30/2009 3:00 PM
20	sometimes	1/30/2009 3:00 PM
21	using standard practices	1/30/2009 2:59 PM
22	yes	1/30/2009 2:59 PM
23	Yes	1/30/2009 2:59 PM
24	yes, for most part	1/30/2009 2:58 PM
25	no	1/30/2009 2:58 PM
26	No	1/30/2009 2:33 PM
27	variable	1/30/2009 2:32 PM
28	yes	1/30/2009 2:31 PM
29	Yes, except where changed field conditions were encountered	1/30/2009 2:31 PM
30	Yes - we handle all unit conversion	1/30/2009 2:31 PM

31	Consistent to what is being researched	1/30/2009 2:31 PM
32	varies	1/30/2009 2:30 PM
33	No	1/30/2009 2:30 PM
34	no	1/30/2009 2:27 PM
35	yes	1/30/2009 2:26 PM
36	Yes, (SF, CUYD, LF)	1/30/2009 2:26 PM
37	yes	1/30/2009 2:25 PM
38	Not always	1/30/2009 2:24 PM
39	typically save the conversions for domestic vs overseas projects	1/30/2009 2:22 PM
40	yes	1/30/2009 2:21 PM
41	mostly yes	1/30/2009 2:20 PM
42	yes	1/30/2009 2:20 PM
43	yes	1/30/2009 2:18 PM
44	measurements are typical taken in english units and often converted to metric, as these are the units used in bid items.	1/30/2009 2:14 PM
45	yes	1/30/2009 2:13 PM
46	Yes	1/30/2009 2:12 PM
47	need to	1/30/2009 2:10 PM
48	Somewhat standard within a trade	1/30/2009 2:04 PM
49	yes	1/30/2009 2:02 PM
50	Manhours, Square Feet, Lineal Feet, CUYD	1/30/2009 1:58 PM
51	no	1/22/2009 5:28 PM
52	yes	1/22/2009 5:23 PM
53	No	1/22/2009 4:51 PM
54	yes	1/22/2009 4:37 PM
55	No	1/12/2009 8:44 AM
56	Not always	1/11/2009 12:08 PM
57	yes	1/10/2009 5:43 PM
58	yes	1/10/2009 5:20 PM
59	?	1/10/2009 5:19 PM
60	no	1/10/2009 4:47 PM
61	Depends on the project. About 70% English units, the rest of the measurements are metric	1/10/2009 4:46 PM
62	Vary basic	1/10/2009 4:40 PM
63	Yes, although some confusion regarding tons and yards still comes up. Results are usually tracked in accordance with units of measure in the contract.	1/10/2009 4:34 PM
64	Within a project, yes	1/10/2009 4:33 PM
65	They were chosen by the Project Manager as the best way to measure production of a certain item	1/10/2009 4:32 PM
66	Generally, yes.	1/10/2009 4:32 PM
67	must be	1/10/2009 4:31 PM
68	No	1/10/2009 4:25 PM
69	no, conversions are required. example is haul trucks are recorded in load count, tons and known volume capacity, reporting is in ECY	1/10/2009 4:22 PM

70	95%	1/8/2009 6:35 PM
71	normally	1/8/2009 6:28 PM
72	Varies by Construction Manager	1/8/2009 6:15 PM
73	yes	1/8/2009 5:58 PM
74	SF, CY, MHRS, WKS, EA …	1/8/2009 5:03 PM
75	yes	1/8/2009 4:17 PM
76	yes	1/8/2009 3:15 PM
77	no, can be lump sum, area, volume, or individual	1/8/2009 3:12 PM
78	No. Units vary to match bid item units on unit-priced work.	1/8/2009 3:05 PM
79	yes	1/8/2009 2:19 PM
80	Yes	1/8/2009 2:13 PM
81	Yes	1/8/2009 2:10 PM
82	Varies project to project	1/8/2009 2:09 PM
83	Yes	1/8/2009 2:08 PM
84	NO	12/12/2008 8:00 AM

Q18 Scale of quantities, approximate monthly total

Answered: 98 Skipped: 77



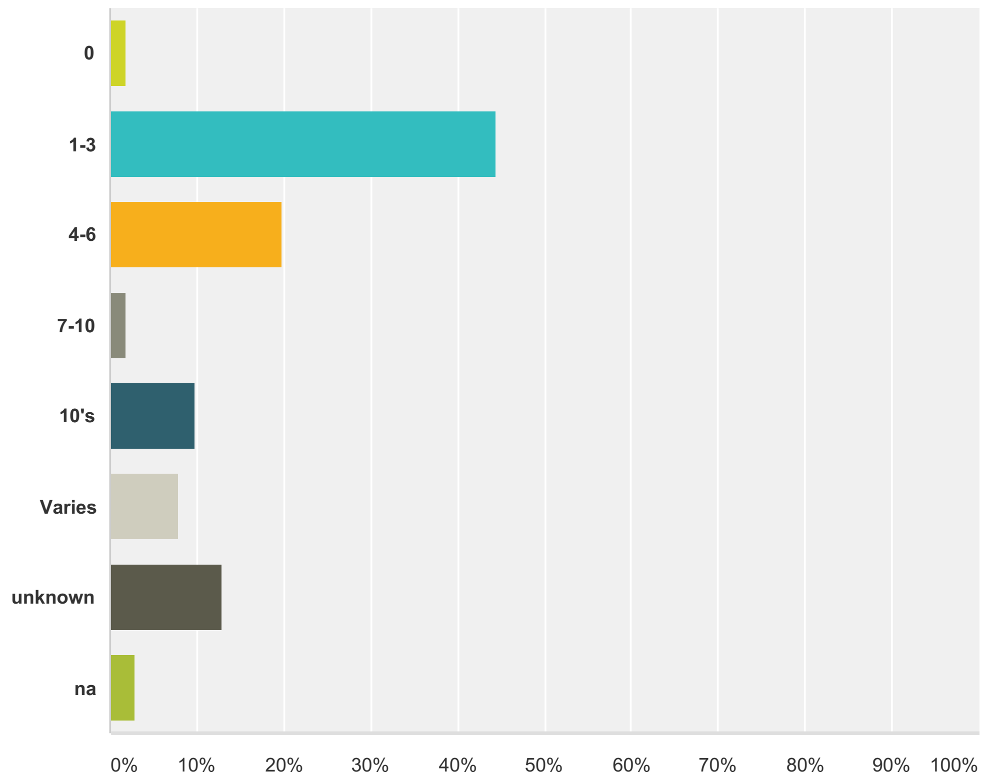
Answer Choices	Responses	
0	**0.00%**	0
10's	**13.27%**	13
100's	**14.29%**	14
1,000's	**22.45%**	22
100,000's	**15.31%**	15
Varies	**16.33%**	16
unknown	**14.29%**	14
na	**8.16%**	8
Total Respondents: 98		

#	Other (please specify), if it varies check best answer and define the independent variable, i.e., what it depend on	Date
1	Millions of hours billions of dollars millions of tons of earth movement	1/30/2009 5:04 PM
2	Varies by operation and by project. Some mining companies can move over a million tonnes of material a day.	1/30/2009 3:05 PM
3	range from 1 to over 1 million units, depending on the unit of measure	1/30/2009 3:04 PM
4	Mine material 200,000 tonnes per day.	1/30/2009 3:04 PM

5	Depends on the size on the project.	1/30/2009 3:03 PM
6	average 500 to 1500	1/30/2009 2:31 PM
7	I don't understand because we have different quantities such as pieces, tons, m³ etc. Do you want me to add them? There are many quantities to check	1/30/2009 2:10 PM
8	Project specific	1/22/2009 5:26 PM
9	60,000	1/22/2009 4:37 PM
10	depending on the acuity of the patient	1/10/2009 5:43 PM
11	It is measured in terms of the total workforce (EJM: 5 slabs this week, accumulated slabs 45, 69)	1/10/2009 5:20 PM
12	In a busy month, a single job could have twenty people with daily time entry, multiple material loads of aggregate or asphalt, etc. In short, easily 50 – 100 transactions per day per job.	1/10/2009 4:34 PM
13	by size of project, by type of the project	1/10/2009 4:33 PM
14	by job	1/8/2009 5:03 PM

Q19 Number of staff required to track the above quantities

Answered: 101 Skipped: 74



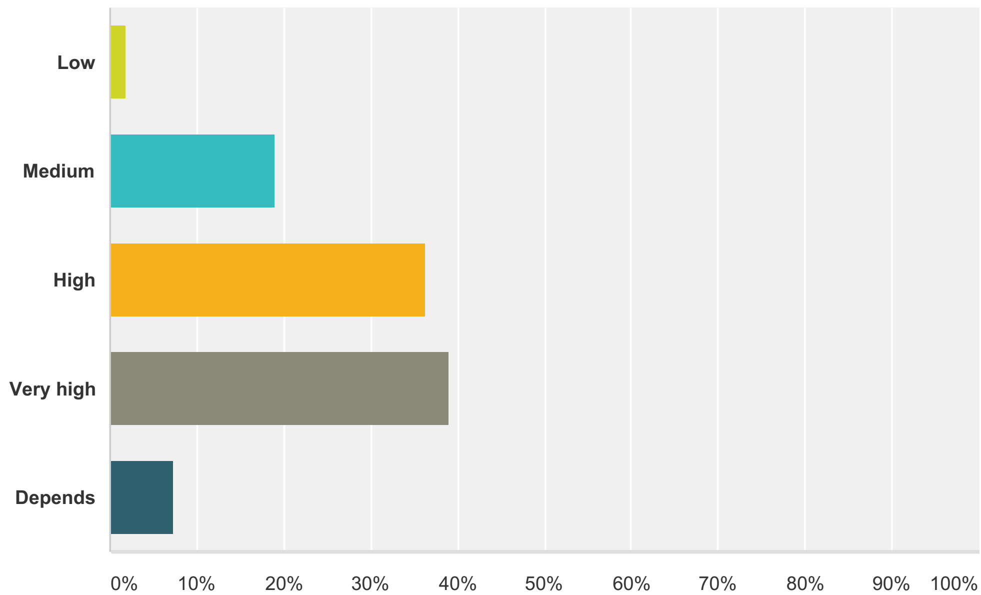
Answer Choices	Responses	
0	**1.98%**	2
1-3	**44.55%**	45
4-6	**19.80%**	20
7-10	**1.98%**	2
10's	**9.90%**	10
Varies	**7.92%**	8
unknown	**12.87%**	13
na	**2.97%**	3
Total Respondents: 101		

#	Other (please specify), if it varies check best answer and define the independent variable, i.e., what it depend on	Date
1	30 to 50	1/30/2009 5:04 PM
2	Process operations in mining is now highly automated in this respect. Construction field efforts can still rely on a large team for manual monitoring.	1/30/2009 3:05 PM
3	Approx. 6 foreman track quantities daily, 3 field engineers verify quantities, one office engineer does the actual recording on a job this size	1/30/2009 3:04 PM

4	automatic once delivered to production facilities I am not familiar enough with quantity tracking in trucked movements to comment there.	1/30/2009 3:04 PM
5	Depends on the size on the project.	1/30/2009 3:03 PM
6	depends on the type of project and their phase.	1/30/2009 3:02 PM
7	1000's around the world	1/30/2009 2:59 PM
8	varies - 1 to 4 per large project ($100 mil US2008)	1/30/2009 2:58 PM
9	8 engineers supervising +/- 20 researchers	1/30/2009 2:31 PM
10	projects vary from small maintenance projects to grassroots mega-projects	1/30/2009 2:22 PM
11	Each VDC team member tracks various metric per project, we have over 40 Integrated Construction Coordinators in the company performing such data collection methods. Is this meant for take-offs?	1/30/2009 2:12 PM
12	numerous projects	1/30/2009 2:04 PM
13	Varies with the size and complexity of the project	1/30/2009 2:04 PM
14	These same staff members perform the construction inspection	1/22/2009 5:26 PM
15	depending on acuity of patient from critically patients 1 nurse to 1 patient acutely ill patients 1 nurse to 5-6 patients (with ancillary staff assisting in data collection)	1/10/2009 5:43 PM
16	In design for bid.	1/10/2009 5:34 PM
17	2	1/10/2009 5:20 PM
18	There is typically a project engineer and contract administrator supporting all significant sized jobs.	1/10/2009 4:34 PM
19	by size of project by type of the project figure 1 field engineer for every $8-10 mm in annual revenue for a given project	1/10/2009 4:33 PM
20	Depends on size of project, typically one person.	1/10/2009 4:32 PM
21	in the order of 1/3	1/10/2009 4:31 PM
22	Typically 2-3 field engineers per project	1/8/2009 5:03 PM

Q20 Importance placed on accuracy

Answered: 110 Skipped: 65



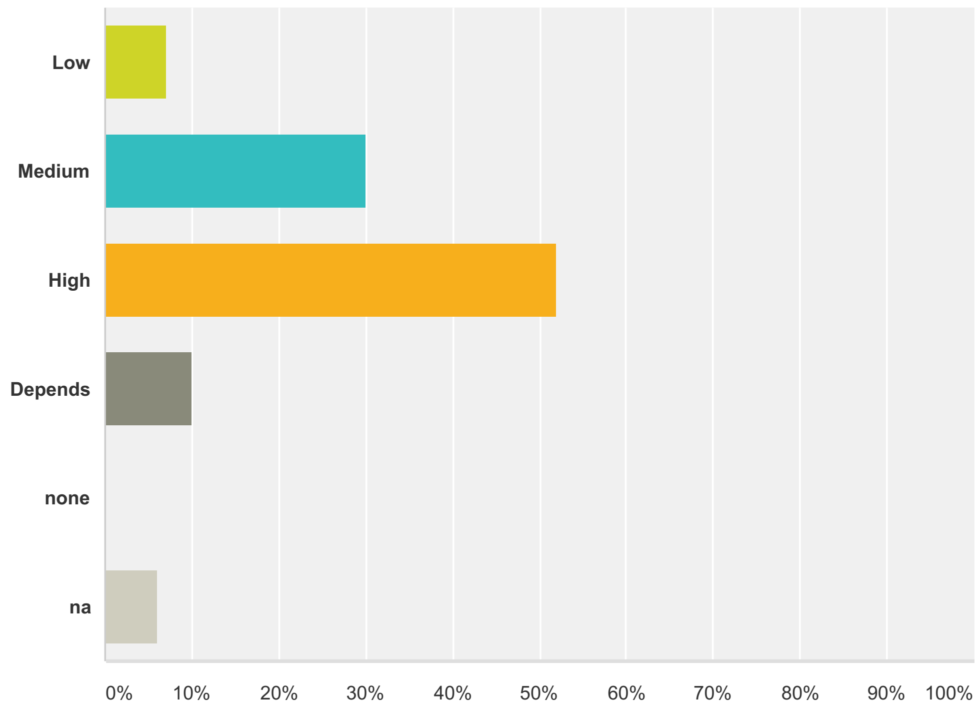
Answer Choices	Responses	
Low	**1.82%**	2
Medium	**19.09%**	21
High	**36.36%**	40
Very high	**39.09%**	43
Depends	**7.27%**	8
Total Respondents: 110		

#	Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on	Date
1	on purpose.	1/30/2009 5:04 PM
2	Very high in mining operations for anything related to product delivery and billing, slightly less so for anything related to production costing. Requirement for accuracy for construction depends on contract form and whether final payments are subject to reconciliation.	1/30/2009 3:05 PM
3	Very important – more so for the items that will be finished products. For example, pipe footage is easy to track, but tons of baserock placed under a roadway can be a little more difficult to quantify if it is already covered by asphalt or concrete	1/30/2009 3:04 PM
4	Measurements of primary production units and unit costs	1/30/2009 3:04 PM
5	because of billing	1/30/2009 3:03 PM
6	Accurate quanities result in more accurate forecasts of cost and schedule.	1/30/2009 2:59 PM
7	Yes very much so, to the degree it was possible to achieve	1/30/2009 2:31 PM
8	varies with unit value (higher unit values demand and justify greater accuracy)	1/30/2009 2:30 PM
9	High accuracy is in construction mostly academic. Data must be first of all complete.	1/30/2009 2:10 PM
10	Labor Time Cards; High Material/Cost tracking quantities; low	1/12/2009 8:44 AM

11	Very important	1/10/2009 5:20 PM
12	Very high because garbage in – garbage out. We do not rely on paper records unless the client asks us for them.	1/10/2009 4:34 PM
13	Paramount, cost forecasts and schedules rely 100% on the accuracy of filed quantities	1/10/2009 4:33 PM
14	it is paramount to accurately record.	1/10/2009 4:32 PM

Q21 Level of detail in acquisition

Answered: 100 Skipped: 75



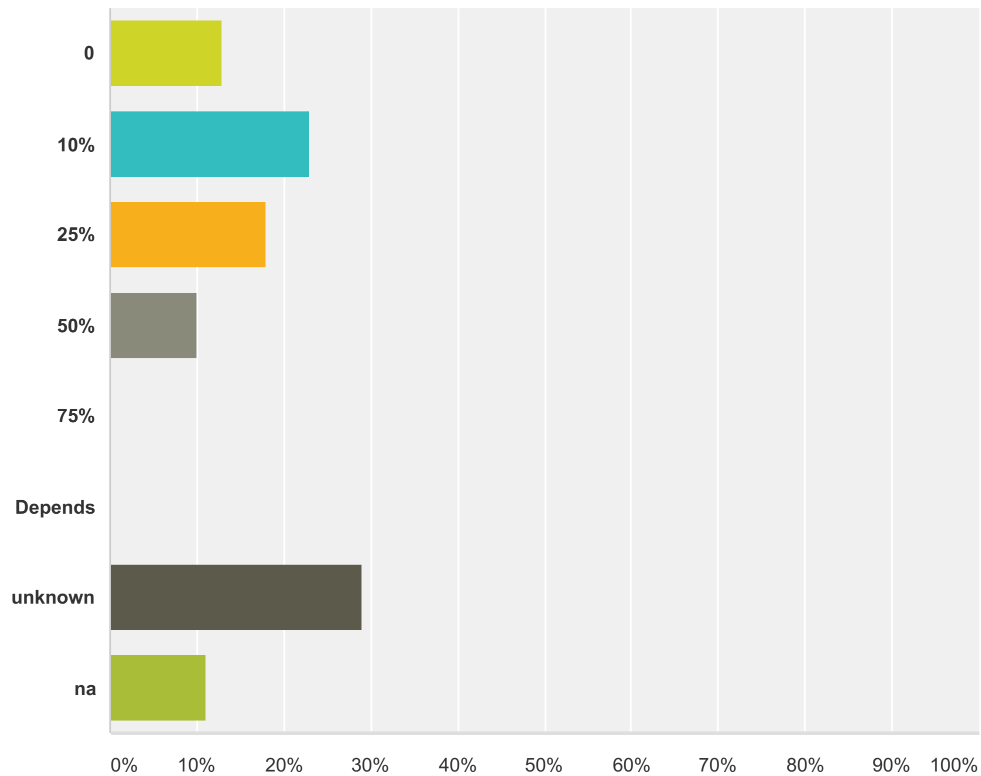
Answer Choices	Responses	
Low	**7.00%**	7
Medium	**30.00%**	30
High	**52.00%**	52
Depends	**10.00%**	10
none	**0.00%**	0
na	**6.00%**	6
Total Respondents: 100		

#	Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on	Date
1	oftem high level of detail required but not always. "best tool for the job" concept applies	3/12/2009 12:35 PM
2	Generally not too detailed as long as final reconciliation is available.	1/30/2009 5:04 PM
3	Generally very high in operations so that variances from production budgets can be quickly identified and understood for management response. Data acquisition for construction will require sufficient detail for timely reporting and corrective action.	1/30/2009 3:05 PM
4	As accurate as we can be – easy to track tonnages coming from a plan, but tough to measure tonnages once they are on the ground. GPS when possible – since this is a very accurate means of measurement	1/30/2009 3:04 PM
5	Two decimal places	1/30/2009 2:31 PM
6	varies with unit value (higher unit values demand and justify finer level of detail)	1/30/2009 2:30 PM
7	depends on what type of model and what phase the model is from. SD - DD - CD - Construction phase...	1/30/2009 2:12 PM

8	The items are generally not arrive at the lowest detail	1/10/2009 5:20 PM
9	?	1/10/2009 5:19 PM
10	on size of project on type of project	1/10/2009 4:33 PM
11	They were specific in keeping an up-to-date journal with quantities	1/10/2009 4:32 PM
12	Basic level: percent installed vs. percent purchased.	1/10/2009 4:32 PM

Q22 Number of items quantity is typically / sometimes estimated

Answered: 100 Skipped: 75



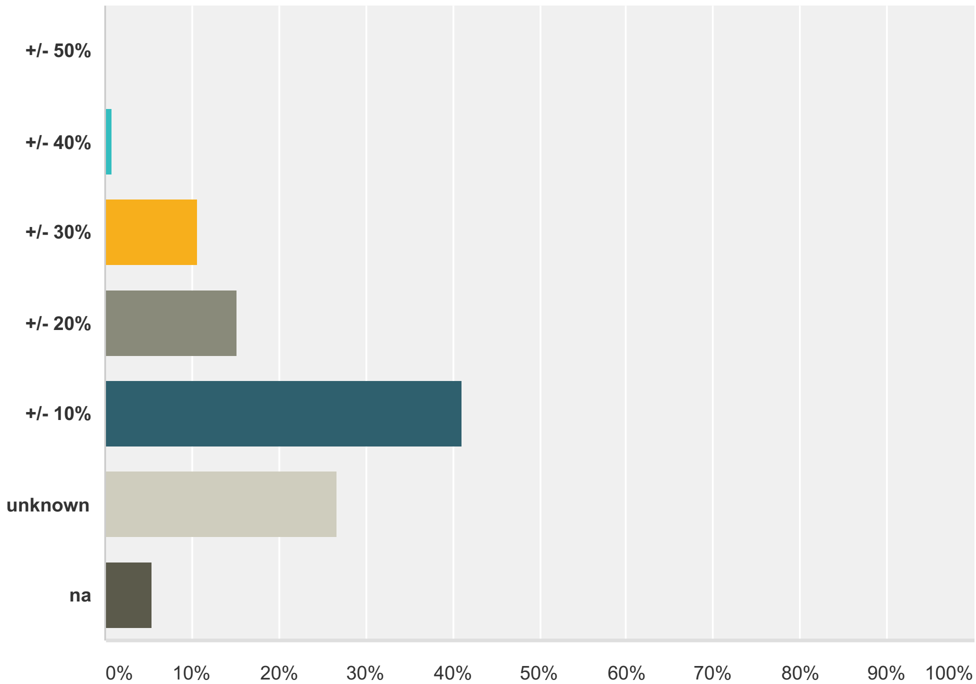
Answer Choices	Responses	
0	**13.00%**	13
10%	**23.00%**	23
25%	**18.00%**	18
50%	**10.00%**	10
75%	**0.00%**	0
Depends	**0.00%**	0
unknown	**29.00%**	29
na	**11.00%**	11
Total Respondents: 100		

#	Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on. Also, provide the method used to estimate the quantity, e.g., unit cost, % of time, % of cost, guess	Date
1	Progress data is often estimated for many items	1/30/2009 5:04 PM
2	We usually have some way to verify a quantity – so I'd like to think less than 10% of the quantity is a true "estimate" – I would say maybe 30% is some sort of conversion based off of the available data (i.e. a ten wheeler carries 10 loads to a dump @ 7 CY per load = 70 CY total). On a lump sum type of project, billing quantities do not have to be exact like they do on a unit price contract every pay period.	1/30/2009 3:04 PM

3	Depends on importance of quantities being tracked.	1/30/2009 3:04 PM
4	The less estimated the lower the cost.	1/30/2009 3:03 PM
5	All quantities are estimated and forecasted based on progress and performance	1/30/2009 3:02 PM
6	depends	1/30/2009 3:02 PM
7	more than 85%	1/30/2009 3:01 PM
8	All quantities are estimated prior to production.	1/30/2009 3:00 PM
9	Digital models are 100% accurate	1/30/2009 3:00 PM
10	Assume You mean guesstimated? We try to keep as low as practical.	1/30/2009 2:59 PM
11	depends	1/30/2009 2:58 PM
12	depends	1/30/2009 2:58 PM
13	The specific program or mailing we are doing.	1/30/2009 2:32 PM
14	15 to 25 per month	1/30/2009 2:31 PM
15	depends	1/30/2009 2:13 PM
16	I have püroblems understanding the question	1/30/2009 2:10 PM
17	depends, The clarity of the document dictates the percentage also the delievery contract type	1/30/2009 2:04 PM
18	depends	1/30/2009 2:02 PM
19	100 items	1/22/2009 4:37 PM
20	Some quantities are done as estimates until surveying work is completed.	1/10/2009 4:34 PM
21	Strucures work, until items are complete % are used so there is a level of subjectiveness	1/10/2009 4:33 PM
22	10 % is approximated.	1/10/2009 4:32 PM
23	depends on the critical nature	1/10/2009 4:25 PM
24	depends	1/8/2009 3:15 PM
25	all items are estimate when establishing budgets; during construction, based on work completed.	1/8/2009 3:12 PM

Q23 Percent accuracy in any typical data set

Answered: 112 Skipped: 63



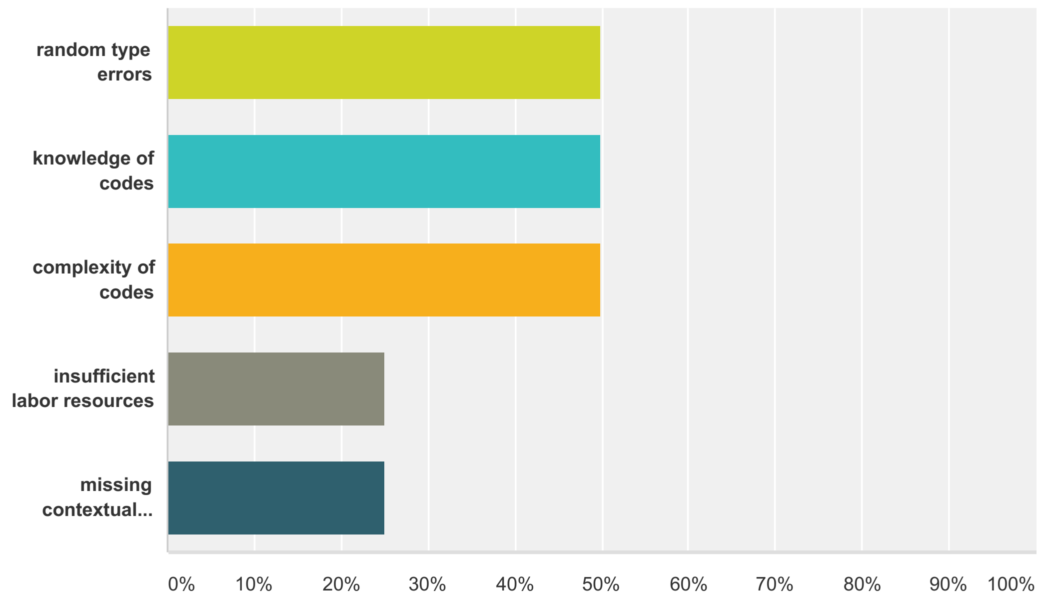
Answer Choices	Responses	
+/- 50%	**0.00%**	0
+/- 40%	**0.89%**	1
+/- 30%	**10.71%**	12
+/- 20%	**15.18%**	17
+/- 10%	**41.07%**	46
unknown	**26.79%**	30
na	**5.36%**	6
Total Respondents: 112		

#	Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on	Date
1	most modern survey work is performed at the 2 sigma level and sometimes but rarely 3 sigma. This is not well understood by many older generation surveyors however their methods produced similar results. Publish accuracy and precision standards often apply.	3/12/2009 12:35 PM
2	+/-10%	1/30/2009 5:04 PM
3	Higher than 90% for anything related to production mass balances.	1/30/2009 3:05 PM
4	Probably 80% accurate – most schedules of value on a billing sheet list finished products, so it is pretty easy to quantify. There is always some room for error (maybe a scale on a crusher belt has not been calibrated recently – or maybe trucks are loaded higher by one loader operator than another)	1/30/2009 3:04 PM

5	How good is your estimate? How good is quantity installed? How good is your forecast? "Garbge In, Garbage Out" in any system, even Excel ...	1/30/2009 3:02 PM
6	close to 100	1/30/2009 3:01 PM
7	100%	1/30/2009 3:00 PM
8	5% to 10%	1/30/2009 2:31 PM
9	80% to 90%	1/30/2009 2:26 PM
10	100 % complete 80 % accurate - wild guess!	1/30/2009 2:10 PM
11	It can vary depending on the risk and what is discovered	1/30/2009 2:04 PM
12	99 %	1/22/2009 4:37 PM
13	95%	1/11/2009 8:45 PM
14	100%	1/10/2009 5:43 PM
15	Certainly high by the time the job is completed and all numbers are finalized. Along the way, they are generally very accurate using 'inputs' rather than survey assessments (which are typically done later).	1/10/2009 4:34 PM
16	Probably 90% based on the skill level of the field engineer	1/10/2009 4:33 PM
17	depends on how important that particular item is	1/10/2009 4:31 PM
18	90-100	1/8/2009 5:03 PM

Q24 What is the source of classification miscodes

Answered: 4 Skipped: 171



Answer Choices	Responses	
random type errors	**50.00%**	2
knowledge of codes	**50.00%**	2
complexity of codes	**50.00%**	2
insufficient labor resources	**25.00%**	1
missing contextual information for classification	**25.00%**	1
Total Respondents: 4		

#	Other (please specify), if it depends check best answer and define the independent variable, i.e., what it depend on	Date
1	systemic error and random error are managed by robust statistical analysis, and by diligent application of standards.	3/12/2009 12:35 PM

Q25 Areas you think need improvement

Answered: 89 Skipped: 86

#	Responses	Date
1	The art and science of measurement are not strongly enough emphasised in engineering and technology education. Conditional variables of measurement and validation are too often overlooked when designing collection methods and procedures. So then the outcomes are taken for granted. Technology is to often substituted for human judgement. We read the value of the measurement but we don't know what it means and we don't know how to validate it. Deployemnt of technology must be accompanied with training to understand the results and not simply report the results. This is the fundamental difference between reliable professional results and not.	3/12/2009 12:55 PM
2	Less paperwork, however simply having drivers fill out paperwork correctly would be the biggest asset.	3/3/2009 8:14 PM
3	Better coordination between the owner and the contractor.	2/5/2009 2:06 PM
4	Institute data warehousing software to automate data collection and sharing information	1/30/2009 3:05 PM
5	larger sample sizes	1/30/2009 3:05 PM
6	Construction quantity tracking methodology is highly variable from contractor to contractor, especially when dealing with lower tier companies. As a client, we have to be educated consumers when selecting contractors so that we have sufficiently reliable and meaningful reporting during the course of a project. Contractor capabilities vary tremendously in the industry, especially when dealing with companies from many different countries.	1/30/2009 3:05 PM
7	I think we are heading in the right direction by utilizing GPS more frequently. There is little margin for error with a data collector and it downloads nicely to create as-builts plans; making quantity tracking and creating as-buits more accurate and quicker to do.	1/30/2009 3:05 PM
8	Consolidation of data so it is more manageable. With the magnitude of items to be tracked, entered, and continulally updated, requires full time attention and often times the overhead to do so is not provided.	1/30/2009 3:04 PM
9	We need further development in the use of 3D modelling as it moves to 4 and 5D modelling. We also need owners and engineers who want and like modelling to assist by CADing their projects. This allows for easy and timely modelling of the project. This will then lead to effective BIM Estimating.	1/30/2009 3:04 PM
10	Universality of methodology. Reduction of field labor.	1/30/2009 3:04 PM
11	Basic needs are now being met.	1/30/2009 3:04 PM
12	Documentation from source to office collecting data	1/30/2009 3:03 PM
13	software capabilities	1/30/2009 3:03 PM
14	The quality of the software on the market that is current sold to meet the requirement	1/30/2009 3:03 PM
15	Consistency, intentionality, precision	1/30/2009 3:02 PM
16	Top Management. Decisions should come from the top ... Do not hesitate to contact me: jlmeynier@integralvision.com Integrated System: Project Management Integral Vision (PMIV) www.integralvision.com	1/30/2009 3:02 PM
17	knowledge of data takers using specific equipment	1/30/2009 3:02 PM
18	Overlap areas leading to problem plastering, floor finish moulding	1/30/2009 3:01 PM
19	Largely a manual and labor intensive process - needs to be streamlined and automated.	1/30/2009 3:01 PM
20	increase use of technologies such as rfid	1/30/2009 3:01 PM
21	Measuring tools	1/30/2009 3:01 PM
22	Alignments across areas of what is the definition of the measurements and the agreed way of distinctive measures	1/30/2009 3:00 PM
23	User friendly technology for data aquisition and management	1/30/2009 3:00 PM
24	need to adopt RFID industry wide	1/30/2009 3:00 PM
25	Managing material supply chain management, Vendor Inventory management	1/30/2009 2:59 PM
26	level of effort need to get accurate estimate	1/30/2009 2:59 PM
27	Use of mobile devices such as mobile phones to collect data.	1/30/2009 2:59 PM

28	Administrative requirements of clients and ownere	1/30/2009 2:58 PM
29	Standardization of cost tracking on each project site	1/30/2009 2:58 PM
30	prefabricated interior units motivation management for labors	1/30/2009 2:33 PM
31	Manual/hand measurements	1/30/2009 2:31 PM
32	The more that is modeled in the BIM, the more accurate we can be. The 90% number above is for the parts we calculate, based on the BIM	1/30/2009 2:31 PM
33	We are constantly trying to improve, even as industry is changing. The larger the database one maintains, the more difficult it is to keep it accurate….	1/30/2009 2:31 PM
34	automated data collection. upstream/downstream integration of data.	1/30/2009 2:30 PM
35	Require AEs to deliver electronic documents to Contractors at bid stage	1/30/2009 2:30 PM
36	Automate data collection in the field log equipment time wirelessly capture level of effort electronically	1/30/2009 2:26 PM
37	Communication between the owner, designer, and contractor when defining what is intended and required when agreeing on model based quantity extraction. Lack of understanding that what is possible and beneficial can be two different things especially between team members. Too often the contract requires model based estimating, but does not specify what this means in detail and who is responsible for what. This can lead to confusion and errors. These definitions are becoming better understood, but the AE community needs to be educated on what is required of them to make this happen.	1/30/2009 2:26 PM
38	Traceability of figures	1/30/2009 2:25 PM
39	Defining metrics to collect	1/30/2009 2:25 PM
40	Base on what client requires	1/30/2009 2:24 PM
41	Automated field data collection and accounting conventions to support automated billing & cash flow.	1/30/2009 2:20 PM
42	Estimating needs to be able to gather data based on real cost from accurate billings.	1/30/2009 2:20 PM
43	The human element is always a factor. The level of care and interest applied varies from one individual to another. Any scheme that can somehow remove these variations is desirable.	1/30/2009 2:14 PM
44	Better awareness and recognition of the benefits BIM can provide	1/30/2009 2:13 PM
45	Better quality of design BIM for increased quantity - Standard collection and tracking mechanism, cost avoidence estimation, getting all team members involved in data collection for more accurate results.	1/30/2009 2:12 PM
46	Overall systems that allow to make use of data without constantly recounting.	1/30/2009 2:10 PM
47	N/A	1/30/2009 2:06 PM
48	digital file management	1/30/2009 2:05 PM
49	Consistancy and future use of data	1/30/2009 2:04 PM
50	Communication between all parties	1/30/2009 2:04 PM
51	We need to get away from manual counts. Bar codes would be helpful	1/30/2009 2:02 PM
52	Communication tools between all stakeholders	1/30/2009 2:02 PM
53	Field input of in place quanities. Accuracy of Design models and transference of quantities from model to estimate.	1/30/2009 1:58 PM
54	We would like to gather more information via GPS for future referencing	1/22/2009 5:26 PM
55	faster and more accurate 3D imaging	1/22/2009 5:23 PM
56	QA/QC	1/22/2009 4:51 PM
57	Interface between management and estimating	1/22/2009 4:51 PM
58	Review process at end of each project	1/22/2009 4:37 PM
59	Transfer of information from remote to central sites on a daily basis	1/12/2009 8:45 AM
60	More GPS quantity measurement and electronic transphere of information will be online in 2009	1/11/2009 8:45 PM
61	We just simply need to simplify and standardize all processes and efforts to collect data.	1/11/2009 12:08 PM
62	nurse workload	1/10/2009 5:43 PM

63	The cost control and the physical progress are not grouped in the same way, because the costs are related to the budget and the principle of the whole project was adjusting	1/10/2009 5:20 PM
64	need strong push to get A&E's to buy into BIM ASAP!!!!!!!!!!	1/10/2009 5:19 PM
65	Less use of engineers and transfer to tech type role	1/10/2009 4:47 PM
66	Integrated electronic analysis and override.	1/10/2009 4:46 PM
67	Coordination, Forecastin, Accuracy	1/10/2009 4:40 PM
68	It would be interesting to improve the interchanges of information between the different parts invovled in the project. I mean, it would be interesting to use a kind of wiki where different departments (environmental, quality, safety…) ciuld share the information.	1/10/2009 4:34 PM
69	Tracking rework, job delay and time wasted due to various job conditions or discrepancies in the plans. Tracking this information could provide very useful feedback on improvement areas and improving trends.	1/10/2009 4:34 PM
70	Training and understanding of field engineers	1/10/2009 4:33 PM
71	Additional staff, however, budget rarely allows this.	1/10/2009 4:32 PM
72	basically quite satisfied	1/10/2009 4:31 PM
73	automation in collecting quantities at given points in the data supply chain. An example is haul trucks, the scale house measures the weight electronically and could be captured at that time.	1/10/2009 4:22 PM
74	The remote monitoring of equipment health.	1/10/2009 4:04 PM
75	Commitment to accuracy of fault analysis move to paperless system in hand but needs to be completed soon	1/8/2009 6:37 PM
76	Testing materal on-site. Even though their are accurate instruction on testing procedure. Over 50% of field collections I have observed are inaccurate done. Which ends up in a large discussion and then most of the time correctly sampled.	1/8/2009 6:35 PM
77	Material balances, supply chain integration	1/8/2009 6:29 PM
78	Accuracy of tracking/estimates	1/8/2009 6:15 PM
79	Communication of productivity to project team	1/8/2009 5:03 PM
80	1)Depending on geographic location, the opportunities to divert and/or recycle waste can vary significantly. We are working on establishing a company-wide policy for waste diversion for all jobsites, regardless of location. 2) Would be great to have a resource that matches waste producers, with the materials salvage market. A way to match source and need. CAIWMB does a pretty good job of this.	1/8/2009 4:40 PM
81	Better definition of what needs to be collected even before the project starts. How the data will be used also needs to be defined.	1/8/2009 4:17 PM
82	Ease of transmission of data from remote location to office.	1/8/2009 3:05 PM
83	GC and Subs cost and quantities availabe via tablet.	1/8/2009 2:48 PM
84	software supports in construction projects in the area	1/8/2009 2:19 PM
85	Near real time tracking and error correction	1/8/2009 2:13 PM
86	Everything always needs improvement.	1/8/2009 2:10 PM
87	Manpower (labor resource FP) loading in schedules	1/8/2009 2:09 PM
88	Increased testing frequency. Better method for inputting data and separating/tracking/sharing data.	1/8/2009 2:08 PM
89	automatization	12/12/2008 8:02 AM

Q26 Your vision for the role of technology or improved methods in your field

Answered: 97 Skipped: 78

#	Responses	Date
1	I fear too heavy of a reliance on technology will continue to erode the quality of collection data. Metrology and Geomatic Engineers should be key in developing collection processes, standards, tools and especially the deployment of the technology to validate the expected results.	3/12/2009 12:55 PM
2	All electronic system that requires no manual knowledge of anything. Craft complete their work but an electronic system actually completes everything necessary	3/3/2009 8:14 PM
3	Digital model to accurate measure the as-built quantities.	2/5/2009 2:06 PM
4	More transparency in supply chain, productivity and cost control information	1/30/2009 3:05 PM
5	direct to presentations	1/30/2009 3:05 PM
6	Improving 3D visualization and modeling will help move projects along faster because visualization is a great public education tool.	1/30/2009 3:05 PM
7	Improved systems and methodology.	1/30/2009 3:05 PM
8	We need to keep exploring GPS systems. We also need to create an environment where our field team is comfortable around computers and electronics since they are the way of the future.	1/30/2009 3:05 PM
9	It starts in the field with the Foreman. They are the ones on the ground and on the front lines. If they can be trained to utilize the technology available to them, quantities can be tracked more accurately.	1/30/2009 3:04 PM
10	Owners and Engineers providing CAD drawings with the tender or design packages to allow modelling to be done quicker and within the time allotted for quantifying and pricing the work.	1/30/2009 3:04 PM
11	Improved systems, methodology.	1/30/2009 3:04 PM
12	Future enhancements possible in ease of reporting and analytical tools.	1/30/2009 3:04 PM
13	Need an expanded role to deal with changing markets, especially recycling	1/30/2009 3:03 PM
14	provide better performance not to be so much manual input	1/30/2009 3:03 PM
15	The greatest impacts to cost and quality are directly related to work process.	1/30/2009 3:03 PM
16	I want to try to require use of TotalStation or similar system on all larger building and renovation projects. Not there yet.	1/30/2009 3:02 PM
17	Technology will always help, but keep in mind that your are still depending of HUMAN to get for example quantities installed ... Depend also the type of project: fast track, Eng. 100% before Constr?	1/30/2009 3:02 PM
18	vital	1/30/2009 3:02 PM
19	I believe that the use of BIM will make determining quantities much easier and much more accurately. We are working on ways that a craftsman can color a set of drawings on a computer screen to record progress.	1/30/2009 3:02 PM
20	workers should be better at checking their own work so QC process can be gradually reduced	1/30/2009 3:02 PM
21	it can solve major problems	1/30/2009 3:01 PM
22	Improvements in RFID/GPS material tracking, tighter integration with 3D model.	1/30/2009 3:01 PM
23	see item 1 - RFID	1/30/2009 3:01 PM
24	Higher accuracy in GPS	1/30/2009 3:01 PM
25	IT has a very important role in providing the framework for collecting the data, it possibilitates the right track of the information follow up	1/30/2009 3:00 PM
26	improve accuracy and ease collection data nad evaluating assests. We no longer use bar codes and laptops, too difficult to maintain in harsh environments and not user friendly.	1/30/2009 3:00 PM
27	long story. order of magnitude increase in building lifecycle information management and simulation.	1/30/2009 3:00 PM

28	all MTO from 3d model	1/30/2009 2:59 PM
29	Automated downloads from 3D system to accounting system.	1/30/2009 2:59 PM
30	RFID and improved user interfaces in mobile devices	1/30/2009 2:59 PM
31	Convincing owners and clients to utilize electronic tools and techniques	1/30/2009 2:58 PM
32	PDA's will likely not help anytime soon. Modernized data entry system would help.	1/30/2009 2:58 PM
33	automatic data collection information sharing	1/30/2009 2:33 PM
34	Better electronic and survey equipment	1/30/2009 2:31 PM
35	BIM driven takeoff, estimating, scheduling, bid management, and procurement will change dramatically over the next 10 years --- such that the construction industry will see a huge improvement in accuracy and efficiency --- as we have seen in manufacturing over the past 15 years.	1/30/2009 2:31 PM
36	We are moving to web-based delivery of data, and trying to deal with the technical demands of interoperability	1/30/2009 2:31 PM
37	fully integrated, automated job site.	1/30/2009 2:30 PM
38	Take a look at www.velasystems.com	1/30/2009 2:30 PM
39	Ask Martin to give me a call re this.	1/30/2009 2:30 PM
40	Development and adoption of construction specific standards for exhange of information between applications, such as agcXML.	1/30/2009 2:30 PM
41	realtime costs of construction. helps to control cost overruns, claims and reduces change/claim settlement time.	1/30/2009 2:26 PM
42	I see model based estimating as a way to more effiecently get "some" quantities from the model and use these to automate "some" of the estimating process. On projects where the design and construction team is tightly integrated and collaborative, much more effieciency can be gained, especially when the model and estimate are updated on a regular basis. However, model based estimating will never replace the need for analysis and review by a seasoned estimator.	1/30/2009 2:26 PM
43	I have created an entire operational management system with cost codes activity codes etc… this hierachichal system was briefly tested and fits in with our ERP system, scheduling, purchasing and admin departments. We will be implementing over the next few months and if it works we will be able to improve our accuracy from 40% to about 80% over time or so I hope.	1/30/2009 2:25 PM
44	Will improve as we move towards model based estimating rather than just quantity takeoffs	1/30/2009 2:25 PM
45	hand held equipment	1/30/2009 2:24 PM
46	technology helps store information	1/30/2009 2:24 PM
47	I love technology and all that it has to offer...I do however find myself repeating a relevant phrase that could be looked at as a vision for the role of improving methods: "never let technology in the way of strategy," in other words, use it but use it judiciously.	1/30/2009 2:22 PM
48	Anything that can cost effectively reduce staff levels at site would be a competitive advantage.	1/30/2009 2:22 PM
49	Using BIM to measure work in place	1/30/2009 2:21 PM
50	Automate downstream decision-making and integrated cost analysis systems.	1/30/2009 2:20 PM
51	I am currently developing other tools that will allow for a complete feedback loop from estimating to budget to procurement to scheduling to field tracking and back to oracle and estimating.	1/30/2009 2:20 PM
52	To the extent that technology can flatten or eliminate the variance between individuals doing the measurement/data capture, this is desirable. The technology would have to be easy to learn/use because the individuals involved can be older and "old school" in their approach and also somewhat resistant to change.	1/30/2009 2:14 PM
53	Complete integration of BIM during project delievery	1/30/2009 2:13 PM
54	My vision is to increase quality of work, eliminate rework, increase communication, increase productivity of self perform functions, increase use of prefabrication of systems in controlled environment rather than in dangerous construction zone. Technology is allowing for the above items to happen, the major obstacle is getting all project team members used to the implementation of new technologies in the field. Our focus is in improving safety and quality control from the laborer up to the superintendant.	1/30/2009 2:12 PM
55	Technology that is robust, easy to handle and will be accepted in the industry	1/30/2009 2:10 PM

56	In new buildings very high. In renovation not so high, but needs some improvements or to initialize some new methods/tecnical aids/softwares.	1/30/2009 2:06 PM
57	quicker and more accurate data tracking	1/30/2009 2:05 PM
58	RFID and 3D modeling are playing a bigger role	1/30/2009 2:04 PM
59	Early coordination and less conflicts in the field	1/30/2009 2:04 PM
60	Technology is only as good as the people that use it. Continuous training is needed.	1/30/2009 2:02 PM
61	Better communication between stakeholders instead of just e-mail chatter, possibly some sort of central webpage that utilizes a program that can show progress of project	1/30/2009 2:02 PM
62	A seemless transition from design models to estimate to as-built quantities.	1/30/2009 1:58 PM
63	Recording more accuracte field will allow us to have more accurate records of our underground utilities. This will allow us to save money in the future.	1/22/2009 5:26 PM
64	3-D	1/22/2009 4:51 PM
65	Would like to integrate a little more technology	1/22/2009 4:51 PM
66	Improved cost estimates and forecasts. Bar coded materials.	1/22/2009 4:37 PM
67	Transfer of information from remote to central sites on a daily basis	1/12/2009 8:45 AM
68	One source equipmentment, with high availibility with automatic information transphere	1/11/2009 8:45 PM
69	Upgrade to more user friendly and up to date software, determine how and what functions in the new software to use.	1/11/2009 12:08 PM
70	technology that will decrease workload on nurse = improved patient safety and hastened patient health recovery	1/10/2009 5:43 PM
71	I think that there should be a basic program for control of projects and that each company what suits the way you work	1/10/2009 5:20 PM
72	BIM	1/10/2009 5:19 PM
73	Has improved automation	1/10/2009 4:47 PM
74	More and more automation	1/10/2009 4:46 PM
75	Construction performance can be improved dramatically if the appropriatge level of Technology is implemented, the implementation is managed and followed up as change and Senior Management uses it to manage	1/10/2009 4:40 PM
76	I think it is important to bring to construction world new methodologies that let us work more efficiently. Sometimes it seems that we are working like in the last century.	1/10/2009 4:34 PM
77	Technology is playing and will continue to play a growing role	1/10/2009 4:34 PM
78	Hand held units are good, such as the GPS rovers	1/10/2009 4:33 PM
79	Very basic technology is used, tape measure & calculator typically.	1/10/2009 4:32 PM
80	better surveying tools	1/10/2009 4:31 PM
81	A formal method for collecting field quantities using electronic methods, manual methods and statistical inference.	1/10/2009 4:22 PM
82	I would like to see faster, cheaper, and more robust methods of laying out profiles for drill and blast and NATM tunnels. This equipment would also give real-time feedback of overbreak, tights & overbreak, and shotcrete profiles.	1/10/2009 4:04 PM
83	Single system to give common process management data is escential	1/8/2009 6:37 PM
84	Stop using summer help to make very important samples. Only lab technicians who have at least passed field technician 1 should be allowed to collect.	1/8/2009 6:35 PM
85	reliable automated data acquisition	1/8/2009 6:29 PM
86	Improved data collection / transmission eliminate human transfer by conversion to digital/electronic methods.	1/8/2009 6:15 PM
87	There is certainly room for improved tracking.	1/8/2009 4:40 PM
88	Each individual worker has a device on which he selects a task when he is working on it. He also selects the part he was working on by clicking on a digital model. Pan tilt zoom camera scanning for quantities collection. Inventory check up and analysis integrated with production to see what has been built.	1/8/2009 4:17 PM
89	cost loaded building plans - highlight portions as work is installed, this would generate pay requests	1/8/2009 3:12 PM
90	Increased use of 3D modeling	1/8/2009 3:05 PM

91	Tablets, integration of schedule, cost, model	1/8/2009 2:48 PM
92	the status of technology or improved methods in the field will keep on rising.	1/8/2009 2:19 PM
93	Converting to web-based and PDA driven data logging next year	1/8/2009 2:13 PM
94	Headed towards automation	1/8/2009 2:10 PM
95	Acurate manpower (labor resource FP) loaded schedules that directly tie to monthly billings	1/8/2009 2:09 PM
96	Use of Table PC for data collection in the field	1/8/2009 2:06 PM
97	minimize errors on interpretation, quantification, questions, etc.	12/12/2008 8:02 AM

Q27 What is your view of activity codes and cost codes (in general any classification / identification code) accuracy, i.e., miscodes

Answered: 88 Skipped: 87

#	Responses	Date
1	Absolute necessity. Can't avoid it. Gets better all the time. classification and coding will continue to improve in both usefulness and accuracy.	3/12/2009 12:55 PM
2	Need to have a person in the company who knows the codes and importance of their use. From my experience this is attainable to a 90-95% accuracy.	3/3/2009 8:14 PM
3	-	2/5/2009 2:06 PM
4	need standardized "sacred" codes that do not change ever to track cost and productivity data on a consistent basis.	1/30/2009 3:05 PM
5	not an issue	1/30/2009 3:05 PM
6	Survey codes for topo are helpful to automate the plan preparation but there is always manual correction time.	1/30/2009 3:05 PM
7	This is important in the project business but less of a factor in mine production.	1/30/2009 3:05 PM
8	30% of the time, Foreman are coding to incorrect cost codes. Consistency or standardzing of coding system from project to project would reduce the amount of errors on cost coding.	1/30/2009 3:04 PM
9	We use a standard cost coding system(following the Masterformat) which easily ties to our scheduling activities. We use Primavera P3 and all our engineers are used to coding activites in primavera. Many of our projects are both cost and resource loaded. So our estimate line items relate to our schedule line items.	1/30/2009 3:04 PM
10	unknown	1/30/2009 3:03 PM
11	For geotechnical engineering, there is no national codes in US	1/30/2009 3:03 PM
12	It would be best if there were standards of any coded item. There are often duplcates. generally accorss disciplines and when the projects are work shared accross companies	1/30/2009 3:03 PM
13	poor	1/30/2009 3:02 PM
14	The first few months of any project are the most important. If a job is setup properly, you minimize headaches, I did not say you remove them, you still will have some. Experience will help a lot.	1/30/2009 3:02 PM
15	key to tracking and reporting	1/30/2009 3:02 PM
16	about 4% which has been that way for over 30 years	1/30/2009 3:02 PM
17	lots of them and is leading to confusion to even create a database	1/30/2009 3:01 PM
18	very accurate - embedded in tools	1/30/2009 3:01 PM
19	not an issue. standard across projects	1/30/2009 3:01 PM
20	It's of high importance but there's a lack of tracking on the cost codes, sometimes referred as the cost of doing business, but what is really is a lacked of tracking the accuracy of the results.	1/30/2009 3:00 PM
21	high	1/30/2009 3:00 PM
22	manageable with standardization and overall process sophistication	1/30/2009 3:00 PM
23	Important look to align with Suppliers part numbers	1/30/2009 2:59 PM
24	Use cost codes but limited number of activity codes.	1/30/2009 2:59 PM
25	subject ot human error on imput	1/30/2009 2:58 PM
26	Quantities are always reconciled at the end of a project, so small discprepencies during the project are not that big of a deal. Large errors can cause significant problems.	1/30/2009 2:58 PM
27	it would be difficult in international projects until they are standardized and automated.	1/30/2009 2:33 PM
28	we tried to avoid mistakes as best we could	1/30/2009 2:31 PM

29	Technology helps make these more consistent.	1/30/2009 2:31 PM
30	A large part if my time this year has been devoted to the CSI committee trying to 'harmonize' UNIFORMAT, and to the ASTM committee that sponsors the standard for UNIFORMAT II; also use MF04. Cost codes are necessary for our business.	1/30/2009 2:31 PM
31	too many codes = too prone to human error. therefore need more automated data collection as above.	1/30/2009 2:30 PM
32	Not applicable	1/30/2009 2:30 PM
33	Accuracy is greatly improved using field devices when compared to manual (paper) collection.	1/30/2009 2:30 PM
34	difficult and labor intensive to achieve an 80% confidence interval. Need to use new technology with appropriate checks and balances to improve the control of construction projects.	1/30/2009 2:26 PM
35	I feel that using activity codes in the model are helpful for scheduling purposes, but our cost codes are kept at the estimate item level. One CAD object may equate to several estimating objects that would have different cost codes. Example would be a concrete wall. We would estimate the formwork and concrete from the single CAD object, but these would be track in Job Cost as two different cost codes.	1/30/2009 2:26 PM
36	See above	1/30/2009 2:25 PM
37	Important at the modeling level i.e. predefined content plans and level of model detail depending on phase of the project.	1/30/2009 2:25 PM
38	Makes it easy to track quantities	1/30/2009 2:24 PM
39	Cost code system seems to work well. Sorry i could not offer more info but as a general contractor we do not self perform much work and therefore our cost data depends on pricing from subcontactors. We never really know if they made a good estimate or not.	1/30/2009 2:24 PM
40	While not my area of expertise, these codes often seem to be used as "holding places" for data that will be inevitably shuffled to another location before finding a final "home."	1/30/2009 2:22 PM
41	Very important to establish early in the project, establish structure and stick to it.	1/30/2009 2:22 PM
42	About 95% accurate	1/30/2009 2:21 PM
43	Absolutely critical.	1/30/2009 2:20 PM
44	Activity and cost codes are essential in order to classify types of items so that they are easily groupd and destinguishable.	1/30/2009 2:20 PM
45	No opinion here.	1/30/2009 2:14 PM
46	They seem most important during tender rather than during construction.	1/30/2009 2:13 PM
47	Activity codes and cost codes play a huge role in project cost control, but it is the people on the jobsites that we are seeing innovation come from.	1/30/2009 2:12 PM
48	I guess miscoding will be around 10%	1/30/2009 2:10 PM
49	Sorry--this is not my area of involvement	1/30/2009 2:06 PM
50	N/A	1/30/2009 2:06 PM
51	coding for time spent is presently under utilized. The coding should be simple and transparent to the employee	1/30/2009 2:05 PM
52	Must be standardized	1/30/2009 2:04 PM
53	Very accurate monitored throughout the project our checks and blances tool. We usually bring up mangers from within and are conservative about new hire responsiblities.	1/30/2009 2:04 PM
54	Our accuracy has increased greatly in the last few years due to having the actual workers and users of equipment filling outtime cards and reports daily. These are also reviewed and coded daily.	1/30/2009 2:02 PM
55	Somewhat complicated; great chance of mistakes when inputting codes	1/30/2009 2:02 PM
56	Most design models do not include activity codes that are detailed enough to go straight into an estimating platform. Field input of actual quanities into the correct cost code is at best a 50/50 split between correct and incorrect.	1/30/2009 1:58 PM
57	Not consistent across personnel due to different priorities and perceptions.	1/22/2009 5:28 PM
58	annoying	1/22/2009 4:51 PM
59	Could use room for improvement	1/22/2009 4:51 PM

60	Implentation of new, better technologies into our company will be helpful to our capability for analysis of our costs and production rates	1/22/2009 4:37 PM
61	Some overall organizational framework is good; too much is unweildy, stifling, and unsuccessful	1/12/2009 8:45 AM
62	95% accuracy is sufficient for estimating and cost control	1/11/2009 8:45 PM
63	Because we have a very combersome way of doing things, our accuracy suffers.	1/11/2009 12:08 PM
64	no view, not involved in this aspect of patient care	1/10/2009 5:43 PM
65	Are very important and simplify the processing of vital data for making management decisions	1/10/2009 5:20 PM
66	ALL of this can be put into the BIM	1/10/2009 5:19 PM
67	Usually miscodes are made under management direction (moving cost around, etc).	1/10/2009 4:47 PM
68	It is as important now as in the past.	1/10/2009 4:46 PM
69	All coding from WBS, OBS and CBS (including activity and cost doing) can support the management of projects. It requires flexibity and obviously integration at the appropriate level.	1/10/2009 4:40 PM
70	Because every job is different, sometimes cost codes don’t really fit with a “standard work.” As a result, we tend to look at comparable jobs when understanding what are jobs actually cost us to build rather than look to an overall code average.	1/10/2009 4:34 PM
71	I have not done any research into this subject	1/10/2009 4:33 PM
72	Not applicable in Heavy / Civil construction.	1/10/2009 4:32 PM
73	must be very dependable	1/10/2009 4:31 PM
74	Miscodes can be from carelessness, deliberate manipulation, human errors, poor information and incorrect setup. Coding with algorithms and sensor based systems must be investigated.	1/10/2009 4:22 PM
75	Yes, some things get miscoded, but in our industry there are relatively few cost code activities and some miscoding doesn't really affect the accuracy of our cost activities and manhour factors. We have a lot of cost and activity history and generally know the ballpark that our numbers will be within.	1/10/2009 4:04 PM
76	Needs disipline to ensure correct codes used bar coding will aid accuracy	1/8/2009 6:37 PM
77	decline	1/8/2009 6:35 PM
78	Very important	1/8/2009 6:29 PM
79	None	1/8/2009 6:15 PM
80	Very useful if they are properly defined. Sometimes tasks get grouped even when they don't have a common unit so it is hard to use them for projects later.	1/8/2009 4:17 PM
81	requires someone savy to know codes are applied correctly	1/8/2009 3:12 PM
82	Usually get picked up fairly easily but correction is often more work than its worth	1/8/2009 3:05 PM
83	Needs to be simplified for field entry yet still have the level of detail.	1/8/2009 2:48 PM
84	sometimes codes are not sufficient for estimates. similar codes are applied then.	1/8/2009 2:19 PM
85	None	1/8/2009 2:13 PM
86	Too often there are a number of codes that could be either expanded or simplified.	1/8/2009 2:10 PM
87	I believe in accurate recording of costs as it is the only way for a business to know what its true costs are. Ideally, they would use this information to estimate prices in the future. Unfortunately for me, this view is not consistent with any business of which I have been associated. Unfortunately for you, technology has nothing to do with this mentality. It is rather the product of the dumbing-down of our society; the best societal example I can give is children sports where they no longer keep score so they don't hurt the feelings of the losing team. You are all winners, they say, just for showing up. How silly is that! The recent bailouts of particularly the financial sector point to the fact that none of those so-called "captains of industry" understood what their true costs were.	1/8/2009 2:03 PM
88	if set up and used properly they can be accurate	12/12/2008 8:02 AM

10 Glossary

Project Monitoring Topics: The needs for monitoring, collection methods, potential issues, and the assignment of features to quantities.

Field Project Management: Monitoring actual cost and progress of work at periodic intervals against: a "budget" and "time schedule of operations" (CPM page 17).

Cost Code: *see feature set*

Factors: the product of which produces a number or expression

Feature set: set of factors concatenated according to breakdown structure and represented with an alphanumeric/alphabetic/numeric nomenclature

Group: similar features that form nodes in breakdown structure

Context: bundle of features that give meaning

Tacit: learned pragmatically in a learning-by-doing environment

Attribute-Value System[341]: a framework comprising a table with

- columns designating "attributes" (aka "properties", "predicates," "features," "dimensions," "characteristics", "fields", "headers" or "independent variables" depending on the context) [exogenous]
- rows designating "objects" (aka "entities," "instances," "exemplars," "elements", "records" or "dependent variables") [endogenous]
- each table cell therefore designates the value (also known as "state") of a particular attribute of a particular object.

Nomenclature: the devising or choosing of names for things

Feature: the things that defines the difference between this and that

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[341] Attribute Value System https://en.wikipedia.org/wiki/Attribute-value_system

Quantity: All measured items. Each item has a unit of measure. In quantity I include quantities such as length, volume, and weight as well as a more theoretical quantity such as cost and time.

Breakdown Structure: relation of features

- Work Breakdown Structure (WBS): Section of breakdown structure that represents work tasks, usually includes work division, operation, and method.
- Location Breakdown Structure: Section of breakdown structure that represents workzones, usually defined by project site through to the workzone
- Resource Breakdown Structure: Section of breakdown structure that represents the applied resources such as labor, material, and equipment

In-progress: An activity that has started but has not finished.

Edge scenarios: Cases that are infrequently encountered therefore the practical experience and collective knowledge is weak. Edge scenarios are a topic for research; it is not possible for anyone to know with confidence if a proposed solution is the right one.

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