Summary for CIFE Seed Proposals for Academic Year 2015-16

Proposal number:	2015-12
Proposal title:	Formally accounting for variability in look-ahead planning
Principal investigator(s) and department(s):	Martin Fischer– Civil and Environmental Engineering
Research staff:	Nelly Garcia-Lopez
Total funds requested:	$39,312
Project URL for continuation proposals	http:// http://cife.stanford.edu/SimulationBasedApproach
Project objectives addressed by proposal	Buildable, Sustainable
Expected time horizon	< 2 years
Type of innovation	Breakthrough
Abstract (up to 150 words)	**The problem:** Field managers lack a method for analyzing the impact of workflow variability on activity execution and understanding how variability is propagated between activities. As a result, they cannot anticipate the impact of variability and rely on their experience and intuition managing variability during look-ahead planning. **The proposed solution:** We propose to develop the Activity Variability Method (AVM), which uses a model representing construction activities, their inputs, and dependencies, to analyze the in-project activity variability and predict its impact on downstream activities. Using the AVM, field managers can implement targeted strategies to shield activities from variability. **The proposed research approach:** The model representing the construction activities, their inputs and dependencies will be developed from literature, and validated with available variability tracking data from three projects from CIFE members. The AVM will be developed based on the application of the Last Planner System and the input from field managers. We will validate the AVM by testing its implementation on a construction project.

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Formally accounting for variability in look-ahead planning

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1 Introduction

Despite recent advances in the use of Building Information Modeling (BIM), lean approaches, and information technology systems, construction projects still continue to face problems managing on-site construction resulting in schedule and cost overruns (Jones and Bernstein 2014). In manufacturing, companies have achieved exceptional performance by systematically seeking to understand and manage variability (Womack and Jones 1996). Recently, construction researchers have revealed the negative impact that workflow variability has on construction performance such as: higher work in process, longer activity durations, and project completion delays (Arashpour and Arashpour 2015). However, field managers[1] lack methods to manage workflow variability in the field.

This need motivated us to submit a Seed Proposal in 2014 proposing to develop a simulation model to help field managers understand the impact of implementing different production management strategies on the production system metrics (time and cost). As part of the work proposed, we carried out two case studies and analyzed the activity variability record of a hospital project with over 30,000 activity entries. We found that projects that were implementing the Last Planner System were collecting valuable variability data during commitment tracking, but lacked methods for analyzing it and leveraging it for predicting activity variability. This motivated us to refocus the research and develop a method that uses the activity tracking data resulting from the Last Planner commitment tracking phase, namely the planned versus actual data for activity completion and the reasons for variance, together with the look-ahead schedule to predict the impact of workflow variability on downstream activities.

2 Engineering problem

We carried out two case studies to understand how field managers at construction sites manage workflow variability during look-ahead and commitment planning. We attended all scheduling and planning related meetings at the projects during a two month period. We found that during the look-ahead planning stage, field managers were able to intuitively identify the constraints that could lead to variability in activity execution and formulate plans to mitigate the impact. However, facing unpredicted variability in short term planning, field managers could not estimate the potential impact of workflow variability on activity execution and predict how variability would propagate to downstream activities. Hence, they could not determine whether the activities for the short term plan could be made ready and commit to finishing them as planned.

We observed this specific problem during the planning process involving the fabrication and installation of the curtain wall for an office building. The field managers were concerned about the fabrication activity supplying the curtain wall components at the rate that the installation activity required. This concern stemmed from the field manager's experience in the previous project, where the installation crew had suffered frequent starvation leading to a delay in the curtain wall installation and cascading delays in the finishing phase for the project.

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[1] In the context of this research we apply the term field managers to those responsible for planning and controlling the work at the construction jobsite, i.e., superintendents, project engineers, and foremen.

To prevent this from happening on the project, the field managers implemented two strategies during the look-ahead planning phase: they set a ten-day material buffer to shield the installation crew from variability in the fabrication activity and created a board to actively track the progress of the curtain wall fabrication and installation activities. However, after eight days of panel production (two days before the planned start for the installation activity) the average fabrication rate was 20% slower than anticipated, resulting in an average production rate of 9.6 units/day. If the fabrication rate continued at the current pace, the installation crew would run out of material on day 46 (Figure 1).

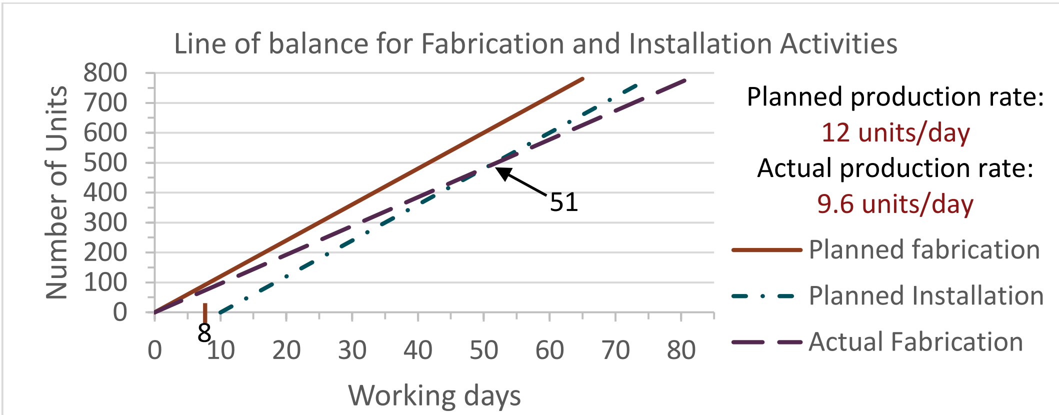

Figure 1: Line of balance view showing the planned fabrication, planned installation, and actual fabrication for the curtain wall activity. At the current fabrication and installation rates, the installation crew will run out of material on day 51.

At this point the field managers were forced to make a decision: should the installation activity be allowed to enter the weekly production plan? According to the Last Planner System, an activity should only be allowed into the weekly production plan if the last planner has a reasonable level of certainty that the activity will have all the prerequisites ready to be executed (Ballard 2000). The field managers wondered: Would the installation crew be starved? What would the impact of the workflow variability be on downstream activities? For instance, the dry wall subcontractor was concerned about his crews being idle while they waited for the curtain wall installation so that they could complete the tie-ins.

The Last Planner System currently does not integrate a method for analyzing the impact of workflow variability on activity execution and for understanding the mechanisms by which variability is propagated between activities. As a result, field managers cannot anticipate the impact of variability and rely on their intuition and past experience implementing strategies to manage variability during look-ahead and commitment planning.

3 Theoretical and Practical Points of Departure

In construction, workflow is defined as the movement of information, materials, and resources through workspaces performing a sequence of activities on components (LCI 2015). Variability is defined as “a departure from uniformity” (Hopp and Spearman 2011). Merging the two definitions, we define workflow variability as a departure from the baseline (or the plan) in the quality or quantity of the information, materials, resource, or workspace flows necessary to perform the sequence of construction activities.

The Last Planner System of production control proposes to reduce workflow variability by increasing planning reliability (Ballard and Howell 1997). Although the Last Planner System has been successful at improving planning reliability (Ballard 2000), it does not formally track, monitor, and anticipate the impact that constraints in the make-ready process have on workflow variability (Bhargav et al. 2015). To address this limitation, we propose to formulate a model of how variability impacts construction activities, and how it is transmitted between activities.

There are two prevailing workflow views in construction production: the transformation view and the flow view. The transformation view represents activities as a series of inputs that are transformed into outputs. This is the traditional view adopted in project management and construction scheduling, representing construction workflow as a sequence of activities connected via precedence constraints (Echeverry et al. 1991). A limitation from the transformation models is their inability to explicitly represent resources and workspaces (Morkos 2014). The commonly used project management tools today give field managers little visibility into the specific flows that are impacted by workflow variability and the downstream activities dependent on those flows. Field managers can only rely on their personal experiences to implement specific measures to shield activities from variability.

The flow view represents construction work as a series of flows composed of: transformation, inspection, moving, and waiting times (Koskela 2000). Managers should aim to optimize the transformation as the main value-adding process. In construction, activities are assembly-type operations that require the following flows: resource (labor, equipment, workspace), information and design, components, external conditions, and prerequisite work (Koskela 1999). Construction activities are particularly vulnerable to variability because all the flows need to be completed for an activity to be executed efficiently, which is also known as the matching problem (Tommelein 1998). The flow view is preferred in Lean Construction (Koskela 1992) and has been partially formalized by some simulation models (Akbas 2003; Choo and Tommelein 1999; González et al. 2009; Tommelein 1998). However, these models do not represent the flows between activities at a production level of detail.

3.1 Mechanisms that cause workflow variability

Variability in the flows between activities is caused by two main mechanisms: occurrence of variability factors and variability in the release of flows from upstream activities.

3.1.1 Variability factors

There is a large body of literature on variability factors that affect construction activities. The most recent compilation of variability factors is from Wambeke et al. (2011)[2]. They performed an extensive literature review and cross-referenced the variability factors, reducing the list to 50 unique variability factors. They found that most of these factors can be categorized into the flows presented by Koskela (2000, 1999), with the addition of a category for management and supervision. These categories are: prerequisite work, design and work method, labor, tools and equipment, materials and components, jobsite, management and supervision, and external conditions.

Although previous researchers have attempted to quantify the impact of the variability factors on activity execution, we still lack a formal understanding of how the variability factors impact the flows.

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[2] This proposal contains just a few key references. The full list of references used to date can be found on the project website.

3.1.2 Variability in the release of flows from upstream activities

As mentioned, construction activities are interconnected by a complex network of flows. Flows released from upstream activities become inputs for downstream activities. Hence, availability of flows for downstream activities depends on the timely release of flows from upstream activities. In manufacturing, material flows between the production units are modeled using queuing models. These models give insight to managers about the impact that variability in upstream activities has on downstream activities (Hopp and Spearman 2011). In construction, the network of flows that needs to be modeled is much more complex because of the temporary nature of construction production units (Koskela 2000), yet managers do not have a method for visualizing the flows between the activities to understand how they are interconnected. Without this knowledge, it is difficult for field managers to understand which of the flows could cause variability in activity execution and implement strategies to shield the activity from variability in that particular flow.

3.2 Conceptual workflow model and theoretical gaps

Figure 2 shows a conceptual model of construction workflow integrating the concepts discussed in the previous section: the flows between activities, the activities, and the mechanisms causing workflow variability (variability factors and variability in the release of flows due to activity variability).

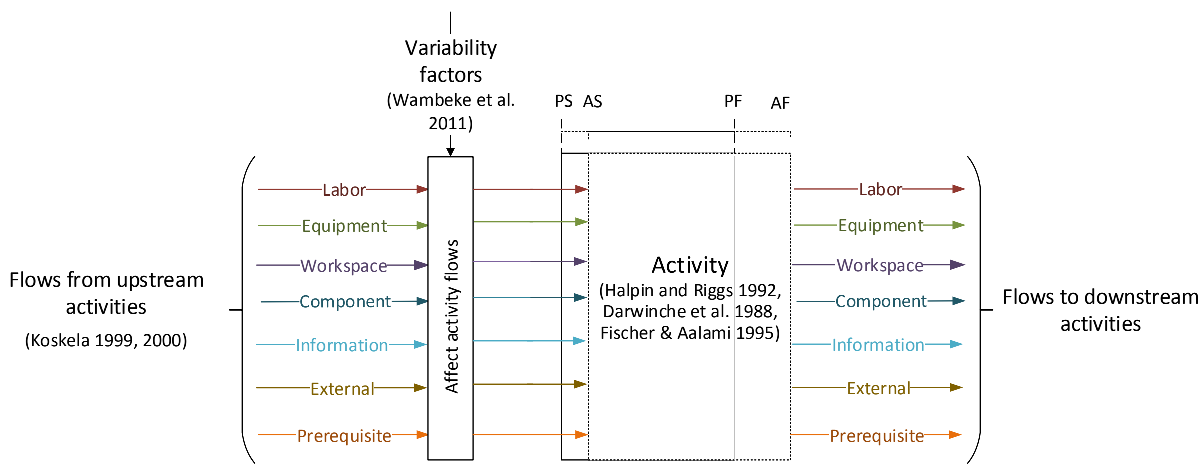

Figure 2: Conceptual model of construction workflow: construction activities require the availability of specific flows to be executed. Variability in the flows is caused by two mechanisms: occurrence of variability factors and variability in activity execution of upstream activities. Note: PS: activity planned start, AS: activity actual start, PF: activity planned finish, AF: activity actual finish.

There are theoretical gaps that need to be overcome to formalize this conceptual model into a computational representation. Firstly, we lack an understanding of what variability factors affect which flows, and how variability in the flows causes variability in the activity execution. Secondly, to operationalize the model, we need to develop measures for the different components that make up the workflow model, namely, the variability factors, the variability in the flows, and the variability in the activity execution.

4 Research Methods and Work Plan

We propose to leverage the activity performance data from the activities that were executed during the previous week, to uncover the flows that were affected by the variability mechanisms, and identify the downstream activities that depend on those flows. Using this information, namely what flows were affected by variability and the activities that could be impacted, field managers can implement specific buffers to shield those activities from variability.

We will develop a computational representation of the workflow model. We will do so by answering the following research questions:

1. What variability factors affect which flows?
2. How does variability in the flows cause variability in the activity?
3. How can field managers measure the variability factors, flows, and activity execution?
4. Based on these measurements, how can a computational model allow field managers to predict how variability is propagated to downstream activities?
5. How can field managers use the model to manage variability and its impact during look-ahead planning?

The first two questions seek to deepen our understanding of the mechanisms that cause variability in the flows between activities and how variability in the flows leads to variability in the activity execution. We will carry out structured interviews with superintendents, foremen, and project engineers, asking them about how specific variability factors affect each of the flows. Similarly, we will inquire about how variability in the quality or quantity of each of the flows leads to variability in the activity execution (variability in the start date, variability in the productivity rate). New interviews will be carried out until we reach saturation. The third question seeks to quantify the critical variability measures that characterize the construction workflow model. We will analyze the data that is currently being collected at construction sites and analyze the potential for data collection given new mobile technologies (Garcia-Lopez and Fischer 2014).

Using our findings from the previous questions, we will develop a computational representation of the workflow model that includes: the flows connecting the activities, the variability factors affecting the flows, and the construction activities. We will develop test scenarios to verify that the model is internally consistent. The model will be validated retrospectively by testing its predictions of workflow variability against actual variability data recorded from three projects.

Finally, we will develop the Activity Variability Method, which is a decision support system that helps field managers anticipate and manage variability during look-ahead planning. This method will be developed based on the steps outlined by the Last Planner System and input from field managers. It will be validated prospectively by carrying out a field experiment and evaluating the usefulness of the method during look-ahead planning.

5 Expected Results: findings, contributions, impact on practice

This research seeks to gain a better understanding of the causes of workflow variability and its impact. We will attempt to formalize a representation of construction workflow that is suitable to predict the impact of variability and help field managers manage variability during look-ahead planning.

There are two main theoretical contributions of this research. The first is a computational model representing construction workflow, considering the causes of workflow variability, and predicting the downstream impact of workflow variability. The second contribution is the Activity Variability Method, which helps field managers to manage workflow variability during look-ahead planning.

This research has a direct impact on practice. Using the Activity Variability Method field managers should be able to anticipate the impact of workflow variability on downstream activities and shield those activities using measures targeting specific flows. This should result in better project schedule conformance and better project performance.

6 Industry Involvement

There are three specific ways CIFE partners can get involved with the project:

1. **Interviews:** Structured interviews with superintendents, project engineers, and foremen. We would like to have a mix of companies and project types.
2. **Access to project data:** Access to historical data from past projects that implemented the Last Planner System and were tracking activity variability (planned vs. actual start and finish) and reasons for non-completion. All data will be kept confidential and anonymized for reporting purposes.
3. **Input and testing developed methods:** Input from field managers that would be willing to evaluate the model representation and the method.
4. **Field study of activity variability method:** We require access to a project that would be willing to test the implementation of the Activity Variability Method during a period of 4-6 weeks.

Some of the CIFE members that have been involved with the research are: Webcor (case studies), Graña y Montero (Last Planner records for non-completion), and SPS (activity tracking data-set).

7 Research Milestones and Risks

The research schedule is outlined in Figure 3.

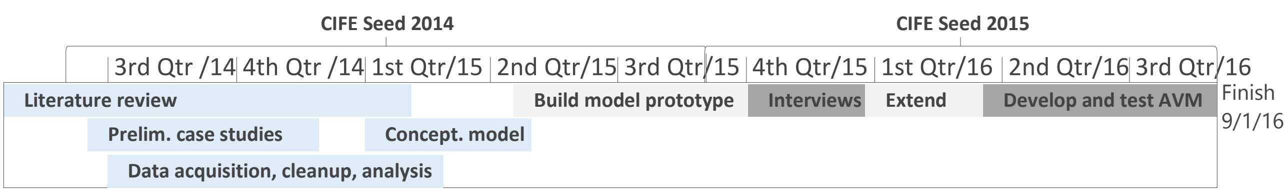

Figure 3: Research schedule highlighting the main phases of the two year proposed project, including the work that has been done so far (blue) and the proposed work (gray).

We anticipate the following risks:

- Difficulty getting access to project data: This risk has been partially mitigated by establishing relationships with CIFE members; however, we will need additional data to validate the AVM.
- Difficulty validating model using project data: Projects are dynamic, field managers are constantly implementing measures to shield activities from variability (albeit intuitively). Hence, it is possible that our variability predictions will not be observed in the variability data for the project. To mitigate this risk we will verify our model with field managers and conduct the field experiment.

8 Next steps

An opportunity for future research is to leverage sensing technologies, such as remote sensing and GPS-enabled mobile devices to enhance the visibility of the resource and workspace flows and gain a better understanding of variability in the flows at a finer level of detail. To continue this work, we would seek funding from an NSF grant. In particular, the Dynamics, Control and Systems Diagnosis program is looking for research proposals that are aligned with our work (NSF 2015).

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