# CIFE Center for Integrated Facility Engineering

## CIFE Seed Proposal Summary Page
## 2014-15 Projects

**Proposal Title: A simulation-based approach to accounting for uncertainty and variability in look-ahead planning________________**

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**Proposal Number: (Assigned by CIFE): _________________________**

**Total Funds Requested: _________**

**First Submission?** **If extension, project URL: ________________**


**Abstract (up to 150 words):**

Construction activities are affected by different sources of uncertainty and variability that affect project outcome metrics. Managers need to plan the work to minimize the negative effect of uncertainty and variability, while meeting other project objectives such as cost and schedule. Managers use two basic production management strategies to achieve this: buffers and variability reduction. Buffers are generally expensive in terms of cost or time, while variability reduction requires additional efforts such as coordination with supply chain. In this research, we propose a simulation-based approach to accounting for uncertainty and variability in look-ahead planning. This method will allow managers to virtually experiment with a computer simulation model of construction operations and vary the different parameters of the production system, such as the location and sizing of buffers (time, capacity, and inventory) together with the exposure to variability.

## Introduction:

Construction projects are considered to be successful or unsuccessful depending on the degree that they achieve the project objectives established by the owner. These objectives are generally expressed in terms of budget, schedule, quality, and safety. Construction projects are exposed to different sources of uncertainty and variability that affect project outcomes, either positively or negatively. Managers at construction sites are faced with the difficult task of planning the work so that the negative effect of variability and uncertainty is minimized, while ensuring that the project objectives are met. As a result, managers must trade off the time and cost benefits of buffers that shield activities from upstream variation with the effort of reducing variability. While the general sources of uncertainty and variability that affect construction operations are known to some extent, current look-ahead scheduling methods rely entirely on the knowledge of the construction managers creating the look-ahead schedules to recognize the specific sources of uncertainty and variability for the upcoming weeks of work and to incorporate appropriate management actions in the schedule.

We propose to develop a look-ahead planning method that considers the most frequent sources of variability formally to combine the knowledge of construction managers with a more formal method. To develop such a method, we will leverage Virtual Design and Construction (VDC) methods such as 4D modeling, Lean Construction, and computer simulation of construction operations. We will model construction operations as chains of activities that are linked by sequential relationships. This will allow managers to understand the effect that production management strategies have on the metrics at different levels of abstraction, namely at the activity level and at the chain level.

## Motivating engineering/business problem:

Activities in a construction site are affected by different sources of uncertainty. Several authors have identified different sources of uncertainty that affect activities on a construction site (Ballard and Howell 1998; Howell et al. 1993). The uncertainty related to these activities leads to variability in their execution. Figure 1 shows an example of a construction crew that is performing the activity "tie rebar." This activity is subject to different sources of uncertainty, such as: lack of lack of labor, insufficient availability of appropriate tools and equipment, incomplete information, lack of materials, uncertainty about completion of previous work, and uncertainty about external factors such as weather. As a result, there is variability in the execution of the activity affecting its outcomes such as: productivity rate, total activity duration, activity cost, activity quality, rework and safety.

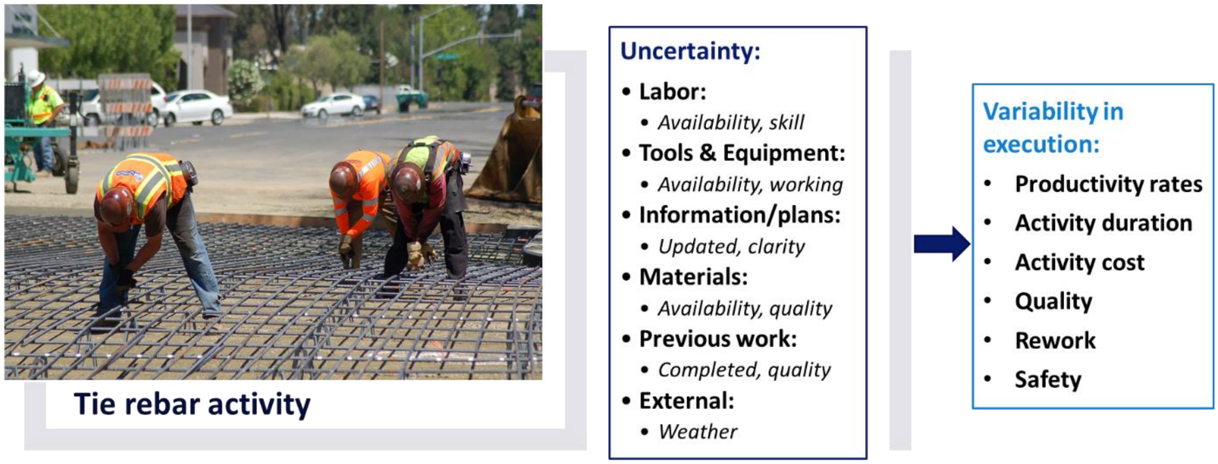



**Figure 1: Activities are affected by different sources of uncertainty, which lead to variability in the execution.**

However, because of the interdependence between activities in a construction site, the variability resulting from one activity will have an impact on downstream activities. This phenomenon is observed easily in construction chains of activities known as "parades of trades" (Tommelein et al. 1999) where different construction crews sequentially follow each-other. Figure 2 shows an example of a "structural parade," where the rebar crew is followed by the concrete crew in the sequence of operations. If there is a delay resulting from variability in the tie rebar activity, the pour concrete activity will be impacted.

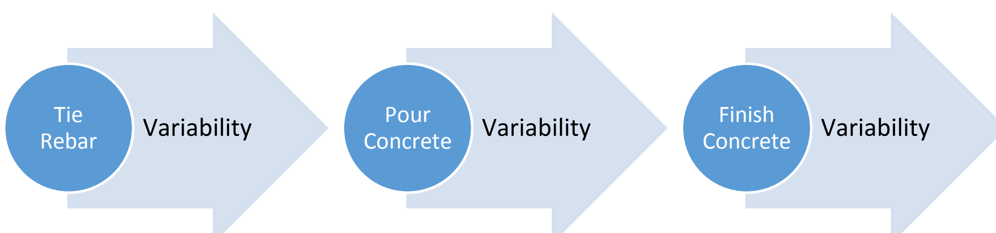



**Figure 2: Example of a "structural parade of trades," where activities follow each other sequentially. Variability in an activity upstream has an impact on downstream activities.**

As a result, uncertainty and variability affect project outcomes in direct and indirect ways (Figure 3). The direct impacts are related to how uncertainty and variability impact a particular activity. For example, the electrical subcontractor might have uncertainty about whether the cable trays will be delivered on time. This uncertainty has a direct impact on the activity's outcomes, such as the activity duration, cost, quality, and safety. However, due to the sequential relationships of construction activities, this uncertainty could also have a cascading impact on downstream activities. In addition to the impacts on a chain of activities, there are typically also project-level effects. The direct impact, combined with the indirect impacts will lead to project-level impacts on project outcomes such as: project duration, project cost, and project safety.

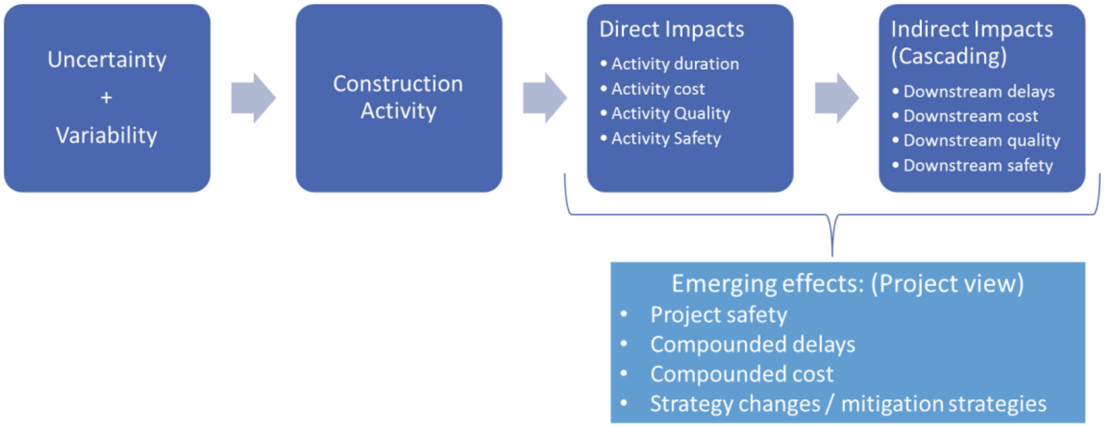



**Figure 3: Direct and indirect impacts of uncertainty and variability on construction activities and downstream activities**

Project managers use schedules as tools to plan and control the project. However, schedules are inadequate tools to account for uncertainty and variability. Consider the schedule shown in Figure 4, which examines the relationships between crews involved in the sequence of activities to build a wall. The sequence between activities is defined via predecessor relationships, as defined by the Critical Path Method (CPM) scheduling technique. We can see that the activity *Install wall studs* has a Start-Start relationship with a time lag of four days with the activity *Electrical rough-in*. It is common for superintendents to define these types of relationships, because the framing crew will start to work and create the work-in-process so that the electrical crew can install their conduits. Because of the difference in the productivity rates of the two activities, the superintendent added a time buffer of four days between the activities to prevent workspace conflicts and ensure continuity of work for the downstream crew. However, these time lags are based on intuition and past experience, rather than on established methods that account explicitly for uncertainty and variability. As a result, they tend to under-estimate or over-estimate the size of the buffers, and there is no systematic way available to improve the estimates of buffers over the course or a project or from project to project.

| Task Name | Duration | Start | Finish | Predecessors |
|---|---|---|---|---|
| Install wall studs | 10 days | Mon 2/24/14 | Fri 3/7/14 | |
| Electrical rough-in | 4 days | Fri 2/28/14 | Wed 3/5/14 | 1SS+4 days |
| Plumbing rough-in | 4 days | Thu 3/6/14 | Tue 3/11/14 | 2 |
| Pre-rock inspection | 1 day | Wed 3/12/14 | Wed 3/12/14 | 3 |
| Install dry wall | 4 days | Thu 3/13/14 | Tue 3/18/14 | 4 |
| Tape and mud | 4 days | Mon 3/17/14 | Thu 3/20/14 | 5SS+2 days |
| Paint | 3 days | Wed 3/19/14 | Fri 3/21/14 | 6SS+2 days |

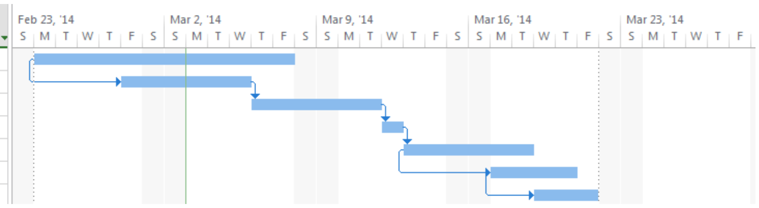



**Figure 4: Schedule of an "interior finishes parade."**

Research efforts have focused their attention modelling construction opertions using simulation software to explore the impact of uncertainty and variability at the project level, measuring project metrics like: total schedule duration and total project cost. This modeling perspective does not capture the local effects of uncertainty and variability at the activity level, which affects the subcontractor metrics. Depeding on the project delivery type, subcontractors might be more incentivized to optimize their local outcome metrics than the project outcome metrics. For example, the superintendent might want the electrical rough-in activity to start as soon as a small batch of walls is framed because this opens up work for other activities, while the electrical subcontractor might want to start the activity once the whole floor has been framed because this ensures that his crews are not idle.

### Theoretical and Practical Point of Departure

There have been considerable efforts from academia and industry to understand the effect of uncertainty in construction. The main focus on this area has been at the organizational level, formulating methods for managing projects under conditions of uncertainty (Ward and Chapman 2003) and managing risks (Kähkönen and Artto 1997). Researchers have also tried to understand the effects of uncertainty on decision-making and how to reduce uncertainty via contractual agreements (Skitmore et al. 1989). Similarly, PERT and other scheduling techniques have incorporated stochastic techniques to evaluate the effect of variability in the activity durations and on the total schedule duration (Carey 1999; Pohl and Chapman 1987). Finally, other researchers have attempted to evaluate the adequacy of contingencies according to the probability of occurrence of a number of possible scenarios (Levitt and Kartam 1990).

Recently, researchers have begun to study the effect of uncertainty and variability in the context of work execution at the jobsite. Numerous researchers have recognized that uncertainty and variability have a negative impact on construction operations and have begun to develop methods to reduce their impact on project outcomes. Uncertainty reduction in the construction site is one of the main pillars of Lean Construction. They argue that the main focus of production control at the jobsite should be in ensuring that the work is protected from uncertainty by following the Last Planner Method (Ballard 2000) and only allowing activities that comply with all prerequisites into the weekly production plan (Ballard and Howell 1998). Similarly, supply chain management has also been identified as a potential means to reduce uncertainty (Vrijhoef and Koskela 2000). Other authors have focused on reducing the variability by standardizing work processes (Mariz et al. 2012), and analyzing operations to remove non-value added activities (Thomas et al. 2002). Similarly, several authors have sought to understand the effect of buffers and how they can minimize the impact of variability in the system (Arashpour et al. 2013; González et al. 2009).

Discrete event simulation is one of the most common tools used by researchers to analyze the effects of uncertainty and variability on construction operations (Tommelein 1998). However, there is still a need to characterize the sources of uncertainty and variability that affect construction operations and understand how the different players in the construction site deal with this uncertainty and variability. Without first understanding these fundamental principles, it will be impossible to generate models that are valid and accurately predict the effects of different production management strategies on the system.
In this research, we will develop a methodology for systematically modelling a series of construction operations to predict the effect of different production management strategies on the project outcomes. It will leverage developments in VDC, such as 4D modelling (Aalami 1998; McKinney and Fischer 1998) and information technology (Fischer and Kunz 2004) together with discrete event simulation methods.

## Research Method

In this research, we will adopt the “Flow view of production” (Koskela 1992) which views production as a series of flows being processed at different stages. Furthermore, we will focus our attention on chains of activities where work is characterized by “parades of trades” (Tommelein et al. 1999). These are sequences of repetitive activities where subcontractors will follow each other as they perform work. According to Tommelein et al. (1999) examples of parades are: structural parade, overhead work parade, perimeter enclosure parade, interior finishes parade, etc. Analyzing parades of trades in the context of this research is particularly interesting because these trades have strong sequential interdependencies. As a result, variability and uncertainty affect not only the station being directly affected by it, but downstream trades as well. Finally, we since we can analyze parades as flows, it lends itself very well to use discrete event simulation to model it.

We will model chains of construction activities (trade parades) taking into account: uncertainty and variability in the activities that are part of it. We will use computer simulation to evaluate the activity outcome metrics and chain outcome metrics of implementing different production management strategies. A framework for the simulation model is shown in Figure 5.

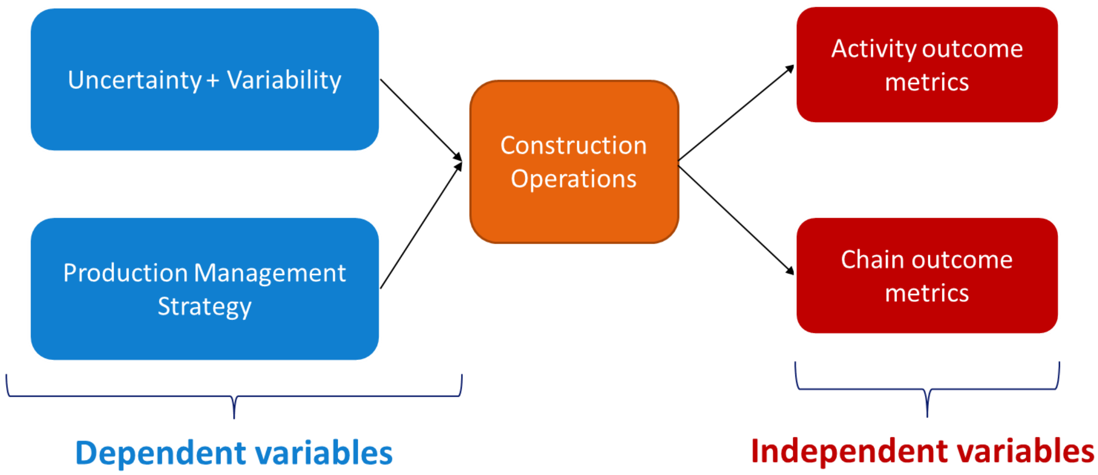



**Figure 5: Framework for the simulation model.**

The simulation model will include the following dependent variables: Uncertainty and variability in the activities and production management strategy.

The construction operations will be modeled using discrete event simulation. The simulation model will include the following independent variables:

- Activity outcome metrics: activity cost (versus plan), activity man-hours (versus plan), idle time, activity duration (versus plan).
- Chain of activities outcome metrics: operation cost (versus plan), total operation man-hours (versus plan), total idle time, total duration (versus plan).

As a result, we will strive to answer the following research questions:

1. What sources of uncertainty that affect different construction activities?
2. What production management strategies are implemented by subcontractors and GCs use to cope with the different types of uncertainty and variability identified in RQ1?
3. How much more predictive power is gained by incorporating the sources of uncertainty and variability identified in RQ1 and the production management strategies identified in RQ2 in a computational model of the construction chain of activities?
4. What metrics would help managers evaluate the effect of implementing different production strategies, such as buffers or variability reduction, on the construction operations?

This research will be divided into two parts. In the first part, we will need to conduct between 3-5 case studies of projects involving managers, subcontractors and workers. The purpose of these case studies will be to understand the sources of uncertainty and variability that affect construction chains of activities. Similarly, we will leverage existing project data (e.g. Percent Plan Complete) that captures occurrences of variability, such as delays, to compute the probability of occurrence of a certain source of variation. This data can then be incorporated into the simulation model.

In the second part of the research, we will build the simulation model of a chain of construction activities, incorporating the parameters discussed previously in this section. The objective is to have a basic simulation that allows us to reach out to industry experts and ask them to evaluate the current model and make changes to it.

## Relationship to CIFE goals

The primary objective of this research is to create a framework for analyzing construction chains of activities under conditions of uncertainty and variability. This research supports CIFE goals directly. Its emphasis is to improve construction operations through the innovative integration of computer simulation, scheduling, and 4D visualization.

The expected contributions of this research are:

1. **A methodology** for identifying, characterizing, and classifying different **sources of uncertainty and variability** related to construction activities.
2. **A simulation model that enables mangers to virtually experiment with different production management strategies and their effect on the system metrics.** This model takes into account the uncertainty and variability related to construction activities.

These findings will allow us to build models of construction operations where we can simulate the effects of uncertainty and variability and evaluate how they impact the project at an activity level and a chain level. Similarly, we can assess the effect of implementing different production management strategies on the metrics at the activity level and the chain level. This will allow managers to evaluate whether a certain policy is likely to improve the system, or whether there can be unexpected consequences due to goal misalignment between the different players (e.g. superintendent and subcontractor).

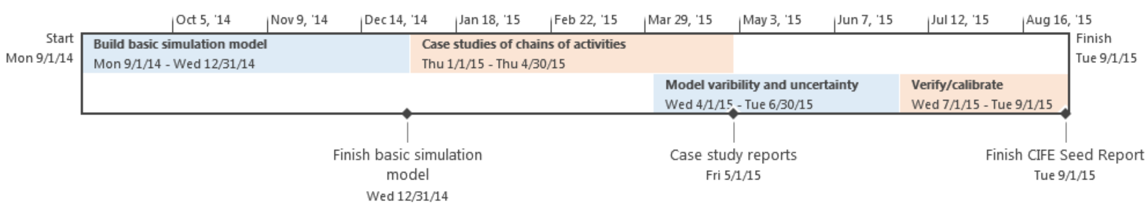
### Industry involvement

CIFE members will be directly involved in the two parts of the research, as mentioned in the research methods section. We will need to carry out between 3-5 case studies analyzing activity chains in their projects. These case studies will involve: managers, subcontractors and workers.

Similarly, we will reach out to CIFE projects that are keeping track of Percent Plan Complete (PPC) and reasons for non-completion in their projects. This will allow us to analyze the data and compute the probability of occurrence of different sources of variability related to construction activities.

Finally, we will ask CIFE members to review the results of the computer simulation model to understand to what extent it conforms to their own experience, and how it can be improved.

### Research plan, schedule and risks




Expected Publications:

1. Methodology for identifying, characterizing, and classifying different sources of uncertainty and variability related to construction operations.
2. Develop a framework for modeling construction operations subject to uncertainty and variability that allows managers to estimate the effect of different production strategies on the project metrics and subcontractor metrics.

### Risk and Mitigation

This research project is subject to several sources of uncertainty and variability that could delay the completion of milestones proposed in the research plan section.

- The most obvious risk to the project is the inability to validate the simulation model proposed in Part 2 of the research. Some possible causes of this risk are: lack of adequate data, model oversimplification, and lack of incorporation of key drivers. One mitigation strategy is to perform the modeling in parallel with the case study developments. This way, we can anticipate missing elements and data and use the findings to complement the simulation model.

- Another risk for the project is that the sources of uncertainty and variability are too large and cannot be adequately classified. This can be mitigated by choosing a few key sources of uncertainty and variability.
- Risk that the subcontractors might not be whiling to disclose practices that they know are not good for the project but they optimize their goals locally. This can be mitigated by triangulating with other sources of data, including: direct observation and interviews from other subcontractors.

## Next steps

The model presented in this research proposal can be extended in two main ways.

1. Extend the simulation model presented in this research by incorporating it with 4D visualization.
2. The present simulation model handles simple chains of activities. This can be extended to model more complex interactions between the different chains of activities to model the construction project more accurately.

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