CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Project Monitoring Methods Exploratory Case Analysis: Industry Responses

By

Forest Peterson & Martin Fischer

CIFE Working Paper #WP112
April 2009

STANFORD UNIVERSITY

If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
The Jerry Yang & Akiko Yamazaki Environment & Energy Building
473 Via Ortega, Room 292, Mail Code: 4020
Stanford, CA 94305-4020

Project Monitoring Methods Exploratory Case Analysis: Industry Responses

Forest Peterson[1] and Martin Fischer[2]

1.0 Abstract:

Topics, issues, intuition

In project type product production the need for feedback creates the task of collecting field progress measurements. This task may be completed by experienced engineers or assigned to interns and field hands. Whichever the case, the process of field production feedback is inherently inaccurate and may lead to unforeseen project events. It is possible that other industry divisions have similar issues and used solutions applicable to construction.

Scope

This paper summarizes a case-based analysis of responses from a focus group. The conclusions drawn from the focus group are then further defined through a questionnaire survey.

Principal findings

A majority (55% to 75% @95% confidence level (CL)) of construction professionals (i.e., salaried) do not use software tools beyond Microsoft office, which indicates software tools (initial/reorganization/training/support) costs are more than the perceived benefits provided.

Conclusions of the paper

The Programmable Logic Controller (PLC) system collects measurements from sensors and links these measurements to an activity's programmable recipe formula and monitoring report. While, this system may not be applicable to most construction sites, components and concepts may be.

[1] Graduate Research Assistant, Dept. of Civil and Env. Eng., Stanford Univ., granite@stanford.edu

[2] Associate Member of ASCE, Ph.D., Professor, Dept. of Civil and Env. Eng., Stanford Univ., and Director, CIFE, fischer@stanford.edu

1.1. Introduction

In the spring of 2007, as part of research into model-based quantity collection and control methods, a questionnaire was distributed by email to a small group of construction, mining and recycling professionals. The questions were open ended and focused on project monitoring methods. The focus group questionnaire was then modified with standard responses and distributed for several months as a survey during autumn 2008.

The ability of model-based systems to plan at a higher level of detail with greater precision and repeatability implies the need for a similarly capable method to monitor field progress. Level of detail is generally correlated to the work breakdown structure. Monitoring at the object level is a lower level of detail than monitoring at the operations level. The collection of sensor-based measurements implies the ability to match these to model-based objects through some method of classification. Due to resource limitations the result of the classification process is increased latency in feedback or decreased accuracy or precision in measurements. The inaccuracy can manifest itself in both measurements and classification of measurements.

From the focus group a small knowledge base was developed of field production monitoring methods. The knowledge from non-construction professionals provided a starting point for investigating model-based quantity collection and control. On further investigation it was found the mining and construction industries are similar, sharing some earthwork and haul operations. Based on this similarity, mining was selected for a case-based analysis of mining methods. From this analysis a potential solution for an issue with classifying field progress measurements expected to be exacerbated by sensor-based methods developed. This method is approached with the intention of an application as either manual or automated classification.

After the focus group analysis the questionnaire was then distributed as a survey to a population in many diverse industry divisions sharing a commonality of the need to monitor progress. This broad domain is defined for the purpose of both generality in topic and to look for reusable knowledge. An industry division inadvertently missed is the commercial airline manufacturing. This division may have provided a transition view of large project methods and assembly manufacturing methods. Any further survey efforts will include this industry division. This paper contains the following topics: underlying intent, questions posed, population, expected results, actual results, conclusions and direction of research.

1.3. Intent of Questionnaire

The questionnaire has three goals interrelated to collecting field progress quantities. First, knowledge on the state of methods used to monitor project progress. Second, identify resource demands and the resulting baseline accuracy expectations. Last, intuition for improvement though reuses of non-construction methods and incremental innovations. A central concept in innovation is that those who perform a function daily may have the best ideas for improvements, so an effort was made to reach trades workers, technicians and engineers rather than management.

Other researchers have given innovative methods to facilitate monitoring of project progress, see figure 1. These methods roughly break down into five categories, these are: vision-based, machine based, micro electromechanical, hand-held computers (HHC) (Saidi 2002) and combinations of these methods. Some vision-based methods are: digital image-based approaches (Golparvar Fard and Peña-Mora 2007), digital and 3D-imaging object recognition (Lytle 2008), 3D range camera (Teizer et al. 2007), and ultra wide-band (UWB) indoor mapping (Fontana 2004). Machine-based methods include 3D machine control (Soderstrom and Olofsson 2007) and onboard sensors (OBS) equipment management (Tatum et al. 2006). Micro electromechanical systems (MEMs) research using Radio Frequency Identification (RFID) component tracking (Ergen et al. 2006) and (Song 2005).

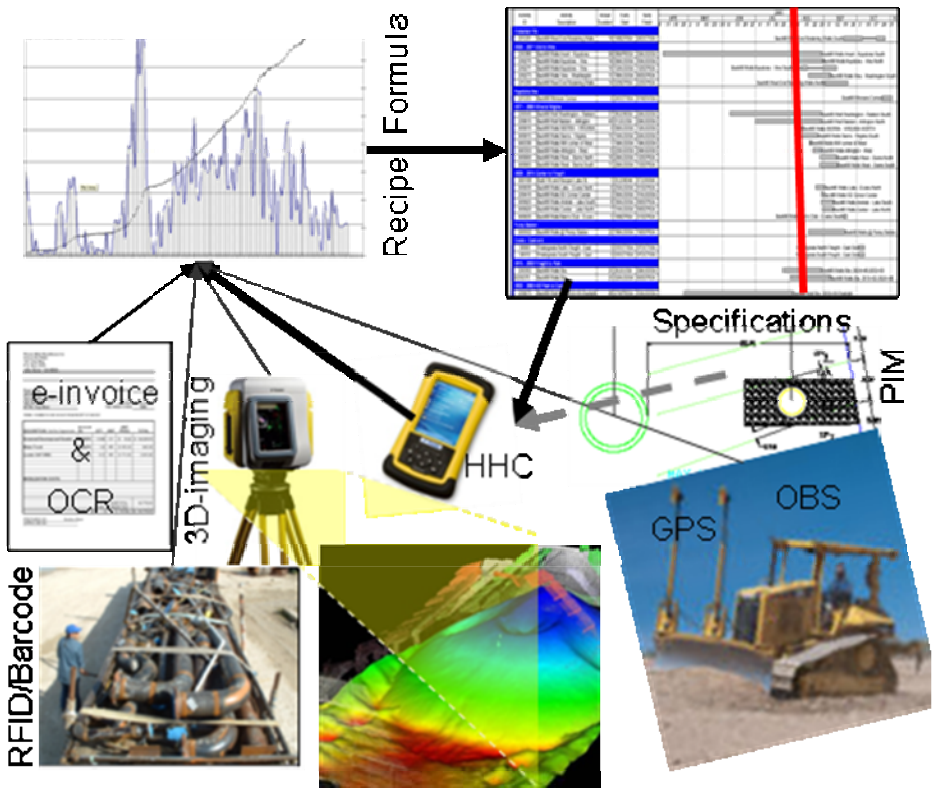

Figure 1 Innovative methods to facilitate monitoring project progress. Graphic is adapted from Song 2005, Trimble, CAT and Isite3D material.

Combinations of the above methods are: automated project performance control (APPC) (Navon and Sacks 2006), sensor based automated data collection (ADC) (Akinci et al. 2006), software such as Graphical information System (GIS) data-fusion (Kizitas et al. 2007) and integrated software support for construction monitoring and control (Fischer and Kunz 1993). Some of the methods outlined above, such as RFID, have been implemented commercially, though most methods are not beyond field trials, particularly object recognition from digital and 3D-images.

1.4. Questionnaire Questions

The questionnaire is divided into categories that provide a holistic view of methods used to collect quantities. These categories are: *quantity-tracking tools, methods of collection, methods of recording, current state* and last *insight into improvement, innovation and coding*. This paper does not cover the full range of the questionnaire but will focus on the electronic collection methods and software tools.

To provide feedback on industry adoption of automation there are two questions concerning the use of electronic collection methods and software tools. It is assumed some of the population surveyed uses manual tracking methods and several questions provide a baseline for later comparison. The current state questions ask four main questions. First, what level of accuracy and precision is expected? Second, what level of detail (LOD) provides this. Third, what resources are required to provide this for the given LOD? And fourth, the number of individual items quantified and the magnitude of measurements. A question concerning how often quantities are estimated is intended to fill the gap between what is possible with the given requirements, methods and resources and what actual project progress is. The last group of questions focuses on the need for improvement. These questions are open ended providing the respondent the opportunity to discuss improvements they perceive are needed, innovative methods adopted and classification issues.

1.5. Focus Group and Survey Population

To better understand field production quantities collection methods, the focus group included professionals from the mining and recycling/waste management industry. The individuals were selected from an available list of alumni employed in the respective industries. From these initial contacts the questionnaire was forwarded to those active in project monitoring.

The survey population was expanded to include a wider domain of industries. The decision to survey outside the construction industry was based on the expectation that other industry divisions may use monitoring methods adaptable to construction. 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 these 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 category 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 data for estimating/forecasting. In contrast, CM firms are interested in monitoring project time variance and verifying GC progress payments requests.

1.6. Expected Focus Group Case-based Solution

The manufacturing industry was expected to have the most automation, from there the level of automation likely decreases in the order listed above to the construction industry which is expected to be the least automated. The most likely peripheral industries expected to have transferable technology was mining and recycling due to the similarity operations and conditions. These two industry division share some of the same activities as construction, such as excavation and haul. The work environment is similar with non-permanent multiple worksites. The expected defining differences that let automated monitoring methods work in mining and recycling is they are routine in processes and semi-permanent. The assumption is these industry divisions will have automated methods in place due to the cyclical nature of the work and yet they will correlate with some construction applications.

It is expected that of the progress monitoring solutions provided by non-construction professionals one or more will stand out as candidates for testing in construction. From this it is expected to define a solution that is likely to benefit construction and begin learning how this system operates and what prevents its implementation in construction.

1.7. Focus Group Analysis

The focus group responses provided several unexpected responses. First, the building contractor unexpectedly preferred manual collection methods for the learning experience provided to new field engineers, see figure 2. 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 as much building material is reused from construction operations as feasible. 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. They would like a method to better document this process and advertise the availability of materials.

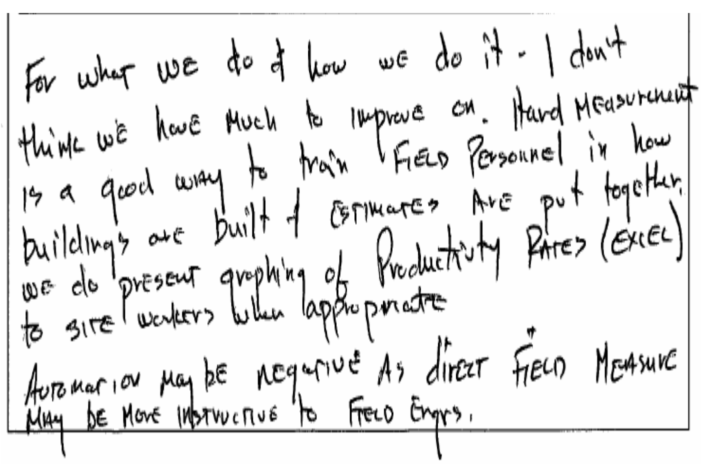
For what we do & how we do it - I don't
think we have much to improve on. Hard Measurement
is a good way to train Field Personnel in how
buildings are built & estimates are put together.
we do present graphing of Productivity Rates (EXCEL)
to site workers when appropriate
Automation may be negative as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

Figure 2 The general builder commented that manual collection methods are preferred because it is a "good way to train field [engineers] how building are built."

As expected the mining industry response described an integrated system made of multiple software tools not typically used in construction. They have had issues with project monitoring and as a solution automated as much of the process as practical. This integrated system consists of a distributed control system, sensors, report generation, a historical library and an enterprise system. Distributed control systems are provided by ABB and Honeywell. The distributed control system uses sensors placed within the process to provide feedback of the process state and process control. The OSIsoft PI system provides report generation and a historical library. The control system, sensors, library and reporting tool are linked with enterprise systems such as SAP and Oracle JD Edwards.

The mining response referenced a company specializing in constructing mining facilities, though not automated they were moving in that direction. They used a flexible system of networked Programmable Logic Controllers (PLC). A review of company websites and a discussion with a technician trained to maintain PLC systems provided further insight. A PLC system is hardwired or wireless with each sensor addressed to a processor specifically programmed for the application, e.g., valve control open and close values. The PLC network itself seems too rigid a system for construction but is simple in concept due to the linear flow of information. This mining knowledge of addressing sensors to a controller possibly will be applicable to construction process monitoring systems.

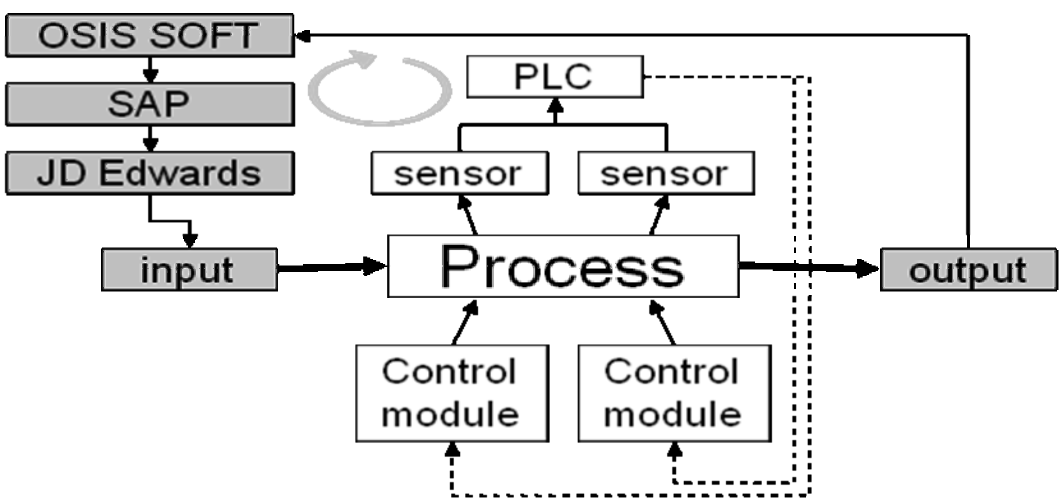

Figure 3 The Programmable Logic Controller (PLC) integrated feedback loop allows self-corrections for variations in production. The input to the process is resources and the output is the product. During the production process feedback between the PLC and reporting system provides preliminary adjustments to the inputs with annual process review making larger adjustments to the system.

1.8. Survey Analysis

The survey provided 170 responses, see table 1, from the construction(109) (nonresidential(56), industrial(2), heavy civil(47), MEP(3)), waste management/recycling(1), mining(11) and the balance(49) from the remaining industry divisions except as noted next. There are insufficient responses from industries outside construction and mining to draw any conclusions from. Although several hundred surveys were sent to each, no responses were received from agriculture, timber, shipbuilding and the railroads. The first three may provide transferable monitoring methods due to similarities in operations and site conditions. A Google search on each of these found ongoing research projects in each for sensor-based monitoring systems, so it is speculated they use predominantly manual methods. A discussion with a Northern California tomato grower confirmed that automated watering methods based on sensor-based monitoring are becoming more common as well as other methods.

Table 1 The percentage of US industry division population represented by survey responses and confidence interval at the 95% confidence level (CL) is presented for the construction and mining industry. These two industry divisions provided the highest confidence interval (CI) for the survey. Petroleum extraction responses (6) were close with .04% of the population but were excluded due to a CI of 40% @ 95% CL. The mining CI is high at 30%, the 11 responses are from 7 well known mining companies and were completed by individuals with an average of 29 (stdev 9) years of experience.

	Const-ruction	Non-residential	Heavy civil	Mining
Returned (ea)	109	56	47	11
% industry div. (US 2006)	.05%	.08%	.14%	.22%
Confidence interval @ 95%CL	9.4%	13.1%	14.3%	29.5%

The mining industry reported electronic quantity collection methods for eight of eleven responses and none for two of eleven, the last did not specify either way. See table 2 for the prevalence of each method and a comparison with the construction industry. A surprising difference is the use of onboard sensors by mining and not civil construction. Onboard sensors (OBS) are included from the factory on some heavy equipment and off-road haul trucks. The benefit of the OBS is the ability to download sensor readings from the equipment and derive the production and activities for the given time period. The mines producing precious metals are more automated in production monitoring than those producing less valuable materials. The 18% of mining responses reporting no electronic collection methods represent these mines. The transition for non-residential building to mining with heavy civil construction as an intermediary is not as clear as expected. The use of GPS, other sensors and a product information model fit this pattern. The use of 3D-imaging, electronic invoices and RFID do not and appear to transition from mining to heavy civil with non-residential construction as an intermediary.

Table 2 Monitoring methods are implemented using various methods. The sensors in the other sensors category are thermal, flow meter, data loggers and Programmable Logic Controller (PLC) system.

Electronic Collection	Const-ruction	Non-residential	Heavy civil	Mining	Balance
n-answers	60 of 109	30 of 60	30 of 49	8 of 11	32 of 50
none	15%	12%	18%	18%	12%
Ave. n-methods (stdev)	1.3 (1.7)	1.4 (1.9)	1.3 (1.4)	2.1 (1.9)	1.2 (1.4)
GPS	23%	15%	33%	45%	14%
3D-imaging	17%	20%	14%	36%	14%
Electronic Invoice	12%	13%	10%	18%	14%
Barcode	13%	12%	14%	9%	18%
Radio Frequency Identification	10%	13%	6%	18%	6%
Other - sensors	3%	0%	6%	27%	6%
Product Information Model	6%	12%	0%	0%	4%
Object Char. Recognition	5%	7%	2%	0%	4%
Total Station	3%	3%	2%	0%	2%
Recipe formula	3%	3%	2%	9%	0%
Onboard Sensors	0%	0%	0%	9%	2%

Table 3 Software tools are categorized as nine broad categories to compile the nearly 70 tools given by survey responses. The mining industry responses show a higher use of software tools and distributed control systems.

Software Tool	Construction	Non-residential	Heavy civil	Mining	Balance
n-answers	71 of 109	37 of 60	34 of 49	8 of 11	36 of 50
Software tools	58%	57%	59%	73%	62%
None	7%	5%	10%	0%	10%
Ave. n-tools (stdev)	1.3 (1.7)	1.4 (2.0)	1.2 (1.2)	2.4 (2.3)	1.0 (1.2)
Enterprise Asset Mgmt.	29%	30%	29%	55%	24%
Product Model	10%	12%	8%	18%	8%
Scope takeoff	8%	10%	6%	0%	2%
Cost Estimate	17%	13%	22%	0%	8%
Time schedule	15%	15%	14%	18%	8%
Quality Control	10%	10%	10%	36%	10%
Integration	8%	8%	8%	0%	6%
Dist. Control System	3%	5%	0%	18%	4%
Elec. Data. Interchange	8%	2%	16%	9%	2%

Software tools are used by 70% of the mining companies. The other 30% of responses did not name any tools or state that none were used. Construction companies from both non-residential and heavy civil reported that almost 60% used software tools. In non-residential and heavy civil 5% and 10% respectively stated they use no tools. The biggest differences between mining and construction is in the use of product models, the lack of estimating software, quality control software and the use of distributed control systems.

1.9. Conclusions from the Focus Group and Survey

The focus group questionnaire provided three main needs from field quantity collection. These are first, as a learning environment for engineers, second, documentation of compliance with government regulations, specifically with LEED certification and third as a learning environment for new engineers. The learning environment and government compliance were not expected and provided illustrations of value from project monitoring.

The three construction industry segments, based on this survey, have different concepts of quantities collection. Of the heavy civil responses over 60% reported that quantities in any reporting period are 10% estimated. The construction management segment has similar results as heavy civil for collection methods, though 70% of responses reports 25% to 50% of quantities are estimated. Of non-residential construction 40% reports 25% to 50% of quantities are estimated. For all three, heavy civil, construction management and building, 20% to 30% do not know what percentage of reported quantities are estimated. At the same time as up to a quarter of reported quantities are estimated, the importance of accuracy is reported as high by nearly 70% of construction industry responses.

The last section of the survey provided open ended questions for improvement. Three common responses are: First, sensor use by 42% responding to *areas needing improvement*. Second, integration of systems was cited by 88% of responses to *vision for improved methods in your field*. Last, improvements of quantities classification methods are given by 52% of those responding to with their *view of classification miscodes codes*.

1.10. Future Direction of Study

The quantities collection method used by the mine operator relied on a system of programmable logic controllers (PLC) and sensors. While such a system is likely not practical for the construction industry, possibly concepts from this system are. The goal of project monitoring is to provide a feedback loop to the project schedule. While the issue in construction seems to be delivering measurements to the process model the option of placing metal conduit to an activity location and hardwiring a sensor is limited. A possible solution is a method to address an “envelope” place the measurement, units and time in the envelope and send the envelope to a “reader”. This may provide a means of delivering measurements to the correct activity code.

As a further test of the addressing system an integrated scope-cost-time model was constructed using archived project documents. A trie database of structs was written to contain a library of the project’s activity classifications, locations, start dates and finish dates. A generic approximate matching algorithm leveraging the recursive properties of the trie database was written to check a given classification at a given time and location against the library. Any entries not contained in the library were returned with suggested corrections within a specified Levenshtein distance, i.e., number of changes made to create a match. Preliminary testing provided good results with finding corrections for prefix miscodes as well as suffix miscodes.

1.11. Conclusion

This paper has examined the question of what electronic collection methods and software tools are employed in other industries, if these are applicable to construction and what prevents their use. A possible solution is to develop a method to assign classification codes to field progress measurements based on time and location. This method in addition to automating the classification process could also reduce the inaccuracies in current classification methods and reduce the need to estimate reported quantities. Thank you to the many people who contributed to this survey.

2.12. Bibliography:

Akinci, B., Kiziltas, S., Pradhan, A. (2006). “Capturing And Representing Construction Project Histories For Estimating and Defect Detection”, 13th (EG-ICE) Workshop, 2006, Ascona, Switzerland.

Ergen, Akinci and Sacks "Tracking and Locating Components in a Precast Storage Yard Utilizing RFID Technology and GPS" Auto in Constr (2007) 354–367

Golparvar Fard and Peña-Mora "Application of Visualization Techniques For Construction Progress Monitoring" ASCE Internl Workshop on Comp in Civil Engrg. 2007

Fischer and Kunz (1993) "Circle Integration" Stanford University, CIFE WP No.20

Fontana, R. J. (2004). “Recent Systems Applications Of Short-Pulse Ultra Wideband UWB Technology.” IEEE Microwave Theory Tech., 52 9 ,2087–2104.

Kiziltas, Pradhan and Akinci “Fusing Data From Multiple Sources to Support Project Management Tasks.”, Internl Workshop on Comp in Civil Engrg, 2007

Lytle, A. "Construction Object Recognition and Tracking" NIST-CMAG 2008.

Navon R. and Sacks R. "Assessing Research Issues in Automated Project Performance Control (APPC)", Auto in Constr. (2007) 474–484, 2006

Saidi, K. (2002) “Possible Applications of Handheld Computers to Quantity Surveying”, PhD Dissertation, The University of Texas at Austin, Austin, TX

Söderström P. and Olofsson T. "Virtual Road Construction – A Conceptual Model" 24th W78 Conference, Maribor, Slovenien. 2007

Song J. "Tracking the Location Of Materials On Construction Projects" Thesis (Ph. D.), The University Of Texas At Austin, August 2005

Tatum C., Vorster M., Klingler M., and Paulson Jr B. "Systems Analysis of Technical Advancement In Earthmoving Equipment", J. Constr. Engrg. and Mgmt. 132, 976 (2006)

Teizer J., Caldas C., and Haas, C. "Real-Time Three-Dimensional Occupancy Grid Modeling for the Detection and Tracking of Construction Resources" J. of Constr Engrg and Mgmt. 880, 888 (2007)