Appendix A. The 12 Pillars of Leadership based on Rojas' study (2013) (cont.)

Pillars	Description
Commitment	• Supervisors and managers must be committed in full to their job and driven by their position. They should genuinely care about what they do. • They represent themselves as members of a team who are obviously dedicated to their career and the goals of the company. • They tend to be self-motivated and overachievers.
Curiosity	• They should always find ways of improving the environment they operate in. • They attempt to learn as much as they can about the various trades that exist on the jobsite. • When unexpected results occur in a project, whether they're good or bad, they will want to know the why and the how so that they can either replicate the good results or dissuade that poor results in future projects.
People Skills	• Project Managers with good people skills are likable because they always respect and appreciate what each member of their crew brings to the table. • They are effective at conflict resolution. Given differences in background, culture, values, attitudes and opinions, conflict is inevitable. The conflict is not a problem, the problem arises when people handle this conflict poorly, and good Managers do not. • They teach workers to listen more than talk and to look at problems form other perspectives. • This skill is very similar to the humility skill in the eyes of employees. Managers with good people skills are well liked and again, employees want to and will work harder for someone they like.
Communication Skills	• In order to allow for maximum worker effectiveness, effective managers must be able to articulate their ideas and orders in a clear, concise, and simple manner to their subordinates. • They must possess excellent written, verbal, pictorial, and diagrammatic communication skills. • They must anticipate communication breakdowns and may sometimes need ask others to repeat back instructions to ensure effective comprehension of messages. • They learn about the issues and problems of their subordinates by being good listeners.
Effectiveness	• They have great organizational skills that prevent problems and setbacks by anticipating them and giving the proper guidance to avoid them. • They ensure their subordinates have all the necessary materials, equipment, tools, and instructions to complete their tasks. • They are able assemble teams of employees that work effectively together and they are able to assess the strengths of their employees.
Knowledge	• They must be lifelong learners who seek out specific training and rigorous coursework that will improve their position as managers. • Modern managers must be as competent working on a computer with project management and accounting programs as they are with other common tools of the construction industry. • They must go beyond the traditional construction craftsmen knowledge.

A Construction Workflow Model for Analyzing the Impact of In-Project Variability

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Abstract

In construction, workflow variability has been associated with poor project performance such as higher work in process, longer activity durations, and project completion delays. In this paper, we analyze the advantages and limitations of state-of-the-art tools and methods for managing workflow in the field, seeking to understand the importance of measuring the activity flows to anticipate variability in the activities' execution. We found that current methods are insufficient to help field managers understand the impact that variability in the activity flows has on activity execution, and understand how variability is propagated between activities. As a result, field managers cannot anticipate the impact of workflow variability and rely on their experience and intuition managing workflow variability during look-ahead planning. We propose a theoretically based workflow model that formally represents construction workflow variability to help field managers analyze the in-project workflow variability and its impact on downstream activities. We developed the model by extending existing representations of construction workflow with the mechanisms that cause workflow variability.

INTRODUCTION

Despite recent advances in the use of Building Information Modeling (BIM), lean approaches, and information technology, field managers[1] continue to face problems managing on-site construction resulting in schedule and cost overruns (Jones and Bernstein 2014). 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 lack methods to manage workflow variability in the field.

In this paper, we analyze the advantages and limitations of current state-of-the-art methods for managing workflow variability in the field, and assess the extent to which they allow field managers to understand and manage workflow variability. Next, we present a theoretically based workflow variability model that extends

[1] In the context of this paper 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.

existing workflow representations (Koskela 1999) and formally represents the activity flows, the construction activities, and the mechanisms that cause workflow variability. The proposed workflow model can help field managers analyze the in-project workflow variability and understand its impact on downstream activities.

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 activity flows (Koskela 1999) (i.e., information, materials, labor, equipment, workspace, or external) necessary to perform the sequence of construction activities. Workflow variability causes variability in the execution of the activities, leading to variability in the activity start, duration, and finish.

The Last Planner System of production control is the most advanced method for managing workflow in the field. It proposes to reduce workflow variability by increasing planning reliability and only executing activities whose constraints have been removed (Ballard 1999).

Planning reliability is measured by tracking the Percent Plan Complete, which is calculated by measuring the number of assignments that were completed on time by the total number of planned assignments (Equation 1).

$$PPC = \frac{Number\ of\ assignments\ completed}{Total\ number\ of\ planned\ assignments} \qquad 1)$$

One of the advantages of PPC is that it is embedded into the Last Planner System of production control. This standardizes, to a certain extent, the process of measuring and tracking PPC. Furthermore, PPC has been correlated with improvements in project performance (González et al. 2010). However, PPC is neither a measure of activity variability nor of workflow variability. There are two main limitations to measuring activity variability using PPC. Firstly, the PPC measures the occurrence of variability in the finish date of the activity, but does not quantify the impact of the variability occurrence. An activity that misses its finish date by two days has the same PPC as an activity that misses its finish date by five days. As a result, field managers cannot compare the level of variability between activities using PPC. Secondly, PPC tracks variability in the finish date of the activity, but does not measure variability in the activity start and in the activity duration. Hence, PPC cannot help field managers understand the impact of factors that affect the activity start from factors that impact the activity duration. Similarly, the PPC serves as an indicator for workflow variability, but does not allow field managers to understand what specific activity flows were affected and to quantify the impact of workflow variability.

On the other hand, tracking the status of the activity constraints helps to prevent field managers from committing to activities that cannot be executed due to missing activity flows. However, the Last Planner System does not formally track, monitor, and anticipate the impact that constraints in the make-ready process have on workflow variability (Bhargav et al. 2015).

Although existing methods define the types of flows that constitute the construction workflow, they do not formalize a management system at the workflow level. Rather, management systems like the Last Planner mostly focus on activities and do not characterize variability at the workflow level.

PROPOSED MODEL FOR ANALYZING WORKFLOW VARIABILITY

In lean construction, construction work is represented as a series of flows composed of transformation, inspection, moving, and waiting times (Koskela 1999). Construction activities are assembly-type operations that require the following flows: labor, equipment, workspace, information and design, components, external conditions, and prerequisite work (Koskela 1999). There are two main mechanisms that cause workflow variability: occurrence of variability factors which affects the activity flows (Wambeke et al. 2011), and untimely release of flows from upstream activities into downstream activities.

Figure 1 shows our proposed conceptual model of construction workflow integrating the concepts discussed above: 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).

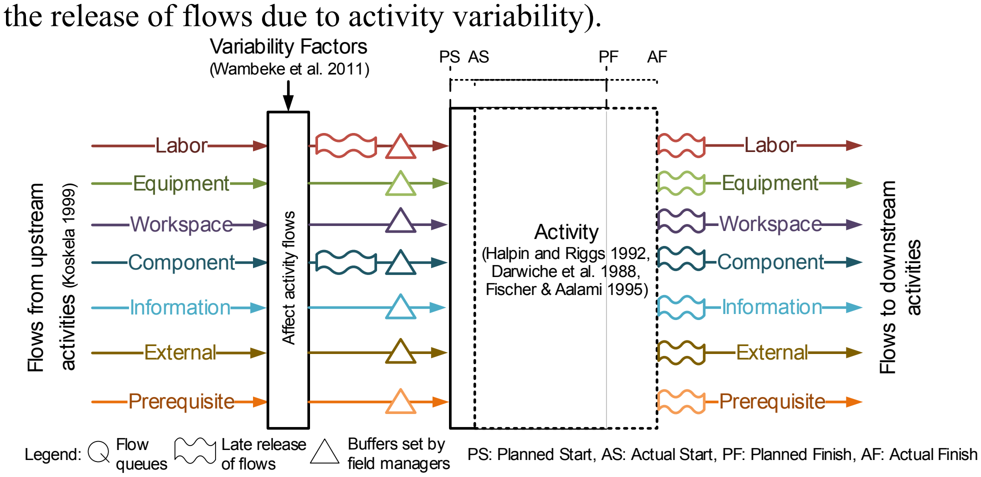

Figure 1: Conceptual model of construction workflow. Note: PS: planned start, AS: actual start, PF: planned finish, AF: actual finish.

Each activity has a set of activity flows that need to be present for it to be executed. Depending on the activity type, these flows might either be released from upstream activities or brought into the project for it to be executed. The first mechanism for workflow variability is the untimely release of flows from upstream activities into downstream activities. If upstream activities are finished late, then there is a late release of activity flows for the successor activities, causing variation in the activity flows and a potential matching problem for downstream activities that depend on those flows. Conversely, if upstream activities are finished early, then there is an early release of the activity flows, causing unplanned buffer accumulation. The second mechanism for workflow variability is the occurrence of variability factors, which causes variability in specific activity flows. Field managers can implement buffers (capacity, inventory, or time) targeted at shielding the activity from variability in specific flows (González et al. 2004; Hopp and Spearman 2011). If the buffers are insufficient to shield the activities from the workflow variability, then there is variability in the activity execution.

Currently we lack an understanding of how the different elements of the workflow model outlined above interact with each other, and how variability in specific activity flows leads to activity variability. To start answering these questions, we wanted to see what evidence of the activity flows and their variability we could observe in a project that was implementing the Last Planner System. We reached out to several construction companies that were implementing the Last Planner System in their projects asking them to share the best activity tracking data-set that they had. In the following section, we present our analysis and conclusions of the best data set that was available to us.

ACTIVITY TRACKING DATA-SET ANALYSIS

The activity tracking data-set corresponds to a hospital project that was carried out in California between November 2011 and June 2014. The team held daily production planning meetings which resulted in a record of 30,005 total activity entries. The project was using a computer system to manage production. The data-set contains the following fields which are of interest to this paper: task name, company, planned start, planned finish, actual start, actual finish, status (completed or non-completed), category for non-completion, predecessor, and successor. Interestingly, the only activity flows that are formally represented in the data set are the predecessor and successor constraints. We performed a manual cleanup of the data to standardize the activity definitions (activity type, subcontractor type, and UNIFORMAT classification). This allowed us to analyze the similarities and differences between the activity entries aggregated by the different groupings. Since the data-set lacked information about most of the activity flows, we tried to understand what factors that were present in the data-set could be associated with higher activity variability.

Activity variability metrics

Workflow variability, i.e., variability in the activity flows, results in variability in the activity metrics, namely, in the activity start, the activity duration, and the total variability. We calculated the activity variability metrics as follows:

$$\Delta S = AS_a - PS_a \tag{2}$$

$$\Delta D = AD - PD \tag{3}$$

$$\Delta T = AF_a - PF_a \tag{4}$$

Where: the start variability (ΔS) is the difference between the actual start of the activity (AS_a) and the planned start of the activity (PS_a), the duration variability (ΔD) is the difference between the actual duration (AD) and the planned duration (PD) of the activity, and the total variability (ΔT) is the difference between the actual finish of the activity (AF_a) and the planned finish of the activity (PF_a).

Table 1 summarizes the activity variability measures for the activity entries in the data-set. Since the means of all the variability measures are larger than the median and the maximum values for the variables are significantly larger than the minimum, we can conclude that the distribution of the activity variability measures is skewed to the right. Hence, it is more likely for an activity to be affected by a delay than to be started or completed earlier than planned. Nevertheless, the fact that the median for all the variables is zero and the interquartile range for the variables is narrow, reveals that the majority of the activities are affected by variability in a small amount while a few activities are severely affected by variability.

Table 1: Summary statistics for the activity variability measures in the hospital data-set. All the variability measures are in days.

Variable	*n*	*mean*	*sd*	*median*	*min*	*max*	*range*	*0.25 quant.*	*0.75 quant.*
Duration Var. (Δ*D*)	25170	1.00	0.83	0.00	-96	222	318	0.00	1.00
Start Var. (Δ*S*)	25170	1.46	7.63	0.00	-6	378	384	0.00	1.00
Total Var. (Δ*T*)	25170	2.26	9.32	0.00	-96	379	475	0.00	2.00

Note – n: number of observations, sd: standard deviation, min: minimum value, max: maximum value, quant: quantile. 4,835 activities were completed without being planned and 6,209 activities did not have predecessors.

An interesting observation is that the correlation between the start variability and the duration variability cannot be established to be non-zero based on a Pearson's correlation test. This suggests that activities that start late are not more likely to take longer to be completed. This same observation was made by partitioning the data by subcontractor, subcontractor type, and the different UNIFORMAT levels.

Analysis of activity variability

In the following section, we will analyze the activity variability metrics by aggregating the activities by: subcontractor group, subcontractor type, and UNIFORMAT classification. We grouped the activities performed by the different subcontractors into the following categories: Core & Shell, MEPF and Controls (MEPFC), Interior, Equipment & Furnishings (Eq. & Fur.), and Management and Supervision (Mgt).

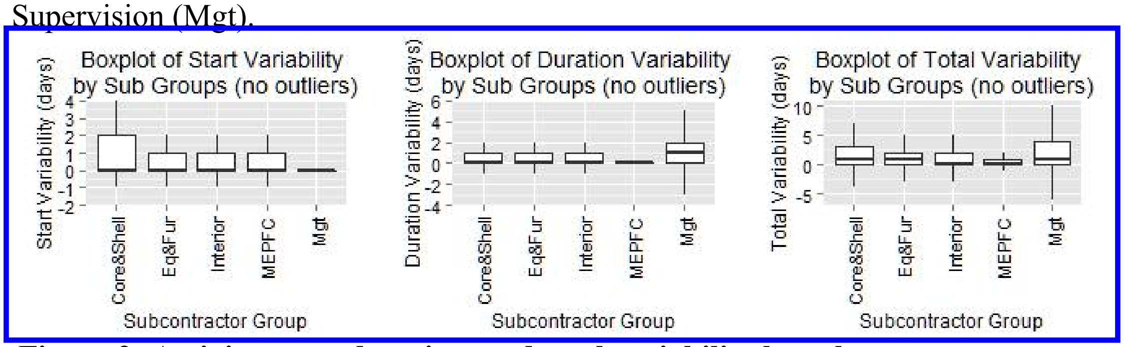

Figure 2: Activity start, duration, and total variability by subcontractor groups.

Figure 2 shows the distribution of the activity variability metrics for the different subcontractor groups. Since variability in production systems is transmitted between the activities, downstream activities tend to exhibit greater variability than upstream activities (Hopp and Spearman 2011). However, in our analysis we found that upstream activities, such as the Core & Shell activities, exhibit greater variability than downstream activities (except for Management). Similarly, we expected activities with reciprocal relationships, such as MEPFC activities, to exhibit greater variability than activities with more sequential relationships, such as Core & Shell activities (Thomas et al. 2004). However, this pattern was not observed in the current project. A similar conclusion can be reached by analyzing Figure 3, where 50% of the most variable activity types are Core & Shell activities.

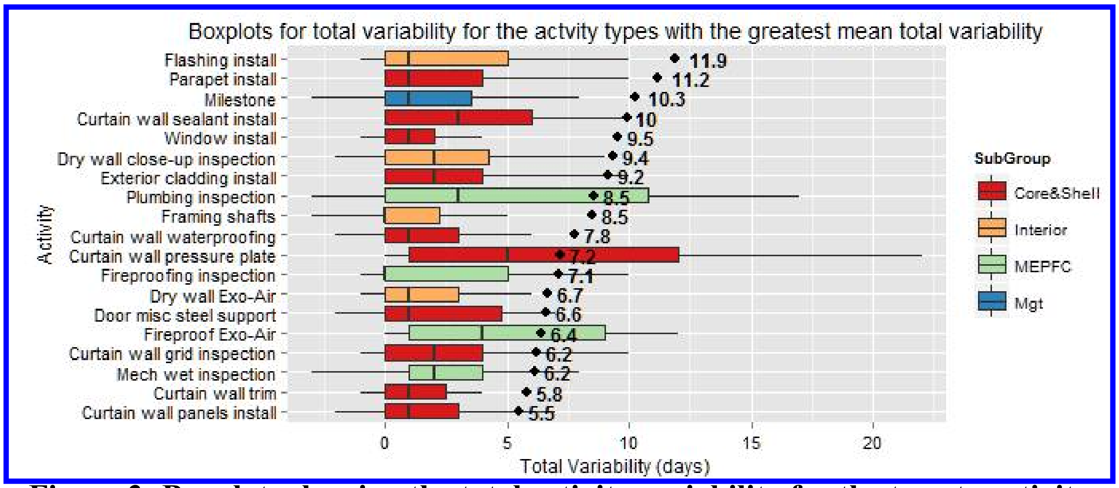

Figure 3: Boxplots showing the total activity variability for the twenty activity types with the highest mean total variability. The diamond represents the activity mean total variability.

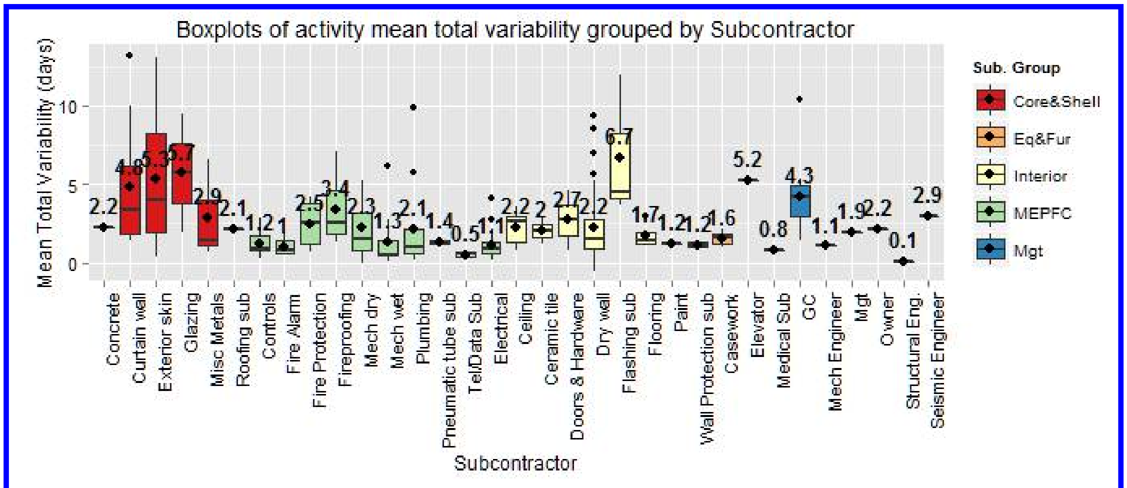

Figure 4: Boxplots for the activity mean total variability grouped by Subcontractor type. The activity mean total variability is represented by the diamond.

Figure 4 shows the boxplots for the activity mean total variability grouped by subcontractor type. The figure shows that for some subcontractors, such as the exterior skin, there is a wide variation in the mean total variability of the activities that they execute. On the other hand, for some subcontractors, such as the concrete subcontractor, there is a small variability in the mean total variability for the activities that they execute. This finding suggests that for some activities knowing the subcontractor type can be a good predictor for the activity total variability, but not for others. A similar observation can be made for the activity start and activity duration, although we did not include the figures due to space constraints.

The average total variability for the activities in the project is extremely unstable at the beginning of the project and stabilizes as the project progresses. The same pattern is observed for the different subcontractor groupings, especially for those with many activities (Figure 5). Similarly, the PPC for the project is also very unstable at the beginning and tends to increase (i.e., improve) as the project progresses (Figure 6). Interestingly, the Pearson's correlation test between the activity variability and the current PPC for the project failed to establish a non-zero correlation between the two variables. The same was true for the Pearson's correlation test between the activity variability and the PPC for the previous week of the project. We can conclude that the PPC was not a good predictor for activity variability for the current project.

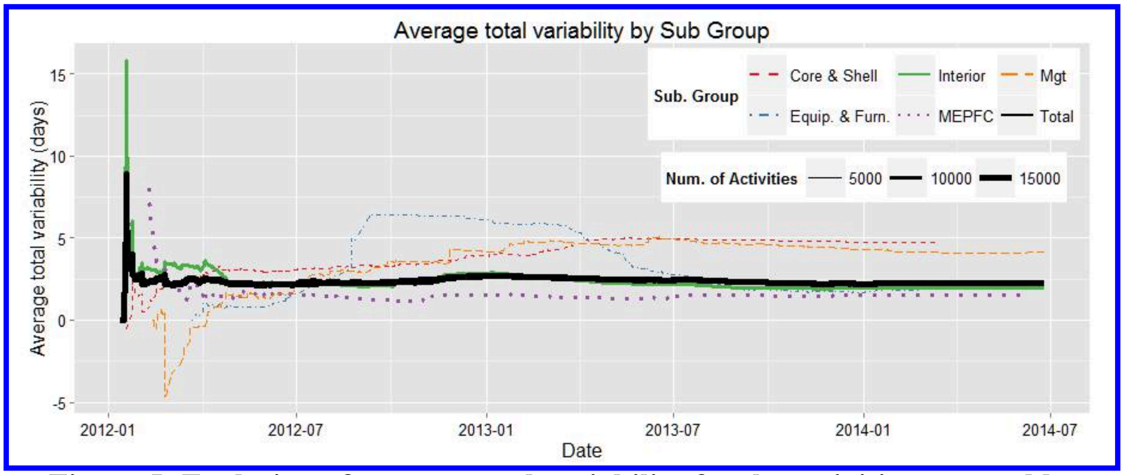

Figure 5: Evolution of average total variability for the activities grouped by their corresponding sub. group.

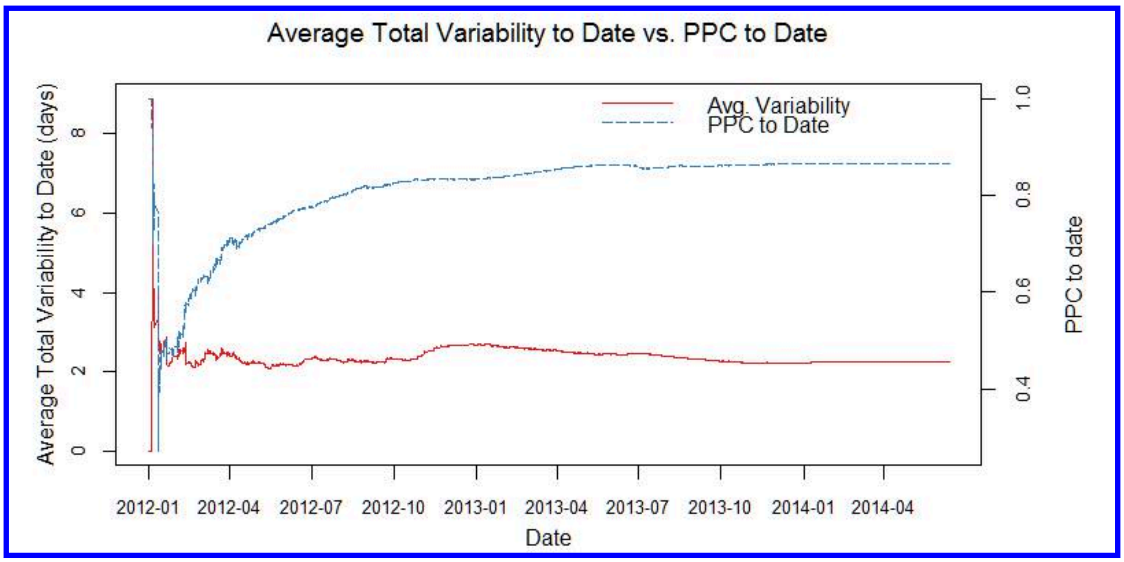

Figure 6: Evolution of average total variability for the project (red) versus the PPC average to date (blue).

Figure 7 shows a mosaic plot of the reasons for non-completion for the activities in the different subcontractor groups. The most prevalent reasons for non-completion are different for each of the subcontractor groups. Using this information, it might be possible to learn the patterns of reasons for non-completion for each of the subcontractor groups and use this information to help field managers anticipate and manage variability. To achieve this, it would be necessary to get access to standardized, consistent, and detailed activity tracking data for a variety of projects. Achieving this has been extremely difficult for us due to privacy concern issues and inconsistency in the data collection practices between projects.

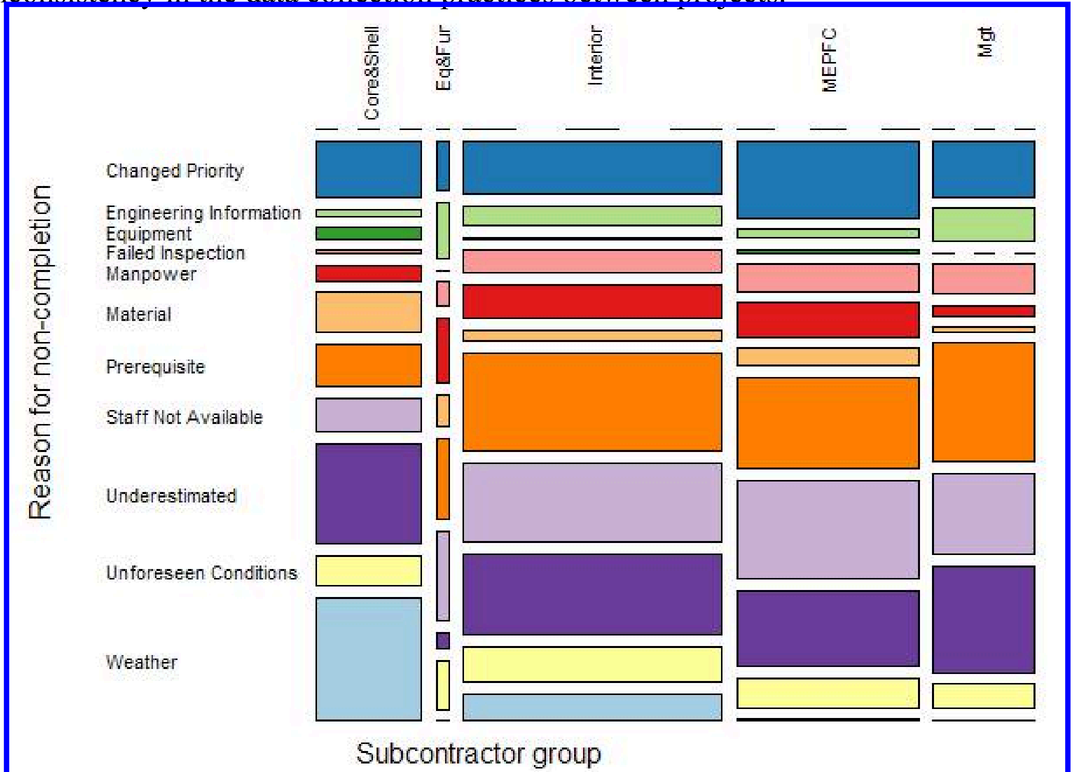

Figure 7: Mosaic plot showing the reasons for non-completion for the activities by the different subcontractor groups.

The only activity flow that is explicitly available in the data-set is the predecessor flow. We analyzed if there was a difference in the activity variability measures given that there was variability in the predecessor's finish. Figure 8 shows the relationship between the activity start variability and the predecessor total variability (i.e., predecessor finish variability). The figure allows us to identify three groups of activities: those whose activity start is not affected by the predecessor finishing late (orange), those whose activity start could be affected by the predecessor finishing late (green), and those that started late due to different reasons than the predecessor finishing late (blue). Understanding which activities are affected by the predecessor finishing late would allow field managers to anticipate activity variability and prevent downstream activities from being affected. This insight supports our hypothesis that it is necessary for field managers to understand how variability in the activity flows leads to activity variability to make better predictions about what downstream activities are prone to variability and how they can be shielded from it. To achieve this, it is necessary to explicitly represent and measure the activity flows.

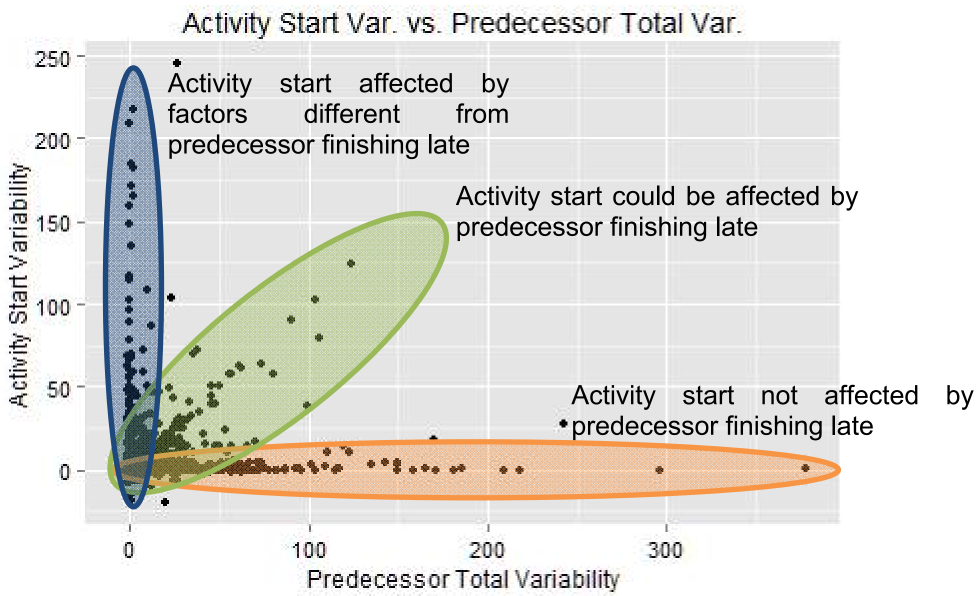

Figure 8: Scatter plot showing the activity start variability versus the predecessor total variability.

Analysis of advantages and limitations of information currently available for managing workflow variability

Current state-of the arts practices for managing production in the field allows field managers to collect information about activity variability at a very high level of detail. Using this information, it was possible for us to identify some broad trends in the data, but we were unable to identify any clear variables that could serve as predictors for activity variability. Furthermore, the lack of standardization in the activity naming and subcontractor naming makes it extremely burdensome to incorporate other projects into the analysis to search for trends between projects.

An important limitation we identified in the current method for tracking activity execution is that if an activity is not started on the planned date, it gets “pushed” to a later date agreed to by the field managers. However, the history for the activity gets lost, which hinders any analysis about the suitability of buffer sizing, as well as the record of variability.

Finally, the most important finding from our analysis is that the information that is currently being collected does not actively track the status of the elements that constitute the construction workflow, i.e., the activity flows. Therefore, it is extremely difficult for field managers to understand the impact of workflow variability and how they can manage it to prevent variability from impacting downstream activities.

CONCLUSIONS AND FUTURE WORK

In this paper we presented a theoretically based workflow model that formally represents construction workflow variability, including: the flows between activities, the construction activities, and the mechanisms that cause workflow variability.

There are theoretical gaps that need to be overcome to formalize this conceptual model into a computational representation. Firstly, we lack an