ABSTRACT

RUSSELL, MARION MARK. Allocation of Time Buffer to Construction Project Task Durations. (Under the direction of Dr. Min Liu).

A variety of buffers are used in design and construction to absorb variation caused by the inherent complexity and uncertainty present in construction projects. This research focuses on time buffers added to construction project task durations. In this research, time buffer is defined as an amount of extra time added during planning to individual task durations to compensate for uncertainty and protect against workflow variation. Although previous research has acknowledged this addition of time buffers, their reasons for use and allocation in practice have not been studied. Excessive time buffers mask the sources of uncertainty that make them necessary. Additionally, overly large buffers are wasteful and can reduce project performance by extending duration, reducing work discipline and coordination. A nationwide survey was administered to project managers, superintendents, and foremen to identify the most frequent and severe causes of the adding of time buffers to construction task durations. Forty-seven individual causes of time buffer were grouped into nine categories: project characteristics, prerequisite work, detailed design/working method, labor force, tools and equipment, material and components, work/jobsite conditions, management/supervision/information flow, and weather. The similarities and differences in perceptions between project managers, superintendents, and foremen in regards to what causes them to add and size time buffers were examined. The research also quantitatively developed risk profiles of the causes of buffer through an integrated risk assessment approach. Further, the causes of time buffer were hypothesized to be correlated and not independent of one another. As a result, the underlying structure of the causes of buffer was
examined using factor analysis. This underlying structure served as a basis for the development of structural equation models (SEM) to identify the causal structure used by construction personnel at different levels of management when buffering and planning for uncertainty in their task durations. A model survey was distributed in order to provide a level of model validation and to obtain feedback of recommended adjustments to the proposed models. Also, case studies were conducted to examine the effects of using the collaborative planning philosophy of Lean Construction on time buffer and project performance. The case studies also investigated the buffer allocation associated with various trades and activity types. This research is significant and valuable as previous research has not been conducted in regards to the causes and allocation of time buffer. Previous research also did not investigate the relationship among variation, buffer, and productivity, at least not using empirical data. The topic is of significant importance in its relation to planning and the inherent complexity, uncertainty, and resulting variation in construction. Construction personnel at every level of management are constantly planning and trying to figure out how best to deal with the uncertainty and variability of construction projects. Understanding why time buffer is added and quantifying the influence of different causes on the way construction personnel at various level of management buffer and plan for uncertainty allows construction companies to take effective steps towards addressing those causes, managing uncertainty, and reducing the associated time buffer in construction projects.
Allocation of Time Buffer to Construction Project Task Durations

by
Marion Mark Russell

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APPROVED BY:

Dr. Min Liu
Committee Chair

Dr. Simon M. Hsiang

Dr. Michael L. Leming

Dr. Edward J. Jaselskis
DEDICATION

I dedicate this work first and foremost to my wife and children. The completion of this journey would not have been possible without their love, encouragement, support, and patience every step of the way. Additionally, this work is dedicated to my mother and father who have been there for me my entire life, and I thank them for all they have done. Also, to my older brother for being a great big brother.
BIOGRAPHY

I am currently a major and civil engineer in the United States Air Force. Throughout the last ten years, I have had several great opportunities with the latest being the pursuit of a PhD. I am thankful for both those opportunities and my brothers and sisters in arms who I have been honored to serve alongside in defense of this great nation. Upon completion of my PhD, I will serve as a military construction program manager for the United States Air Force. Thereafter, I will serve the remainder of my military career as a professor in the Civil and Environmental Engineering Department at the United States Air Force Academy in Colorado Springs, Colorado.
ACKNOWLEDGMENTS

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CHAPTER 1

1.0 INTRODUCTION

Time buffer, defined for this research as an amount of extra time added during planning to individual task durations is often used to compensate for uncertainty and protect against workflow variation. Time buffer is the difference between the scheduled or planned task duration and the minimum duration the task should take based on an optimum or baseline productivity. This baseline productivity is the best productivity a contractor can achieve on a given project and typically occurs when the material, equipment, information, and plan are adequate (Sakamoto et al. 2002). The use of “allocation” in the title refers to the verb form of the word and is defined as “to designate for a special purpose” and “to distribute according to a plan” (Merriam-Webster (2012)). This research effort addresses the need to examine the root causes of time buffer in construction project task durations. Furthermore, an understanding of “why” time buffer is added to task durations helps the understanding of “how” time buffer is added through model development of the causal structure used by construction personnel when planning and buffering for uncertainty. The research also examines the buffering tendencies of various construction trades and activities as well as the benefits of collaborative planning efforts in the reduction of time buffer. Construction project task durations for this research focuses on the time in days or hours assigned to construction activities associated with the completion of the construction project.
1.1 Background

Construction is a very complex process and nearly every single project is unique. The resulting number of parts, relative lack of standardization, multiple participants and constraining factors make construction projects a difficult endeavor (Ballard and Howell 1995). Adding to this complexity is the high degree of interdependency inherent to the construction process. Complexity can be defined as "something made up of closely connected parts which are difficult to explain or understand, or a number of different parts intricately related" (Hornby 1974). This complexity is combined with the ever-growing economic demand to deliver projects more quickly while minimizing costs, resulting in uncertainty as a characteristic component of construction and often leading to variation. Uncertainty can be generally defined as a set of possible outcomes where probabilities are assigned to each possible outcome. However, uncertainty as it pertains to the research here is a "presence of doubt, changeability, and lack of assurance or reliability" (Hornby 1974). While variability or variance in statistics is a measure of how far a set of numbers is spread out, variation as discussed in this research is defined as the difference between what was planned and what actually happened (Wambeke et al. 2011). Further, variability as discussed in this research pertains to the propensity for variation due to the inherent uncertainty in construction projects.

Construction personnel involved with the project have a natural tendency to compensate for the uncertainty by adding buffer to task durations to absorb the resulting variations in the work plan. In fact, standard practice is to try to build as much buffer as possible into the duration of tasks for which one is responsible (Ballard 2000a). This results
from lacking a mechanism for coordination. Buffers can be seen as wasteful because they do not directly add value to a construction project even though they allow downstream operations to continue. One definition of waste includes “anything that is different from the minimum quantity of equipment, materials, parts, and labor time that is absolutely essential for production” (Vrijhoef 1998). The minimum is however not necessarily the optimum or most efficient way to do things. In Lean Construction, waste is defined as anything that does not generate value, where value is the things the customer is willing to pay for. Essentially, buffers help make the project insensitive to perturbation; however, too much buffer is waste (workers waiting on work) and not enough can result in a project being susceptible to productivity losses and schedule degradation (work waiting on workers) when variation does occur. Perhaps most importantly, buffers mask the sources of uncertainty that make them necessary. Low variation levels in a project do not alone guarantee good productivity or reduced waste, because the presence of excessive buffers can absorb the variation and adversely impact performance. It is evident that buffers are used in construction, but the underlying causes of time buffers, both the frequency and severity thereof and how buffer allocation occurs when planning, are unclear.

Recent research on variation proposed a systematic means of prioritizing the causes of variation to be targeted for reduction through the use of a risk assessment matrix (Wambeke 2011). This research also uses a risk assessment matrix through an integrated effort to develop risk profiles for the causes of time buffer. Risk profiles can be an effective tool for prioritizing risk treatment efforts (Gencturk 2010). Ideally, we would like to eliminate all of the uncertainty associated with the different causes of time buffer; however,
in today’s construction industry environment of limited resources, the risk profiles help to categorize and prioritize the factors for management to address. Additionally, there is great importance in comparing the perceived need for time buffer to the actual causes of task duration as it reveals disconnects in the underlying structures of time buffer and task variation. Management benefits from understanding which causes of uncertainty personnel plan for and do in fact cause variation as well as understanding which causes personnel unnecessarily plan for and those they fail to plan for and do not realize are the cause of performance problems.

Most construction personnel at every level of management will acknowledge that they are constantly planning and trying to figure out how best to deal with the uncertainty and variability of construction projects. Plausibly and arguably, construction personnel do not consider the causes of time buffer independently but rather group them together and prioritize them through the use of a mental model and/or certain questions they ask when planning construction task durations. Further, the priority and interrelationships of the underlying factors are different depending on what level of management is asked. This research incorporates the use of factor analysis and structural equation modeling to develop these models used by construction personnel when task planning and allocating time buffer.

Ballard et al. (2003) argued the first line of defense against project degradation advocated by lean construction is to reduce uncertainty and variability in an effort to reduce waste and ultimately increase productivity performance. They suggested the use of a collaborative planning tool called The Last Planner System® (LPS®). The use of this tool will eventually create confidence both that interests will be protected and that work flow will
be managed (Ballard 2000b). Construction personnel will be able to provide unpadded durations for their assigned tasks. Essentially, buffer sizes can be reduced if work flow variation can be reduced, and project durations can be reduced by reducing buffers.

Due to the inherent complexity, uncertainty, and variability of the construction process, it is important to study the root causes of time buffer used to protect against those challenging characteristics. Once the root causes are identified, methods for addressing the most problematic areas and an understanding of how construction personnel at various levels of management allocate the time buffer can be developed. Construction managers can then take effective steps towards addressing those causes, managing uncertainty, allocating time buffer where it is needed most and reducing the overall associated time buffer in construction projects.

1.2 Research Objectives

The primary goal of the research is to better understand the allocation of time buffer to construction project task durations. Guiding this research are ten individual research objectives that support the overall framework of the research. These research objectives were studied and analyzed through the use of a questionnaire survey, a model survey and two separate case studies. The questionnaire survey was used to determine the causes of buffer and their frequency and severity. Based on preliminary analysis of the survey responses, it was hypothesized that construction personnel do not consider causes of buffer independently but rather group them together and prioritize them through the use of a mental model when
planning task durations. The development of this causal structure is used for decision support through identification of risk areas, and the prioritization, prevention, and mitigation of those risks. The model survey collected feedback and input to provide a level of model validation, while the case studies focused on comparing the buffering tendencies of various trades and activities, and investigating the effect of the use of LPS® on the amount of time buffer present and project performance. Together, the surveys and case studies support the overall objectives of this dissertation.

Objective 1: Identify the causes of time buffer and determine which are the most prevalent and severe in terms of additional time included in construction project task durations.

Objective 2: Quantitatively develop risk profiles of the causes of time buffer so they may be prioritized for mitigation efforts.

Objective 3: Determine the differences in opinion and perception between different levels of management, different trades, different levels of experience, the difference between contractors and subcontractors, and the difference between contractors using traditional management approaches and those using lean construction techniques.

Objective 4: Compare and contrast the overall most severe causes of time buffer with the most severe causes of duration variation to identify disconnects between the perception of concerns about uncertainty and the reality of what causes task duration variation.

Objective 5: Identify the underlying factors that correlate the individual causes of time buffer.
**Objective 6:** Develop the mental model and associated causal structure used by project managers and field level managers (superintendents and foremen) when buffering and planning for uncertainty.

**Objective 7:** Examine the effect of traditional management and planning on the allocation of time buffer and the associated impacts on task variation and productivity.

**Objective 8:** Examine the effects of lean construction techniques such as LPS® results on the allocation of time buffer to construction project task durations and the implications on project performance.

**Objective 9:** Determine construction trades and activities to be targeted by management for time buffer and variation reduction. Further, investigate how the reasons for time buffer allocation compare to the causes of variation in practice for a given construction project.

**Objective 10:** Through the use of a model survey, attempt to validate the SEM developed mental models of how construction personnel plan for uncertainty and allocate time buffer to construction project task durations.

### 1.3 Research Design

**1.3.1 Design Overview and Scope Limitations**

There were two primary methods of data collection in the research: the development and distribution of a questionnaire survey as well as a model survey and the execution of two case studies. The surveys contributed directly to addressing the first six objectives and the tenth objective, while the case studies were used for investigation of the seventh, eighth, ninth and tenth objective. The details of the surveys and case studies are discussed in
Chapter 3 (Methodology) and Chapter 4 (Research Results and Analysis), but a brief description of each is provided as an overview. Also, a flow chart of the overall research design is included below (Figure 1.1). Research is an ever forward process and often iterative. The dashed lines in the flow chart represent the need for future research and case studies to further validate the author’s findings and further investigate the allocation of time buffer to construction project task durations. The research boundary is defined by the scope described in this section. In construction there exist multiple types and layers of buffer. The different project participants to include owners, architects and engineers, general contractors, sub or trade contractors, suppliers and all their project managers, superintendents, and foremen use different types of buffer such as money, inventory, capacity, plan, and time to reduce the impacts of uncertainty on a construction project as it transitions from initial owner thoughts into a design and ultimately to construction. Although they are all important areas for research, the scope of this research is limited to the time buffer added to task durations by the project managers, superintendents, and foremen of general and subcontractors. Given the scope limitations discussed in the following sections, the research results will be relevant and the research method can be applied to other types of projects and trades with appropriate adjustment.
1.3.2 Questionnaire and Model Survey

For the first phase of this research, a questionnaire survey was developed and distributed to construction companies across the United States for completion. The survey was used to determine the causes of uncertainty or concerns about potential for variation that result in the addition of time buffer in construction task durations. Additionally, the frequency and severity associated with each of the causes was collected. The respondents of the survey were foremen, superintendents, and project managers working for general contractors and trade contractors throughout the country. There were a total of 180 usable
survey responses used for data analysis. The survey data input is limited to those personnel who volunteered to complete the survey from each of the participating companies. The subcontractors and general contractors who participated in the survey were all from the commercial sector of the construction industry. Although this is a research limitation, the commercial sector is an important sector, accounting for approximately 48% of construction employees (Dept. of Labor 2012) and 25% of the total construction value put in place each year in the United States (National Research Council 2009). A second limitation of the survey is that the likely difference between union and non-union perceptions of risk was not captured.

A model survey was distributed to obtain feedback and a level of validation for the developed task planning mental models. The participants were asked to choose the models which best fit their mental thought process and causal structure for how they consider potential for variation and causes of uncertainty when task planning and allocating time buffer. Additionally, they were asked to modify the best overall model they selected so it better fit their task planning process or to draw their own model. There were a total of 34 field management level surveys completed and 29 upper management level surveys completed. The results are limited to these 63 personnel who voluntarily participated in the model survey. The surveys were anonymous and no information aside from level of management was collected.
1.3.3 **Case Studies**

Two case studies are used in this research to contribute to the time buffer body of knowledge and build on the survey results and hypotheses. As Meredith (1998) discusses, researchers use either a rationalist or case study research paradigm approach. The rationalist approach involves the use of quantitative methodologies such as modeling by equations, laboratory experiments, and statistical survey analysis to explain what happens and how. Conversely, the case study approach does not involve experimental controls or manipulations and instead is more process or means oriented with the intent of helping the researcher comprehend why certain characteristics or effects occur, or do not occur. This case study approach is in line with the objectives of the time buffer research.

The data collection process varied slightly for the two case studies and both methods are discussed in further detail in Chapter 3 (Methodology). Time buffer can be a very intangible piece of data to collect, and the major challenge of these case studies was attempting to empirically capture that data as accurately as possible. A more quantitative method using productivity was used in the first case study of a mechanical contractor, while a more subjective interview method was used to document the time buffer in a case study involving a general contractor. These case studies investigated research objectives spurred by the survey results including the comparison of buffer amounts in lean and traditional planning as well as the buffer and variation associated with various trades and types of activities. Additionally, the effects of time buffer on project performance were investigated. Two case studies were conducted in this research making it a multi-case design. Although not required, multiple cases can strengthen the results by replicating the pattern-matching,
thus increasing the confidence in the robustness of the theory (Yin 1994). The case studies’ characteristics are outlined in Table 1.1. Although the research is limited to the trades and construction projects involved in the case studies, the methodology can be applied to other projects and trades as well.

Table 1.1: Case Study Project Characteristics

<table>
<thead>
<tr>
<th>Planning Method</th>
<th>Mechanical Contractor Case Study</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Project Cost (M = million)</td>
<td>Traditional (Non-LPS)</td>
<td>LPS</td>
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<tr>
<td>$33M Total ($9M Mechanical)</td>
<td>$211M</td>
<td></td>
</tr>
<tr>
<td>Duration of Study</td>
<td>14 Months (Jan 2012 - Feb 2013)</td>
<td>19 Months (Oct 2011 - May 2013)</td>
</tr>
<tr>
<td>Contract Type</td>
<td>Lump Sum</td>
<td>GMP</td>
</tr>
<tr>
<td>Scope of Work</td>
<td>122,000 SF Medical Facility</td>
<td>350,000 SF Data Facility</td>
</tr>
<tr>
<td>Average Daily Manpower</td>
<td>45</td>
<td>140</td>
</tr>
</tbody>
</table>

1.3.4 Analysis Techniques

While there are two primary means of data collection, the approaches and techniques used in data analysis are numerous and are briefly discussed here. The survey identified the causes of time buffer and the frequency and severity of each cause. Risk assessment was used to categorize the causes based on an integrated approach using histogram analysis and a risk assessment matrix. The research then hypothesized that these individual causes of time buffer are not independent and multicollinearity exists; therefore, factor analysis was used to determine the correlation of the causes.
The survey results also indicated the existence of Simpson’s Paradox as the correlation of overall frequency to severity changed somewhat when the causes were broken into four groups of risk level through the use of clustering in Statistical Analysis System (SAS®) software.

Another hypothesis driven by the survey results was that construction personnel have a mental model they use when allocating buffer and planning for uncertainty. That is they do not consider all the causes at the same time or with the same priority and some hierarchy exists. Structural Equation Modeling (SEM) analysis was used to develop the model. SEM is a methodology for representing, estimating, and testing a network of relationships between variables. In this model development, Simpson’s Paradox also supports interest in partitioning the survey responses by levels of management when developing the model of the causal structure used by construction personnel as the model of all survey respondents will likely differ from the model for each level of management. These differences across the levels of management are an important aspect of the model analysis. A survey was also used to obtain feedback and validation of the data based models.

The case studies involved the collection of productivity data, percent planned complete (PPC) data, time buffer data, variation data, as well as feedback from surveys and interviews. The case study analyses used the collected data to examine the survey findings regarding trade time buffer allocation behavior and the effect of using lean planning techniques on project performance both at the project and trade level. Two by two matrices were used to identify critical activities for the mechanical contractor case study and critical trades for the general contractor case study.
1.4 Research Significance

Construction is an industry with characteristically inherent complexity and uncertainty existing in the execution of construction projects. This complexity and uncertainty lead to variation. Research has been conducted on the factors affecting productivity as well as the resulting variation. Researchers have also acknowledged the use of various types of buffers to compensate for the uncertainty and absorb the variation it causes. Some lean researchers argue that the use of buffers is waste as they do not directly add value to a project (Ohno 1988; Womack and Jones 1996). Others argue that due to the uncertainty and variability inherent in construction, buffer will always be necessary to ensure flexibility in responding to problems (Howell et al. 1993; Ballard and Howell 1995; Tommelein et al. 1999). Researchers do agree that overly large buffers are wasteful and can reduce project performance by extending duration, reducing work discipline and coordination. The questions become “what causes construction personnel to use buffer in the first place?” and one of “how lean is lean enough?” How much do personnel buffer, how can the time buffer be reduced, and where should time buffer be allocated first?

The elimination of all uncertainty, variability, and associated time buffer in construction is unlikely. However, understanding and addressing the root causes of buffer will help us to reduce it through better planning and allocate it where it is needed most (lower the river to reveal the rocks), consequently reducing project duration costs. As Hopp and Spearman (2008) state, “understanding the underlying causes of variability and the causes of the buffers it begets is essential to the design and management of efficient production systems”. The literature review will further discuss the existing research and illustrate the
lack of research conducted regarding the understanding of the root causes and allocation of time buffer specifically as well as the effects of lean construction techniques on time buffer in construction projects. These gaps in the construction related body of knowledge illustrate that this research is a significant contribution to the body of knowledge. The research analysis methods and results will have a broader impact in their ability to be applied in multiple other domains to include the military, air transportation, supply chain, and hospitals especially when considering different levels of management.

Aside from the importance of the research contributions to the construction related body of knowledge, there is significance in the practical application and lessons learned by the participating companies. Hopefully, those companies and individuals who assisted this research through the completion of surveys and case study participation will learn and improve as a result of this research. Additionally, the goal was for this research to be an initial look into time buffer as an important aspect of construction engineering management and the construction industry as a whole. Hopefully, this research makes a respectable contribution and provides the foundation for additional research opportunities and ideas in regards to time buffer in construction task durations.
CHAPTER 2

2.0 LITERATURE REVIEW

This literature review was completed to study the existing research pertaining to the definition of buffer, the function of buffer, and the types of buffer, to provide a foundation for defining buffer for this research and identifying the causes of buffer and their relation to productivity, work flow, and variation. Further, the purpose of this literature review is to study factors in construction literature which affect cost contingency as well as productivity as they are hypothesized to be closely related to the causes of buffer. An introduction to Lean Construction is also included since part of the case study will document the effect of lean planning philosophies on buffer. Also, risk assessment, factor analysis, and structural equation modeling were used in this research and are therefore included in this literature review as well.

2.1 Construction Research Pertaining to Buffer

2.1.1 Buffer Defined

When addressing a topic such as buffer, there is great importance in first clearly defining it. There are not only several definitions and functions of buffer in construction literature but also several types of buffer addressed in construction literature. This literature review will summarize those definitions and functions and includes a discussion of five main types of buffer in construction literature: financial, inventory, capacity, plan, and time. Hornby (1974) wrote that a buffer is an apparatus for lessening the effect of some impact.
Horman and Kenley (1998) defined buffer as an allowance used to accommodate the impact of unexpected influences and other difficulties encountered in a construction project. Alves and Tommelein (2004) define buffers concisely as resource cushions, i.e., money, time, materials, space, etc., used to protect processes against variation and resource starvation. According to Ballard and Howell, buffers operate to provide a cushion or shield against the negative impact of disruptions and variability (Howell et al. 1993; Ballard and Howell 1995). Horman (2000) added that buffers of different types not only provide shielding, but they provide the ability to efficiently respond to variable conditions thereby enhancing overall performance. Sakamoto et al. (2002) noted that buffers function to absorb problems and perturbations, and allow varying rates of production. Production systems must be able to absorb variation in order to avoid loss of throughput, wasted capacity, inflated cycle times, larger inventory levels, long lead times, and poor customer service (Hopp and Spearman 2008). Ballard (2005) has called construction one type of such production system, albeit one of greater complexity and uncertainty, that uses various types of buffer to absorb variation that occurs due to uncertainty in construction projects.

Construction literature focuses on five main types of buffer. Hopp and Spearman (2008) list inventory, capacity, and time as three types of buffer. Ballard and Howell (1995) introduced a fourth type of buffer called plan buffer. The literature also discusses the use of cost contingency as a financial buffer. These five types of buffer are described in Table 2.1.
The focus of this research is the “within activity” time buffer that is an amount of extra time (hours or days) added to individual task durations to compensate for uncertainty and protect against variation. Figure 2.1 is intended to help illustrate the time buffer discussed in this research. The time buffer is the difference between the scheduled/planned task duration and the minimum duration the task should take based on an optimum or baseline productivity. Baseline productivity is defined as the productivity of the subset of work days where the highest daily output of quantities was achieved (Horman and Thomas 2005). The size of the subset in workdays is 10% of the total workdays, but not less than five workdays. By definition it represents the best performance the contractor achieved on the

<table>
<thead>
<tr>
<th>Type of Buffer</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Inventory</td>
<td>Buffers of physical material stockpiles (Horman and Thomas 2005). Large buffers of inventory can lead to congestion which impedes performance, but material stockpiles which are too low can lead to stopped, slowed, or disrupted production.</td>
</tr>
<tr>
<td>2. Capacity</td>
<td>Buffers of additional manpower and/or equipment provided to an operation beyond the anticipated need for completion (Horman and Thomas 2005). Additional capacity provides an operation the ability to rapidly respond to situations caused by uncertainty and variability. Too much capacity buffer can also result in inefficient labor and equipment use.</td>
</tr>
<tr>
<td>3. Plan</td>
<td>Buffers that are inventories or backlogs of workable assignments (Ballard and Howell 1995). Plan buffer provides alternative tasks for crews to perform that keep them working in the right sequence when the main tasks planned cannot be performed or when assignments are completed sooner than expected.</td>
</tr>
<tr>
<td>4. Time</td>
<td>Buffer that takes the form of additional time added into a task to protect against uncertainty and to absorb variation. The concept of float is one such use of time buffer and is seen in the Critical Path Method. Float provides some flexibility in determining start dates for activities, without delaying the project’s completion (Alves and Tommelein 2004). A similar example is the use of a deliberate pause or time lag inserted between step in an operation (Horman and Thomas 2005). Lee et al. (2006) points out time buffers have been mainly used as a contingency such as adding a percentage of the activity duration at the end of the activity to accommodate uncertain and variable conditions.</td>
</tr>
<tr>
<td>5. Financial</td>
<td>Money in the construction project budget reserved to pay for unforeseen design or construction costs (Risner 2010).</td>
</tr>
</tbody>
</table>
project and occurs when material, equipment, and information flows are good and the plan is adequate (Sakamoto et al. 2002). Other approaches for determining a contractor or trade’s minimum duration may be based on historical labor curves for their company and/or the expertise and experience of the construction personnel conducting the task planning and assigning durations.

![ACTIVITY A](image)

**Figure 2.1:** Time Buffer

2.1.2 **Research on the Management and Effects of Buffer**

Since there is usually a significant amount of uncertainty associated with actual task durations, there are a couple of options when scheduling. The uncertainty can be simply ignored and the expected or most likely time duration for each activity can be used or a contingency allowance (buffer) mentioned previously can be included in the estimate of activity durations (Hendrickson and Au 2008). The first option usually results in overly optimistic and unreliable schedules. The second leads to the discussion of more formal
incorporation of uncertainty as seen in the Program Evaluation and Review Technique (PERT) method. The optimistic (O), most likely (M), and pessimistic (P) activity durations are used to calculate the expected durations ($T_E$) of the activities (see Equation 1 below).

$$T_E = \frac{(O + 4M + P)}{6} \quad \text{Eq. 1}$$

Unfortunately, the PERT method does have several drawbacks. First of all, the procedure focuses on a single critical path, when many paths might become critical due to random fluctuations and PERT tends to underestimate actual project durations (Hendrickson and Au 2008). A second problem is the incorrect assumption that task durations are independent random variables. Task durations are in fact correlated with one another as a problem encountered on one task will likely influence tasks which follow. PERT also requires labor intensive data collection as three duration estimates are required for each activity instead of one. Although PERT does attempt to quantify the amount of time buffer in task durations it does not address the question of what causes buffer to be included in those durations.

The time buffer added to tasks is usually subject to either Parkinson’s Law or student syndrome (Lechler et al. 2005). Parkinson’s Law states that people will always use this time buffer because the task will grow to take as long as the time allotted for it to be done. In other words the work will expand to fill the time allotted by for example working more slowly, or rechecking work multiple times before declaring it complete. The student syndrome is based on the tendency of people to waste time buffer by starting their tasks later
than the planned start or even as late as possible without impacting the next schedule task or their deadline. Sometimes the later start does impact the next task or causes a deadline to be missed and schedule variation occurs. Both of these issues result in wasted time and money as well as reduced productivity. Goldratt (1997) similarly argues that instead of being used to deal with uncertainties and variation, the time buffer is always used as a part of the time to perform a task. Goldratt developed Critical Chain Project Management to manage this time buffer and calls for removing all buffer within the activities and placing it at the end of the project and allowing activity delays to be absorbed by the pooled buffer. Unfortunately, there are few if any construction projects published where this method has been used successfully. One reason may be that allowing pooled buffer to absorb a delay will have an immediate and problematic domino effect on the downstream activities in regards to schedule, manpower, equipment, cost, etc due to the complex interdependencies existing in construction projects. As part of the Last Planner System®, Ballard (2000a) introduced Phase Scheduling which uses pull and team planning techniques to develop schedules for each milestone based phase of work. He notes that it is critical that task durations not be padded with time buffer to allow for variability in this planning process. Instead, the team works together; applying minimum duration estimates for each activity and develops the phase schedule. If there is time left over between the milestone date and phase schedule completion, then and only then is buffer added to those activities with the most uncertainty or greatest need for extra time.

Tommelein et al. (1999) stated that successful project managers take proactive steps to establish buffers to shield crews from variability in construction. They noted common
causes included “change orders, late replies to requests for information, lack of materials, physical interference between materials, and work-space congestion” but did not develop a thorough list of factors or explore further into them. Lee et al. (2006) have developed a new buffering approach, reliability and stability buffering, as a means to reduce uncertainty caused by errors and changes, in particular, when concurrent design and construction is applied to an infrastructure project. While they identify design errors and changes as causes of time buffer, their research is limited to those two factors and current construction literature does not address the perceived frequency and severity of the root causes for the addition of time buffer.

The literature acknowledges the existence of time buffer and suggests methods for managing the time buffer, but little research has been done to examine and identify the root causes of time buffer in construction project task duration estimates. Furthermore, to the knowledge of this researcher, there has not been research done to compare perspectives of different groups (levels of management, trades, general to subcontractor, levels of experience, lean to non-lean) on the causes of time buffer. Nor have the causes of the perceived need for time buffer been compared with the reality of what causes actual variation in task durations. Based on the literature review, there exists a gap in the body of knowledge in regards to the causes and perceptions of time buffer in construction. Identifying potential causes of buffer begins with the assumption that factors affecting productivity and those considered when adding cost contingency to projects are closely related to those causes of uncertainty and concern that cause construction personnel to add time buffer to task
durations. The next two sections, 2.2 and 2.3, address the factors causing cost contingency and those affecting productivity respectively.

2.2 Construction Research Pertaining to Factors Affecting Cost Contingency

One of the topics reviewed dealt with factors that result in the addition of cost contingency to a project budget. Cost contingency is defined as an amount of money reserved to pay for unforeseen design or construction costs in the project (Risner 2010). The uncertainty in construction at the heart of this cost contingency is very much the same uncertainty that results in the addition of buffers in construction. Risner (2010) discusses design errors and omissions, scope changes, and unforeseen field conditions as factors driving cost contingency. Mak and Picken (2000) used risk analysis to determine site conditions, access, additional client requirements (scope changes), contract period, and project coordination as what they called risk events that contribute to uncertainty associated with a specific project. Chan and Au (2009) studied factors that contractors perceived to be important when pricing “time-related” contract risks. Their literature review and factor list included factors relevant to our study of time buffer such as project size, project complexity, construction method, degree of difficulty, risk associated with inherent nature of the work, project duration, location, labor reliability, labor availability, owner, project duration (contract period), and site constraints. Smith and Bohn (1999) investigation of contract contingency included factors such as scope changes, specifications, design quality, damaged or late materials, resource availability, site access, delays in addressing problems, quality
problems, poor productivity, weather, and construction methods. Günhan and Arditi (2007) also considered factors that drive cost contingency as a way to deal with uncertainties. They listed project complexity, inherent uncertainty in the performance of the parties involved, design and scope changes, permit issues, differing site conditions, schedule constraints, and constructability issues as examples of such factors. Harbuck (2004) documented cost variation associated factors such as design errors and changes, specification requirements, differing site conditions, delays, scope changes, and permits. Just as cost contingency considers the impacts of uncertainty and potential for variation related to these factors, construction personnel too may consider many of the same factors when considering the amount of time buffer to add to their task durations.

2.3 Construction Research Pertaining to Factors Affecting Productivity

Factors which affect construction productivity are equally important in developing a thorough list of factors for investigation. There has been a significant amount of research done in reference to factors affecting construction productivity. Borcherding and Gardner (1981) identified material and tool availability, rework, overcrowded work areas, inspection delays, foreman incompetence, crew interference and turnover, and foreman changes as the top factors affecting productivity. Thomas and Yiakoumis (1987) grouped factors affecting productivity into four main categories: environmental, site, management, and design factors. Herbsman and Ellis (1990) categorized influence factors as either technological or organizational. The technological factors included specification, design, material, and
location, while the organizational factors included production, social, and labor factors. Thomas and Sakarcan (1994) used a factor model to classify scope, work content, design features, specifications, component size, rework, material, tools, equipment, information, plant status, weather, sequencing, and congestion as productivity factors. Using an artificial neural network, Portas and AbouRizk (1997) predicted productivity rates for concrete work and found work complexity, superintendent skill, crew skill, design accuracy, dimensions, degree of repetition, working condition, site congestion, and site access as primary factors affecting productivity. Somnez and Rowlings (1998) also studied concrete placement and found quantity, job type, crew size, percent overtime, crew composition, weather, and the concrete pump to be the most pertinent factors impacting productivity. Rojas and Aramvareekul (2003) determined the top factors associated with productivity to be scheduling, manpower experience and motivation, adverse working conditions, and scope changes. Liberda et al. (2003) determined lack of detailed planning, inadequate supervision, and lack of information were the three primary factors impacting productivity. Recently, Dai et al. (2009) used a nationwide survey of nearly 2000 craft workers to examine 83 different productivity factors. They identified tools and consumables, materials, engineering drawing management, and construction equipment as having the greatest impact on productivity from the craft workers’ perspective. Kimpland (2009) categorized factors as internal or external. He classified lack of foreman planning and communication skills, cultural resistance to change, poor communication between foremen and project managers, and lack of technical training at the craft level as the top internal factors. The top external factors included poor quality of plans and specifications, slow responses to questions, unrealistic schedule demands.
from the customer, and lack of qualified labor. Wambeke et al. (2011) completed a thorough literature review of productivity factors including the factors previously mentioned to identify 166 total factors that affect productivity. Not surprisingly many of the factors overlapped or were repeated, and he cross-referenced and reduced those factors to 50 causes of variation which were also considered when developing the baseline of time buffer factors.

2.4 Research Pertaining to Lean Construction

2.4.1 Lean Construction Background

The following background information on the Lean Construction Institute (LCI) was obtained from the organization’s website: www.leanconstruction.org. LCI is a non-profit research organization which was founded by Glenn Ballard and Greg Howell in 1997. LCI's purpose is to reform design and construction through new approaches to project design and delivery. Lean theory, principles and techniques, taken together, provide the foundation for a different, more collaborative, and more effective form of project management. According to LCI, the Lean approach can generate significant improvements in schedule with dramatically reduced waste. The Lean Project Delivery System® (LPDS) was developed by LCI and applies principles pioneered in manufacturing to construction. The purpose of LPDS® tools is to facilitate planning and control, maximizing value and minimizing waste throughout the construction process. The key differences between lean construction and other forms of project management were outlined as follows by Wambeke (2011):
• **Control** is redefined from "monitoring results" to "making things happen." Planning system performance is measured and improved to assure reliable workflow and predictable project outcomes.

• **Performance** is maximizing value and minimizing waste at the project level. Current practice attempts to optimize each activity and thus reduces total performance.

• **Project Delivery** is the simultaneous design of the facility and its production process. This is concurrent engineering. Current practice, even with constructability reviews is a sequential process unable to prevent wasteful iterations.

• **Value to the customer** is defined, created and delivered throughout the life of the project. In current practice, the owner is expected to completely define requirements at the outset for delivery at the end, despite changing markets, technology and business practices.

• **Coordinating action through pulling and continuous flow** as opposed to traditional schedule driven push with its over-reliance on central authority and project schedules to manage resources and coordinate work.

• **Decentralizing** decision making through transparency and empowerment. This means providing project participants with information on the state of the production systems and empowering them to take action.

In summary, lean construction is a production management based project delivery system emphasizing the reliable and efficient delivery of value while minimizing waste. Lean construction challenges the generally accepted belief that there is always a trade between time, cost and quality.
2.4.2 **Last Planner System**

The addition of time buffers to project task durations during planning is central to this research. This section serves to introduce the planning process used in lean construction as one of the case studies was carried out with a company who practices lean construction techniques. The Last Planner System (LPS) is the planning process associated with and advocated by the LCI. It involves collaborative planning which is scheduling intended to engage all members of the project team. The main objective of LPS is to create and maintain reliable workflow between crews through reliable weekly work plans (Howell 2009). It is essentially identifying all of the pre-requisite tasks and constraints for a given task and then ensuring it is feasible for those pre-requisites to be completed and for those constraints to be removed prior to beginning the task. Figure 2.2 illustrates the flow process associated with the LPS.

Phase scheduling is a part of the LPS process in which pull techniques and team planning are used to develop schedules for each phase of work (Ballard 2000a). The phase schedules produced are based on targets and milestones from the master project schedule and provide a basis for lookahead schedules. Each phase is scheduled by working backward from the milestones and identifies conditions required for work to be released from one activity to the next and the coordination necessary to allow multiple activities to proceed concurrently (Howell 2009). Near the end of the process, durations are established for each activity to determine if there is any time left between the calculated start date and the possible start date. It is critical those durations are not be padded to allow for variability when performing the work. Once an ‘ideal’ schedule has been developed and if extra time
does exist, this leftover time can be assigned to the most uncertain and potentially variable task durations, can be used to delay the start of the phase in order to invest more time in prior work, or can be used to accelerate the phase completion date.

Ballard focused his research on percent planned complete (PPC) which measure the percentage of tasks from the weekly work plan that were completed. He found that by using a collaborative planning approach like LPS, PPC typically increased from about 55% to over 70% (Ballard 2000b). It has also been shown that construction labor productivity is
positively correlated with PPC (Liu and Ballard, 2009), but its relationship or impact on time buffer has not been empirically demonstrated.

2.5 Construction Research Pertaining to the Use of Risk Assessment

2.5.1 Risk Assessment Background

The word “risk” is used in many different ways and with many different words, such as “hazard” or “uncertainty” (Jannadi and Almishari 2003). The Random House College Dictionary defines risk as “exposure to the chance of injury or loss” (Hertz and Thomas 1983) and the Health and Safety Commission defines risk as “the likelihood that harm will occur” (Health and Safety Commission 1995). Every activity, not just in construction but in life, is characterized by some presence of risk. Many kinds of risks exist and are studied to include safety risk, social risk, business risk, investment risk, military risk, political risk, etc. Although risk cannot always be totally avoided, the risk can be assessed and then minimized. Risk assessment involves identifying risks in the area of concern and then classifying the risk by assigning an appropriate risk level (Wheeler 2002). Risk has two components: a probability or likelihood of occurrence and a consequence of occurrence. Likelihood is defined as the probability or frequency the event will occur, and consequence is typically defined as impacting cost, schedule, or performance parameters. The resulting risk, categorized as low, moderate, high, or extremely high in a risk matrix, such as the one in figure 2.3 used in military planning, can then be prioritized for mitigation or elimination. It should be pointed out that a risk matrix is just one tool or method for categorizing risk.
The value of the risk can also quantitatively be calculated for comparison through use of Equation 2 below. The expected value of risk or risk rating \( R \) of an item is the product of the likelihood or probability \( P \) of occurrence and the consequence of the occurrence \( C \) (Gencturk 2010).

\[
R(n) = P(n) \times C(n) \quad \text{Eq. 2}
\]

2.5.2 Risk Assessment in Construction Research

Risk assessment in the construction industry is completed and researched in multiple important aspects of construction. Much literature exists in regards to risk assessment in construction and this section mentions a few of them. In regards to scheduling, Mulholland and Christian (1999) developed a systematic way to estimate the amount of risk in a construction schedule at the initiation of a project. Jannadi and Almishari developed and computerized a risk assessor model (RAM) to determine the risk associated with a particular activity and the justification factor for a proposed remedy. Similar to studying activity risks,
several researchers have studied the risk associated with different types of construction such as highway, high-rise, and mountainous jobsites. Choi et al. (2004) suggested a risk assessment procedure composed of four steps of identifying, analyzing, evaluating, and managing risks inherent to underground construction projects. Some risk assessment has also been done in the area of construction contracts such as Chan et al.’s (2010) study of risk assessment for guaranteed maximum price and target cost contracts. Another high emphasis area is that of occupational risk assessment to evaluate and improve construction safety (Pinto et al 2011). The author too has accomplished risk assessment to include the use of a risk matrix as part of a solution to unexploded ordnance discovered on his construction jobsite at Langley Air Force Base, Virginia.

2.6 Construction Research Pertaining to the Use of Factor Analysis

2.6.1 Factor Analysis Background

The procedures for undertaking factor analysis were first developed early in the twentieth century by Charles Spearman, and since that time there have been numerous texts written entirely on the subject of factor analysis (Spearman 1927; Harmon 1976; Kim and Mueller 1978). Factor analysis is used to analyze a large set of observed variables in which multicollinearity exists with the ultimate goal of identifying a reduced set of factors that summarizes and describes the interrelationships among the variables in a concise and understandable manner (Gorsuch 1983). Multicollinearity is a condition in which the independent variables are themselves correlated (Pett et al. 2003). This author hypothesized
the many individual causes of buffer considered during this research are not independent and multicollinearity exists in the buffer variables (i.e., some of those individual causes of buffer are correlated to others). The basic assumption of factor analysis is that within a collection of observed variables (causes of buffer), there exists a set of underlying factors, smaller in number than the observed variables, that can explain the interrelationships among those variables (Kim and Mueller 1978).

2.6.2 Factor Analysis Use in Construction Research

Trost and Oberlender (2003) studied 45 potential drivers for predicting early cost estimate accuracy on construction projects and used factor analysis to group them into 11 orthogonal factors. Factor analysis was performed to extract 4 major factors from 25 motivational attributes affecting worker’s productivity in Australian construction industries by Doloi (2007). Lu et al. (2008) used factor analysis to group 35 critical success factors pertaining to contractor competitiveness into 8 clusters. Craft workers’ perspective of the impact 83 productivity factors on construction productivity was studied by Dai et al. (2009) and factor analysis revealed 10 latent factors representing the underlying structure. Most recently, Wambeke et al.’s (2011) research on the causes of starting time and duration variation in construction project tasks used factor analysis to identify 9 major factors from in his list of 50 causes of variation. Factor analysis is a commonly used method to analyze data in construction as well as many other fields of research; however, factor analysis has not
been used to analyze the interrelationships of the individual causes of time buffer in construction project tasks.

2.7 Construction Research Pertaining to the use of Structural Equation Modeling

2.7.1 Structural Equation Modeling (SEM) Background

The origins of SEM date back to the 1920s, when a geneticist named Sewell Wright attempted to solve simultaneous equations to explain genetic influences across generations (Maruyama 1998). SEM in literature is also referred to as covariance structure analysis and is a highly flexible and comprehensive methodology for representing, estimating, and testing a network of relationships between both observed (directly measured) variables and latent (unobservable) constructs or factors (Rigdon 1998). The SEM allows analysts to determine the underlying structure of a set of indicators and examine the strength of the relationship between these theoretical constructs (Jackson et al. 2005). To that end, one of the major applications of SEM is causal modeling, or path analysis, which hypothesizes causal relationships among variables and tests the causal models with a linear equation system. The term causal model must be understood to mean: "a model that conveys causal assumptions," not necessarily a model that produces validated causal conclusions (Pearl 2009). These models can involve either the previously discussed manifest variables, latent variables, or both. Another application is confirmatory factor analysis which tests models of relationships between latent variables (constructs or factors) and measured variables which are the
indicators of common factors (Suhr 2006). This research was conducting using both the confirmatory factor analysis and path analysis procedures.

There are several justifications for the use of SEM as well as advantages over traditional statistical methods such as regression analysis. A fundamental premise of multiple regression analysis is that all variables are assumed to be independent. The fundamental causes of buffer are believed to have multicollinearity. SEM is a multivariate technique incorporating both observed (measured) variables and unobserved (latent constructs) while traditional techniques analyze only measured variables (Suhr 2006). Also, multiple regression ignores measurement error and with a survey of this type there is inherent measurement error stemming from both inaccurate ratings on a Likert scale and inconsistent responses to quantitative questions. The SEM framework accounts for these errors in measurement, thus producing more accurate representations. Finally, standard regression models only allow for explicit modeling of direct effects whereas SEM allows for direct, indirect, and correlative effects to be explicitly modeled (Molenaar et al. 2009).

Software capable of testing causal models with latent (unobserved) variables has been developed for use by analysts to apply SEM to solve real-world problems. The first of such widely available software programs was LISREL (for Linear Structural RELations) (Hatcher 1994). Another package is Statistical Analysis System (SAS) which uses the PROC CALIS procedure and statements to test these latent variable models. SAS version 9.2 was used to conduct SEM in this study.
### 2.7.2 Structural Equation Modeling use in Construction Research

Structural equation models are ideally suited for many of the research issues dealt with in construction engineering and management (Molenaar et al. 2000). SEM has very recently been utilized in construction-related research. SEM analysis has been used to provide insight into the factors that can be used to understand the susceptibility of a project to contract disputes (Molenaar et al. 2000). Mohamed (2002) used SEM to explore the relationship between safety climate and safe work behavior on construction sites. Islam and Faniran (2005) used SEM to describe and quantify the influence of situational factors on project environment and organizational characteristics of effect project planning. Wong and Cheung (2005) used SEM to examine partner trust level in their performance, permeability, and relational bonding in the partnering success evaluation. Leung et al. (2009) used SEM to cross check the interrelationships among the stressors and establish an integrated stressors-stress model while identifying the critical stressors influencing construction estimators in Hong Kong. In 2009, Molenaar et al published a paper presenting the results of a SEM that describes and quantifies the relationships between corporate culture and safety performance. Benson et al. (2011) used SEM to develop a model to provide guidance to practitioners in the construction business on the organizational attributes that they could improve to achieve organizational flexibility and not only survive but grow. SEM use in construction is growing but to date and to the knowledge of the author no one has used SEM to model the mental thought process and causal structure construction personnel use to buffer and plan for uncertainty.
2.8 Summary

Based on the research to date there seems to be a definite and growing interest in the study of several aspects of buffer in construction (Howell et al. 1993, Ballard and Howell 1995, Goldratt 1997, Ballard 2000a, Ballard 2000b, Horman 2000, Horman et al. 2003, Alves and Tommelein 2004, Horman and Thomas 2005, Lee et al. 2006, Hopp and Spearman 2008). A considerable amount of research has been completed on different types of buffer, factors affecting cost contingency, and factors affecting productivity. That research is used as a foundation for studying the allocation of time buffer to construction project task durations.

As a result of the literature review, several gaps in the body of knowledge have been identified and this proposed research provides the overall framework for taking initial steps to filling those gaps with important contributions regarding the allocation of time buffer to construction project task durations. The identified gaps include:

1. There exists a need to identify the root causes of time buffer from both a frequency and severity standpoint as it is allocated to construction project task durations.
2. The time buffering behavior at different levels of management, different trades, and different activities has not been researched nor has the comparison been made between the perception of the need for time buffer with the reality of what most often causes variation.
3. A recommended prioritization for mitigation efforts has not been documented regarding the causes of time buffer.
4. To the knowledge of the author, no models have been proposed to describe the thought process and causal structure applied by project managers and field managers when planning for uncertainty and allocating time buffer.

5. No one has documented the effects of using the LPS® on the allocation of time buffer over the course of a construction project or the impact of time buffer on project performance.

Several data analysis methods have been introduced to include risk assessment, factor analysis, and structural equation modeling, and they will be further discussed in how they will be used to meet the research objectives in Chapters 3 (Methodology) and 4 (Research Results and Analysis). The research design, content, and analysis techniques collectively are important and valuable as they directly contribute to filling the noted gaps in the body of knowledge. Additionally, this research is repeatable and can be easily applied to other construction project and trades, providing a broader impact on the construction community.
CHAPTER 3

3.0 METHODOLOGY

The literature review discussed in the previous chapter, served as the initial step of the research as it identified what research has been conducted and identifies gaps in the knowledge base pertaining to the allocation of time buffer. Those gaps in the body of knowledge drive the objectives. This chapter of the dissertation will detail the design of the work effort undertaken to deliver those objectives. Each of the two surveys and each of the two case studies will be discussed regarding their design and data collection plan.

3.1 Time Buffer Survey

3.1.1 Research Objectives Addressed by the Time Buffer Survey

Objective 1: Identify the causes of time buffer and determine which are the most prevalent and severe in terms of additional time included in construction project task durations.

Objective 2: Quantitatively develop risk profiles of the causes of time buffer so they may be prioritized for mitigation efforts.

Objective 3: Determine the differences in opinion and perception between different levels of management, different trades, different levels of experience, the difference between contractors and subcontractors, and the difference between contractors using traditional management approaches and those using lean construction techniques.
Objective 4: Compare and contrast the overall most severe causes of time buffer with the most severe causes of duration variation to identify disconnects between the perception of concerns about uncertainty and the reality of what causes task duration variation.

Objective 5: Identify the underlying factors that correlate the individual causes of time buffer.

Objective 6: Develop the mental model and associated causal structure used by project managers and field level managers (superintendents and foremen) when buffering and planning for uncertainty.

3.1.2 Time Buffer Survey Overview and Design

A questionnaire survey was developed to study which causes of uncertainty or concerns about potential for variation result in the most frequent and severe addition of time buffer in construction task durations. The survey was carried out nationwide, involving foremen, superintendents, and project managers and consisted of three parts. The survey is discussed throughout this section and the full version can be found in Appendix A and Appendix B.

Through a combination of the literature review and research team discussions with construction project managers, superintendents, and foremen, 47 individual causes related to time buffer in construction tasks were identified and included in the survey. Several of these time buffer causes are similar to Wambeke et al.’s 50 individual causes of construction task starting time and duration variation which he identified based on 166 previously discussed
factors that affect productivity (Wambeke et al. 2011). Wambeke et al.’s 50 factors were cross referenced with additional causes found in literature as well as additional causes recommended by construction industry personnel. In some cases a more general term was applied for a group of related variation factors. For example, eight of Wambeke et al.’s labor force factors were reduced to labor force reliability, labor force availability, and crew inefficiencies. In this category, morale and language barrier were kept the same, and concerns about being pushed into using more manpower was added. The greatest emphasis in determining the final list of causes was placed on selecting the most relevant causes from a prospective view during the planning or pre-task time frame rather than a retrospective view of what actually caused the variation. In other words, which causes construction personnel are concerned about or perceive as potential for problems due to uncertainty as they assign task durations. This prospective view is an important difference to note between the retrospective look at causes of variation in Wambeke et al.’s research and the causes driving the need for time buffer in this research.

The seven categories that impact productivity established by Koskela (2000) to include connected work, detailed construction design, components and materials, workers, equipment and tools, space, and external conditions, along with Wambeke et al.’s (2011) added eighth category of management/supervision/information flow were used as a framework to separate the 47 buffer factors. Based on the nature of some of the identified buffer factors, the researcher also felt it was necessary to add one additional category: project characteristics. The nine categories are listed and described below:
1) *Project Characteristics*: Pertains to concerns/uncertainty about characteristics specific to the project and one’s trade.

2) *Prerequisite Work*: Pertains to items that must be completed before one can start their task. If there is concern or uncertainty the item (permits, prerequisite work, or rework on a prerequisite task) will not be completed on time, then consider to what extent one’s duration estimate is affected. This can also be thought of as confidence in the schedule or work plan.

3) *Detailed Design / Working Method*: Pertains to concerns/uncertainty about having an accurate and available design and a feasible working method to complete the required task.

4) *Labor Force*: Pertains to concerns/uncertainty about availability, reliability, and capability of the labor force to complete the required task.

5) *Equipment and Tools*: Pertains to concerns/uncertainty about the availability, reliability, and capability of required equipment and tools to complete the required task.

6) *Material and Components*: Pertains to concerns/uncertainty about receiving the correct and necessary materials from the supplier when and where you need them. This can be thought of as trust or confidence in one’s supplier(s).

7) *Work / Jobsite Conditions*: Pertains to concerns/uncertainty about the physical space available to perform one’s job.

8) *Management/Supervision/Information Flow*: Pertains to concerns/uncertainty about the management system regarding issues related to communication, trust, changes, and getting questions answered when they arise.
9) **Weather**: Pertains to concerns/uncertainty about the climate at the location of the project and what weather conditions are prevalent such as temperatures, rain, and wind.

The following table displays the entire list of 47 buffer factors and to which of the nine categories they belong.

<table>
<thead>
<tr>
<th>Table 3.1: Individual Causes of Time Buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>----------------------------------------</td>
</tr>
<tr>
<td><strong>1. Project Characteristics</strong></td>
</tr>
<tr>
<td>Contract delivery method</td>
</tr>
<tr>
<td>Contract period</td>
</tr>
<tr>
<td>Size of project</td>
</tr>
<tr>
<td>Complexity of the project (interdependency of activities)</td>
</tr>
<tr>
<td>Complexity of the task (degree of difficulty/inherent nature of your work)</td>
</tr>
<tr>
<td>Size of your company</td>
</tr>
<tr>
<td><strong>2. Prerequisite Work</strong></td>
</tr>
<tr>
<td>Delays in obtaining permits</td>
</tr>
<tr>
<td>Completion of prerequisite work (work before you is not done yet)</td>
</tr>
<tr>
<td>Rework being required due to quality of prerequisite work</td>
</tr>
<tr>
<td>Delays in inspections for previously completed work</td>
</tr>
<tr>
<td><strong>3. Detailed Design &amp; Working Method</strong></td>
</tr>
<tr>
<td>Design constructability</td>
</tr>
<tr>
<td>Quality of documents</td>
</tr>
<tr>
<td>Poor performance due to unfamiliarity with the scope of work</td>
</tr>
<tr>
<td>Strict specification requirements</td>
</tr>
<tr>
<td>Quality control requirements</td>
</tr>
<tr>
<td>Low degree of repetition in your tasks</td>
</tr>
<tr>
<td><strong>4. Labor Force</strong></td>
</tr>
<tr>
<td>Reliability of your labor force</td>
</tr>
<tr>
<td>Availability of your labor force</td>
</tr>
<tr>
<td>Inefficiencies in your crew due to lacking experience/skills</td>
</tr>
<tr>
<td>Concerns about being pushed into more manpower &amp; creating inefficiencies</td>
</tr>
<tr>
<td>Low morale or lack of motivation</td>
</tr>
<tr>
<td>Language barrier among workers/supervisors</td>
</tr>
<tr>
<td><strong>5. Equipment &amp; Tools</strong></td>
</tr>
<tr>
<td>Reliability of your trade’s equipment and/or tools</td>
</tr>
<tr>
<td>Availability of your trade’s equipment and/or tools</td>
</tr>
<tr>
<td>Capability (productivity) of your trade’s equipment and tools</td>
</tr>
<tr>
<td>Time required to repair equipment if breakdown occurs</td>
</tr>
<tr>
<td>Time required to replace equipment if breakdown occurs</td>
</tr>
<tr>
<td><strong>6. Materials &amp; Components</strong></td>
</tr>
<tr>
<td>Receiving incorrect quantity of materials</td>
</tr>
<tr>
<td>Receiving incorrect material type or damaged materials</td>
</tr>
<tr>
<td>Receiving materials for task later than expected/planned</td>
</tr>
<tr>
<td><strong>7. Work &amp; Jobsite Conditions</strong></td>
</tr>
<tr>
<td>Overcrowded or cluttered work area/jobsite congestion</td>
</tr>
<tr>
<td>Difficult access to work area</td>
</tr>
<tr>
<td>Method of material transfer required from receiving area to task location</td>
</tr>
<tr>
<td>Distance of material transfer required from receiving area to task location</td>
</tr>
</tbody>
</table>
Table 3.1 Continued

| 8. Management, Supervision, & Information Flow | Confidence in request for information (RFI) process |
|                                             | Liability pressure (liquidated damages, contractual deadlines, etc) |
|                                             | Preparing for duration negotiation |
|                                             | Positive company recognition |
|                                             | Trust in superintendent (based on their reputation, experience, & knowledge) |
|                                             | Trust in project manager (based on their reputation, experience, & knowledge) |
|                                             | Trust in owner (based on their reputation, experience, & knowledge) |
|                                             | Required coordination with other trades |
|                                             | Changes in scope of work (tendency of owner to make changes) |
|                                             | Communication between owner/engineer and project manager |
|                                             | Communication between project manager/superintendent and foreman |
|                                             | Communication between foreman and workers |

| 9. Weather | Climate – potential weather conditions associated with the location of the project |

3.1.3 Time Buffer Survey Data Collection Plan

A contractor general information survey and a time buffer survey were developed and used to answer the research questions. The initial plan had been to distribute a survey that contained questions regarding company demographics, individual demographics, and time buffer related questions. Pilot study feedback deemed the survey was too long and expressed concern participants might get burned out before reaching the questions regarding time buffers. Additionally, foremen and superintendents did not feel comfortable answering or did not know the answers to the contractor general information questions. As a result, the survey was divided into two separate surveys: the contractor general information survey and the time buffer survey. This split and additional revisions of the time buffer survey helped shorten the surveys to an acceptable length. The contractor general information survey was typically completed by a project manager and took about 5 minutes to complete, collecting information such as the company type (subcontractor or general contractor), company size, annual revenue, average project size, backlog or pending work, and whether or not they use
the Last Planner System©. The time buffer survey was used to collect responses from construction personnel at three different levels of management: project managers, superintendents, and foremen. The foremen level also included those with the similar job titles of supervisor or trade lead.

The time buffer survey included three sections. The first section asked participants to provide background information such as their trade, position, and experience. Sections two and three involved obtaining feedback pertaining to the previously discussed categories and individual reasons for adding buffer in task durations. In section two the participants were asked to rank order the nine overall categories. They were asked to think about their planning process and consider the uncertainty or potential problems they face in each of the categories. Then, based on their experience, decide which categories contain the most critical and prevalent causes of uncertainty when they are budgeting time into task durations. The participants were also asked whether or not they felt the uncertainty associated with the category is under their responsibility to control or mitigate. Figure 3.1 below shows the questions in the second section of the survey.
The third section expanded the nine categories into the 47 causes or reasons that impact task duration estimates. The purpose of this third section was to find out which causes most frequently and severely impact task duration estimates. For each cause of time buffer, the respondent was asked how frequently the cause influences their duration estimate by circling one of the following seven frequency responses: never, rarely, occasionally, sometimes, frequently, usually, or always. Next for each cause, the respondent was asked to consider a two week (10 day) activity and estimate how much time (days) they would include
or allocate for the given cause when planning task durations and to protect against the effects of uncertainty. The respondents chose one of the following seven severity responses: 0, 0.5, 1, 2, 3, 5, or 7, where the six step sizes between the responses are set at 0.5, 0.5, 1, 1, and 2, 2 to accommodating the need for larger noticeable differences with higher severity responses. The decision to use seven choices for both frequency and severity was made to balance having too many choices with still being able to capture just noticeable differences. The time buffer survey took approximately 20 minutes to complete. Figure 3.2 below provides an example of a question from the third section of the contingency survey. The question in the example is about labor related causes.

![Table: 4. Factors Related to Labor]

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of your labor force (concerns about absenteeism or people arriving late and/or leaving early due to illness, injury, family, or personal situation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of your labor force (Crew size limitations due to other tasks/projects)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inefficiencies in your crew due to lacking experience/skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concerns about being pushed into using more manpower and creating inefficiencies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low morale or lack of motivation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Language barriers among workers/supervisors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.2: Example from Section Three of Time Buffer Survey
3.1.4 Time Buffer Survey Pilot Study Calibration

The survey went through multiple drafts and revisions as the researchers attempted to balance the depth and breadth of the survey. The survey had to be simple enough for the participants to not only understand what was being asked but also for them to be willing to take the time to complete the survey and give their honest opinions. At the same time the questions were framed in a manner to allow the collection of quantitative data for analysis. A pilot study was conducted with a construction company in Colorado as well as a local construction company to help avoid potential problems associated with the length, clarity of the questions, and the instructions provided for completion of the survey. Additionally, the pilot study was used to help validate the relevance of the factors chosen and allow suggestion of additional factors. The survey was distributed to two project managers, three superintendents, and three foremen (mechanical, electrical, and roofing) for pilot study completion. Four factors were added and one factor was slightly modified based on discussions with the pilot study participants. “Over commitment” was modified to be “liability pressure” and includes concerns about over committing due to a tight schedule, liquidated damages, and contractual deadlines. The factors of “positive company recognition”, “preparing for duration negotiation”, “concerns about being pushed into using more manpower”, and “poor performance due to unfamiliarity (with the scope)” were added. Based on the research team’s previous experience with a survey, the necessity to translate the survey into Spanish was asked of the pilot study participants. Since the survey would not be completed by laborers and given most everyone at the foreman level and above speaks English as a minimum, the survey was not translated. Another important result of the pilot
study was the suggestion of both an online and hard copy version of the survey. The two versions allowed foremen and perhaps some superintendents who may not have computer access during the workday to complete a hard copy of the survey, while the online version provided a convenient method for those who do have computer access. Both surveys were of the same format and content, but the hard copy version was used more frequently.

3.1.5 Time Buffer Survey Distribution

The survey was distributed to general contractors and subcontractors throughout the United States in an effort to obtain a representative sample of survey participation and responses. A few avenues of distribution were used to facilitate survey participation throughout the United States. Four local contractors were provided surveys for distribution and another nine contractors from six different states were contacted via a construction consulting company. Two professional civil engineering organizations also provided contact information for multiple construction companies throughout the United States. A total of approximately 175 different companies across 37 states received the survey and request for completion during the summer of 2011. Participation was voluntary and companies were encouraged to have as many project managers, superintendents, and foremen as possible complete the survey by hand or online. The survey distribution, completion, and collection period ran approximately 10 weeks from 1 August 2011 until 14 October 2011.
3.2 Case Studies

The case studies were a multipurpose and integral part of this research. The primary goal of the case studies was to further validate the survey results while also gathering quantitative data from actual construction projects. The original intent was to conduct case studies with both general and trade contractors and also to perform a study with two companies whose main difference was that one used lean construction techniques and the other used more traditional planning methods. In the end, two companies, who recently participated in research with Dr. Brad Wambeke, continued their support to N.C State University civil engineering research by willingly participating in the time buffer research. One of these companies was a mechanical trade contractor and the other was a large general contractor. A separate study was completed with each of these companies. Attempts to secure other companies’ participation seemed promising based on preliminary discussions but ultimately fell through for varying reasons to include project delays, resource limitations, and unreliable communication from the points of contact. Each company received and approved initial case study proposals outlining the purpose, objectives, and type of data to be collected. Ultimately, two case studies were conducted to examine the relationships between time buffer, performance, and variation. The data collection process varied slightly for the two case studies and both methods are discussed in further detail in the following sections. Time buffer can be a very intangible piece of data to collect, and the major challenge of these case studies was attempting to empirically capture that data as accurately as possible. A more quantitative method using productivity was used in the first case study of the mechanical contractor, while a more subjective interview method was used to document the
time buffer in the general contractor case study. The following sections describe the overview, design, and data collection plan for each case study.

3.3 Case Study 1 (Mechanical Trade Contractor)

3.3.1 Research Objectives Addressed by Case Study 1

Objective 7: Examine the effect of traditional management and planning on the allocation of time buffer and the associated task variation and productivity.

Objective 9: Determine construction trades and activities to be targeted by management for time buffer and variation reduction. Further, investigate how the reasons for time buffer allocation compare to the causes of variation in practice for a given construction project.

3.3.2 Case Study 1 Overview and Design

The first case study involved a mechanical contractor specializing in plumbing, heating, ventilation, and air conditioning. Results from the initial time buffer survey in this research pointed to a greater tendency to add time buffer by mechanical, electrical, and plumbing trades. Hanna (2002) noted that utility trades, specifically mechanical and electrical contractors, comprise a labor-intensive segment of the construction industry in which labor can account for 50-60% of the construction cost. Additionally, by their nature, mechanical and electrical construction tasks are complex and small changes can have large project impacts. As a result, a case study involving a mechanical contractor was of interest to the researchers. Furthermore, mechanical tasks are common to most all projects in the
construction industry. The project in this case study was the new construction of a 122,000 square foot medical facility with a lump sum total project cost of $33 million. The mechanical and plumbing work completed accounted for $9 million of the project cost. The mechanical and plumbing scope included all the sheet metal, piping, controls, insulation, equipment, and testing and balancing within the central energy plant, data center, medical office building, and outpatient building of the facility. The work was mostly self-performed by the mechanical contractor with a few subcontractors working for them as well. Although interested in the application of lean construction techniques, the contractor did not use the LPS® for task planning. The same project manager and superintendent remained on the job for the entire 14 month duration and were directly involved in the task planning. The project ran from January 2012 through February 2013 and data was collected for the entire project duration.

The mechanical trade contractor case study was performed to demonstrate the use of time buffer over the course of a project with a traditional planning system (i.e. – not the LPS®). Additionally, the project’s productivity and variation trends were collected for comparison. Also of interest to the researchers and the contractor were the buffer and variation trends of different mechanical and plumbing activity types in order to identify the most problematic activities (large amount of buffer and/or variation) in their work.
3.3.3 Case Study 1 Data Collection Plan

The task data collected over the twelve month study period included the activity description, phase (mechanical or plumbing), activity type, and schedule information to include the planned schedule and durations, the best possible durations, and the actual schedule and durations. Additionally, productivity rates were collected for the different activity types and project as a whole. The method used for determining time buffer for this case study was using the company’s baseline productivity rates. These rates for this company are based on historical records of their performance and represent the productivity expected if everything goes smoothly and constraints have been removed. It is possible that some time buffer does still exist in these baseline productivity rates and that is noted by the researchers as a limitation of the research. The best possible duration for the planned task was calculated using this baseline productivity, and the difference between the scheduled duration and the best possible duration was recorded as the time buffer for the task. The researchers and participating company felt this calculation was the most accurate indicator of time buffer possible for this project. Duration variation data was also calculated in this case study. The specific variation studied was any task durations that actually took longer than what was planned. These “delays” were calculated for comparison with the time buffer. Planning meetings were usually held bi-weekly and task planning was done approximately four weeks out. As a result, the data was analyzed on a monthly basis for the duration of the project. The emphasis of the first case study was to examine the time buffer trends, variation, and productivity over the course of the project and for the different mechanical activity types.
3.4 Case Study 2 (General Contractor)

3.4.1 Research Objectives Addressed by Case Study 2

Objective 8: Examine the effects of lean construction techniques such as LPS® results on the allocation of time buffer to construction project task durations and the implications on project performance.

Objective 9: Determine construction trades and activities to be targeted by management for time buffer and variation reduction. Further, investigate how the reasons for time buffer allocation compare to the causes of variation in practice for a given construction project.

3.4.2 Case Study 2 Overview and Design

The second case study involved a large general contractor working on a 350,000 square foot data facility with 18 trade contractors total on the job. The project was ground up with a steel structure, precast walls, and complete build out of data hall suites and administration areas. The total cost for the guaranteed maximum price contract was $211 million with a project duration spanning 24 months. The project was split into two phases: Phase A/B and Phase C/D. As previously mentioned, the initial time buffer survey results indicated a difference in how different trades allocate time buffer to construction project task durations. Additionally, the survey highlighted the perception of those using LPS® on their construction projects that there was a lower frequency and severity of time buffer in their task durations (Russell et al. 2013). Howell and Ballard (1996) assert that “improved planning stabilizes the work environment and reduces the need for large buffers.” They
promote LPS as a planning tool that directly attacks the source of uncertainty and improves performance through improving reliability of the plan. As a result, this case study involved data collection from five specialty trades and was based on the hypothesis that collaborative planning techniques such as LPS® will result in a more reliable work plan than traditional management methods and reduce the amount of time buffer deemed necessary to be added to construction task durations. The LPS® method applied in this project was designed to improve both productivity and project progress. Additionally, the time buffer sizes and variation of each trade were analyzed to highlight efficient trades as well as those requiring management attention. Finally, the root causes of variation were compared with the causes of time buffer identified by various construction personnel on the project.

3.4.3 Case Study 2 Data Collection Plan

The general contractor in the second case study used the LPS® method as the basis for their weekly planning meetings. The weekly last planner meeting involved the project engineer, superintendents, and trade foremen. In this meeting, the team reviewed the previous week’s work plan and reported whether or not each task was completed. Additionally, if any change in the starting time or duration had occurred, the magnitude and root cause of that variation was recorded. Next, each trade reviewed the three week look-ahead plan they had developed. The use of the look-ahead plan is a key aspect of the LPS method (Wambeke et al 2012). The look-ahead plan’s purpose is to identify and remove constraints, which are items that need to be completed and/or addressed before a task begins.
The look-ahead plans were developed by the trade foremen as they considered activities on the master schedule for inclusion in the upcoming weekly work plans. The foremen themselves were directly involved in the decision making of task durations. Foremen are closer to the actual construction work than any other supervisors or managers on a project, and thus are recognized as a valuable source of information about the project (Coble 1994). These last planners are the key to the LPS® concept of planning the work with input from those directly performing the work. As a result, the researchers arranged to meet with each of five trade contractor foremen over the course of 16 months (February 2012 – May 2013) to collect time buffer data. The five participating trades were mechanical, electrical, plumbing, drywall, and painting. The researchers met with each foreman on a nearly monthly basis to discuss the durations assigned to the upcoming 3-4 weeks of activities. Although this method of time buffer collection was more subjective in nature, the foremen responsible for assigning the task durations provided their input of each activity’s best possible duration into a data spreadsheet. Their best possible duration was based on optimum productivity rates, their experience, and scope of each task. They were specifically ask to consider those things and determine the best possible duration for each activity assuming there was no concern about uncertainty or potential for variation in the task. Further, the planned crew, equipment, and materials were to remain the same. For example, they were not to develop best durations by increasing the planned manpower on a given task. The time buffer was then calculated as the difference between the planned duration and the best possible duration for each task. Again, variation was also collected from the weekly meetings and was defined for this case study as any delay to an activity’s
completion, whether as a result of starting time variation or duration variation. Wambeke et al. (2011) defined starting time variation as the difference between the planned and actual starting time of a task on a weekly work plan and duration variation as the difference between the planned and actual task duration. These definitions were used for application in this research. Both case studies also collected data from construction personnel regarding the reasons they buffer as well as the root causes of the variation on the projects. This qualitative data is used to examine a difference in the perception and reality of the need for time buffer. Finally, feedback about the use of LPS was obtained via a survey of the foremen on the general contractor case study. Their responses are summarized and discussed in Chapter 4 (Research Results and Analysis) as well and provide real world insight into the use of collaborative planning techniques such as LPS.

3.5 Construction Task Planning Mental Model Survey

3.5.1 Research Objectives Addressed by the Mental Model Survey

Objective 10: Through the use of a model survey, attempt to validate the SEM developed mental models of how construction personnel plan for uncertainty and allocate time buffer to construction project task durations.

3.5.2 Model Survey Overview and Design

Model validation is an essential part of the model development process if the model is to be accepted and used to support decision making. Although the SEM procedure provides
the internal validity for the models, the author wanted real world practical application feedback as well from the construction personnel being modeled. This external feedback provides an additional level of model validation. A survey was developed and distributed to construction personnel on both case study projects and also to two additional construction companies in the area. Due to time constraints, only a four week window was available for distribution and completion of the model survey. The results help identify which of the proposed models fits construction personnel the best. Further, feedback was used to slightly adjust the best model for real world application.

3.5.3 Model Survey Data Collection Plan

The method of external validation involved creating a model survey for the two levels of management discussed earlier: field management (foremen and superintendents) and upper management (project managers). After extensive research group discussions, a format was established for the model survey. Each of the two levels of management would be asked about the three best frequency data based models and the three best severity data based models corresponding to their level of management. They were to rank order each set of three models 1 through 3 (where 1 was the best) in regards to which model best fit their task planning process. They were told to consider how they prioritize the factors as well as how they interrelate or influence each other when planning for uncertainty and allocating time buffer. Finally, they were told to pick the best overall model (#1 of 6) and circle it. This is the format that entered the pilot study completed with three field managers and four project managers. Pilot study feedback resulted in a three page model survey for distribution. The
first page included a clear but concise overview of the model survey followed by step by step instructions for completion. To the right of the instructions was a blank space for the participant to either modify the best overall model they picked so that it better fits their own task planning thought process or draw their own model using a set of the given factors. Instead of being limited to the six models, this space provided to modify or draw their own was a great idea and method for honest feedback. If the best model did not require modification, they were told to write the letter corresponding to that model in the blank space. The second page of the survey included the three frequency data based models and a list of the associated factors with a brief description of each. Some descriptions and factor names were also clarified based on pilot study feedback. The third page of the survey included the three severity data based models and a factor list as well. The guidance to rank order the three models on each page and then circle the best overall model remained the same. The final step asked the participants to circle the top three factors in the factor description block they are concerned about in regards to potential for variation or uncertainty leading to the need for time buffer.

The model surveys were distributed and completed a couple of different ways. A total of four different companies participated in the survey with three being general contractors and one a trade contractor. A jobsite visit to the general contractor case study was used to distribute the survey to both project managers and field managers throughout the day. Also, the author attended a quarterly meeting of project managers for the trade contractor and facilitated the completion of the project manager survey there. The model
survey was also distributed by e-mail to all four participating companies and both levels of management.
CHAPTER 4

4.0 RESEARCH EXECUTION AND ANALYSIS

4.1 Time Buffer Survey

4.1.1 Time Buffer Survey Results

The final count of useable surveys was 180 surveys from 36 different companies including both general contractors and subcontractors. An additional 32 surveys were not used in this analysis. These surveys were incomplete with 29 of the incomplete surveys having been submitted online. One possible reason for the incompletes was the inability to begin the online survey and then return to complete it at a later date. The survey had to be completed in one sitting. Additionally, the online version required participants to click “next” at the bottom of each section to advance to the next section. Most of the incomplete online surveys had the first section completed but had left sections two and three blank, possibly a result of this oversight or misunderstanding.

General contractors made up 28% of the participating companies and subcontractors the other 72%. Project managers accounted for 51% of the responses, superintendents completed 27% of the surveys, and foremen the other 22%.
The trades were separated into four trade groups for comparison. The utilities category includes the mechanical, electrical, plumbing, and fire protection trades and accounted for 44% of the responses. The structural category includes the steel, concrete, masonry, roofing, and earthwork trades and accounted for 22% of the responses. The finishes/surfaces category includes carpentry, drywall, ceiling, painting, and glazing and accounted for 17% of the responses. The last category was for the general contractors who are responsible for multiple trades. This category accounted for the remaining 17% of responses.
4.1.2 Time Buffer Survey Analysis

Research Objective 1: Identify the causes of time buffer and determine which are the most prevalent and severe in terms of additional time included in construction project task durations.

Several researchers have acknowledged the existence of time buffers in task duration estimates (Howell and Ballard 1993, Goldratt 1997, Ballard 2000a, Horman et al. 2003, and Lee et al. 2006). It is clear buffers are used and deemed necessary, because workflow is subject to many influences that obstruct and delay the progress of construction projects. That being said, typically if a foreman, superintendent, or project manager is asked how much buffer is included in their estimate, they will answer “none”. Buffers are considered waste as they do not directly add value to the construction task and as a result construction planners do
not typically discuss the deliberate insertion of buffers in their schedules to manage their programs (Horman et al. 2003). This survey gave construction personnel an anonymous means to express their most frequent causes of uncertainty and whether or not they buffer to protect themselves against that uncertainty. Of the 180 surveys, only 1 survey participant answered they never considered the impact of uncertainty caused by any of the 47 causes and they would not add any time to a duration estimate to protect themselves against that uncertainty.

The second section of the survey asked the participants to rank order the uncertainty in the nine categories as it pertains to their task durations and then answer whether or not they felt the uncertainty related to each category was their responsibility to manage and mitigate. Table 4.1 below summarizes the results of section two. It is interesting to note that as the category rank goes up (i.e. less uncertainty associated with the category), the percentages of participants who feel responsible for managing the category is higher. This implies the categories such as management/supervision/information flow, labor force, equipment and tools, and materials and components have less uncertainty as a result of a responsibility to control or mitigate that uncertainty. On the other hand, the detailed design/working method, project characteristics, work/jobsite conditions, and prerequisite work had the most uncertainty associated with them, yet less than half of the participants felt the uncertainty was their responsibility to mitigate. This disconnect seems to show that if construction personnel do not feel an area is their responsibility then it is not their problem.
In order to determine the most prevalent and severe causes for time buffer to be added to construction task durations, the 47 individual causes contributing to uncertainty in task duration planning were rank ordered based on their average frequency and average severity responses. The frequency relates to the likelihood that a particular risk will occur and severity relates to the impact that risk will have on the task. The frequency responses were first assigned a quantitative value. The responses of never, rarely, occasionally, sometimes, frequently, usually, and always were assigned values of 0, 1, 2, 3, 4, 5 and 6 respectively. The top twelve (i.e. the top 25%) frequency factors and severity factors are summarized in Table 4.2 and includes the category the cause is associated with. The most frequent and severe factors coincide strongly with the overall category ranking completed in section two of the survey and previously discussed. Some of the top ranked causes are consistent with previous research. Lee et al. (2006) found that design errors (quality of documents) and changes (tendency of scope changes) are two of the main factors that cause uncertainty in

<table>
<thead>
<tr>
<th>Category</th>
<th>Overall Category Rank</th>
<th>Responsible (% &quot;Yes&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Characteristics</td>
<td>2</td>
<td>22%</td>
</tr>
<tr>
<td>Prerequisite Work</td>
<td>4</td>
<td>48%</td>
</tr>
<tr>
<td>Detailed Design/Working Method</td>
<td>1</td>
<td>46%</td>
</tr>
<tr>
<td>Labor Force</td>
<td>7</td>
<td>85%</td>
</tr>
<tr>
<td>Equipment &amp; Tools</td>
<td>9</td>
<td>94%</td>
</tr>
<tr>
<td>Materials &amp; Components</td>
<td>6</td>
<td>86%</td>
</tr>
<tr>
<td>Work/Jobsite Conditions</td>
<td>3</td>
<td>44%</td>
</tr>
<tr>
<td>Management/Supervision/Information Flow</td>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>Weather</td>
<td>8</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 4.1: Time Buffer Survey Section Two Results Summary
construction. Chan and Au (2009) found project complexity to be one of the most important factors that contractors consider when they are pricing time-related contract risks. Through the results of a case study, Wambeke et al. (2011) found material delivery (late materials) to be a severe cause of task variation. Additionally, one factor just outside the top twelve at thirteen, the request for information process, is consistent with Kimpland’s (2009) finding that “slow responses to questions” was one of the top external factors that impacted productivity and led to uncertainty. After speaking to a few of the respondents, it became apparent that “contract period” was closely tied to “liability pressure” in its interpretation as contract periods result in pressure to finish on time and can lead to over commitment. Similarly, prerequisite work was closely associated with project complexity as meaning the interdependency of the tasks.

The top three factors, project complexity, complexity of trade task, and quality of documents, are the same for both frequency and severity, but in a slightly different order. The factors of required coordination with other trades, contract period, material transfer distance, material transfer method, and work area access are highly ranked frequency factors that do not show up in the top twelve severity factors. Conversely, the factors of strict specification requirements, quality control requirements, low degree of repetition, and late materials are highly ranked severity factor that are not included in the top twelve frequency factors. This finding leads to the second research objective of determining to which risk profile the different factors belong.
Table 4.2: Overall Top Twelve Most Frequent and Severe Causes of Time Buffer

<table>
<thead>
<tr>
<th>CAUSE</th>
<th>AVERAGE FREQUENCY</th>
<th>CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Complexity</td>
<td>3.90</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Complexity of Trade Task</td>
<td>3.79</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Quality of Documents</td>
<td>3.54</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Size of Project</td>
<td>3.32</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Required Coordination w/ Trades</td>
<td>3.23</td>
<td>Management/Supervision/Info Flow</td>
</tr>
<tr>
<td>Contract Period</td>
<td>3.11</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Design Constructability</td>
<td>3.01</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Tendency of Scope Changes</td>
<td>2.93</td>
<td>Management/Supervision/Info Flow</td>
</tr>
<tr>
<td>Material Transfer Distance</td>
<td>2.90</td>
<td>Work/Jobsite Conditions</td>
</tr>
<tr>
<td>Material Transfer Method</td>
<td>2.88</td>
<td>Work/Jobsite Conditions</td>
</tr>
<tr>
<td>Work Area Access</td>
<td>2.84</td>
<td>Work/Jobsite Conditions</td>
</tr>
<tr>
<td>Weather/Climate</td>
<td>2.84</td>
<td>Weather</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CAUSE</th>
<th>AVERAGE SEVERITY</th>
<th>CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of Documents</td>
<td>2.14</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Project Complexity</td>
<td>1.93</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Complexity of Trade Task</td>
<td>1.91</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Tendency of Scope Changes</td>
<td>1.61</td>
<td>Management/Supervision/Info Flow</td>
</tr>
<tr>
<td>Weather/Climate</td>
<td>1.56</td>
<td>Weather</td>
</tr>
<tr>
<td>Design Constructability</td>
<td>1.44</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Size of Project</td>
<td>1.41</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Work Area Access</td>
<td>1.35</td>
<td>Work/Jobsite Conditions</td>
</tr>
<tr>
<td>Strict Specification Requirements</td>
<td>1.34</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Quality Control Requirements</td>
<td>1.24</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Low Degree of Repetition</td>
<td>1.24</td>
<td>Detailed Design/Working Method</td>
</tr>
<tr>
<td>Late Materials</td>
<td>1.24</td>
<td>Materials and Components</td>
</tr>
</tbody>
</table>

Research Objective 2: Quantitatively develop risk profiles of the causes of time buffer so they may be prioritized for mitigation efforts.

Risk assessment involves identifying risk in the area of concern and then classifying the risk by assigning an appropriate risk level (Wheeler 2002). Objective one of this research is synonymous to risk identification as it identifies root causes of time buffer in construction project tasks. As a complement to identifying the causes of time buffer, this second objective creates risk profiles through an integrated approach of using histogram data analysis and the use of a risk assessment matrix to analyze which factors belong to each risk profile. The 47
individual causes of time buffer were assigned to one of four risk profiles: a high frequency and high severity time buffer occurrence, a high frequency and low severity time buffer occurrence, a low frequency and high severity time buffer occurrence, or a low frequency and low severity time buffer occurrence. First, histogram data analysis was run on the frequency and severity responses for the 180 completed surveys. Histograms use tabular frequencies over discrete intervals or bins to show the proportion of cases that fall into each of several categories (Howitt and Cramer 2005). The bins for this analysis were the seven different response options for both frequency and severity. An example of the histogram output for the quality of documents factor can be seen in the table below. A total of 94 histograms were created to summarize the responses for both frequency and severity of the 47 causes.

Table 4.3: Histogram Output for Quality of Documents

<table>
<thead>
<tr>
<th>Factor Frequency</th>
<th>Count of Responses</th>
<th>Factor Severity</th>
<th>Count of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18</td>
<td>0</td>
<td>51</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>0.5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>7</td>
<td>19</td>
</tr>
</tbody>
</table>

Next, four separate “counts” were calculated for each cause’s frequency and severity. Each count was based on the sums of the upper or lower two values. The high frequency sum was based on the total count of “usually” (5) and “always” (6) responses. The high
severity sum was based on the total count of 5 day and 7 day responses. The low frequency sum was based on the total count of “never” (0) and “rarely” (1) responses. The low severity sum was based on the total count of 0 day and 0.5 day responses. The decision to only use the sum of the upper and lower two bins was made to emphasize the most important causes for each profile. The analogy of using a highlighter when reviewing an article applies. Typically one only highlights the major or most important points. If that person were to highlight over half or the entire article (i.e. sum the upper and lower three or four bins), there would be no “highlights”. The sum of the upper and lower three bins was attempted and confirmed the use of two bins was adequate. This research then integrated the use of a risk assessment matrix, commonly used in military planning, to analyze which factors belong to each risk profile. According to Wheeler (2002), risk has two components: a probability or likelihood of occurrence and a consequence of occurrence. Consequence is typically defined as impacting cost, schedule, or performance parameters. These two components are represented well by the survey questions in this research with likelihood being the frequency each factor causes uncertainty impacting task duration estimates and consequence being the severity in days of time buffer added to task durations due to those causes. The resulting risk, categorized as low, moderate, high, and extremely high in the risk matrix, can then be prioritized for mitigation or elimination (FM 100-14, 1998). The normalized “counts” of low and high frequency were plotted on the x-axis and the normalized “counts” of low and high severity were plotted on the y-axis. The risk level or expected value of risk (product of frequency and severity) was calculated for the causes in each profile to determine the top 12 important causes for each profile, focusing on those in the upper right higher risk areas of the
matrix. These groupings can be seen in the four profile graphs in Figure 4.3 and are summarized in Figure 4.4.

Figure 4.3: Frequency and Severity Risk Profiles
Although some causes tended to have moderate frequency and severity throughout the four graphs and did not end up in a specific profile, this method accounted for profiling of 77% (36/47) of the causes. Additionally, some of the most prevalent causes overall show up in more than one risk profile. The low frequency/high severity causes were the most difficult to profile as very few of the factors were obviously located in the high or extremely high portion of the risk matrix. Taleb’s Black Swan Theory provides some explanation for this result in the low frequency/high severity profile. Taleb says that planners fail to buffer or protect against the rare yet severe factors of uncertainty (those he calls the black swans) (Taleb 2007). Wambeke et al.’s (2011) case study research on causes of variation shows the existence of black swans in the construction industry as material delivery (late materials), over commitment (liability pressure), and request for information process were three causes.
of low frequency/high severity variation. Another possible explanation is that there is not a lot of frequency and severity tradeoff in the construction industry and it is more about ranking or prioritizing the uncertainty. In other words, perhaps construction personnel tend to add more time buffer to those factors they are more frequently concerned about. The graph below in Figure 4.5 of the overall average frequency and severity illustrates this apparent correlation.

![Figure 4.5: Overall Average Frequency versus Average Severity](image)

Figure 4.5: Overall Average Frequency versus Average Severity
The author examined the graph further by first partitioning the data points into four risk levels using SAS® software to conduct cluster analysis. Cluster analysis provides a method for investigators to decide where to draw lines between similar groups or “clusters”. Clustering hierarchically groups or clusters objects so that objects in the same cluster are more similar to each other than objects in the other clusters (SAS 2012). The clustering completed with this data consisted of grouping points close to each other in terms of distance and separating these from points that are more distant (Ramsey and Schafer, 2002). A dendrogram is graphical diagram with a tree-like structure used to display relationships resulting from a clustering operation and guided the selection of the variables (causes) in each of four risk levels: low, moderate, high, and extremely high. A box was put around each risk level cluster of causes to create the steps in the Figure 4.6 below.
The causes in the upper steps represent those requiring attention first as they are the causes of time buffer construction personnel are most concerned about due to uncertainty and potential for variation. As one moves down the steps, the confidence in the causes increases and there is less uncertainty and need for time buffer in the task durations. Clustering helped reveal something interesting about the step graph. There is a greater tendency to tolerate or manage the risk when the risk is lower (higher level of confidence). That is there is much less tradeoff between severity and frequency in the bottom step or lowest risk level. There is a greater tendency to trade frequency for severity and vice versa when there is a higher level of risk such as in the upper three steps. This was determined by calculating the change in...
frequency and severity between any two factors within each step or cluster, and comparing the percentage of positive values (no tradeoff between frequency and severity) to the percentage of negative values (tradeoff between frequency and severity). The percentage of negative values for each step is included in Figure 4.6. This resulting reverse in correlation present in the partitioned groups is an occurrence called Simpson’s Paradox. Simpson’s paradox says that a correlation present when a data set is analyzed becomes reversed when the set is broken into similar groups (Pearl 2009). The differences here within each level of risk raised spurred the question about differences among groups. Time buffer was hypothesized to be added for different reasons depending on who is asked and further the allocation of time buffer during task planning was hypothesized to be different depending on the level of management involved. The reason for these differences can be tied to the differences in the levels of understanding, control and responsibilities of the levels of management on a construction jobsite, and other construction environment factors.

*Research Objective 3: Determine the differences in opinion and perception between different levels of management, different trades, different levels of experience, the difference between contractors and subcontractors, and the difference between contractors using traditional management approaches and those using lean construction techniques.*

The survey results do not allow us to determine a specific frequency or buffer amount for each cause as participants were asked to consider the causes one by one and independent of each other. Construction personnel likely consider multiple factors at once when
estimating task durations. However, the survey responses do allow for a comparison of the average frequency and average severity among different groups.

The first comparison made was between the different levels of management – project managers, superintendents, and foremen. The results are displayed in Table 4.4. The survey responses were sorted by respondents’ job position and then the average frequency and severity was taken for each cause. The frequency of the causes due to uncertainty and the magnitude of buffer added to protect against that uncertainty were then rank ordered for each job position. A total of 17 causes were required to capture the top twelve most frequent causes and a total of 18 causes were required to capture the top twelve most severe causes for each level of management. The top twelve (~25%) were included to highlight the differences in perception about the causes outside of the top five. The top five most frequent and the top three most severe causes were nearly identical aside from occurring in a slightly different order. Beyond those, there were some noticeable differences in the top twelve amongst the levels of management as well as some notable differences outside of the top twelve. In regards to frequency, foremen ranked required coordination with other trades as 3rd most important; however, superintendents and project managers ranked this factor 4th and 6th respectively. This difference is possibly a result of the foremen being more involved in those coordination efforts than higher management levels. Perhaps for a similar reason, material transfer distance and method were ranked higher by the foremen than superintendents or project managers. Another big difference between foremen and the superintendents and project managers was in the causes of overcrowded jobsite and request for information process. Foremen ranked these 10th and 11th respectively while overcrowded jobsite came in
at 16th for superintendents and project managers and request for information process came in at 25th for superintendents and 22nd for project managers. The tendency of scope changes ranked 7th among foremen and superintendents, but only 15th for project managers. Conversely, work area access was more important to project managers (8th) than superintendents (12th) and foremen (14th), perhaps due to their responsibility for the entire construction site rather than smaller work areas. Liability pressure was a much greater concern for superintendents (10th) and project managers (18th) than foremen (36th).
Table 4.4: Top Twelve Most Frequent and Severe Causes of Time Buffer by Job Position

<table>
<thead>
<tr>
<th>Factor</th>
<th>PM - Avg Freq</th>
<th>Rank</th>
<th>SUPT - Avg Freq</th>
<th>Rank</th>
<th>FOREMEN - Avg Freq</th>
<th>Rank</th>
<th>Factor</th>
<th>PM - Avg Sev</th>
<th>Rank</th>
<th>SUPT - Avg Sev</th>
<th>Rank</th>
<th>FOREMEN - Avg Sev</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Complexity</td>
<td>4.09</td>
<td>1</td>
<td>3.71</td>
<td>1</td>
<td>3.69</td>
<td>2</td>
<td>Project Complexity</td>
<td>2.15</td>
<td>1</td>
<td>1.06</td>
<td>2</td>
<td>1.00</td>
<td>6</td>
</tr>
<tr>
<td>Complexity of Trade Task</td>
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<td>3.63</td>
<td>3</td>
<td>3.77</td>
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<td>Complexity of Trade Task</td>
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<td>Quality of Documents</td>
<td>3.95</td>
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<td>3.65</td>
<td>2</td>
<td>3.38</td>
<td>5</td>
<td>Quality of Documents</td>
<td>2.04</td>
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<td>1.65</td>
<td>9</td>
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<td>Size of Project</td>
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<td>Required Coordination w/ Other Trades</td>
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<td>0.97</td>
<td>16</td>
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<td>19</td>
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<td>8</td>
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<td>10</td>
<td>2.94</td>
<td>8</td>
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<td>Weather/Climate</td>
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<td>3.18</td>
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<td>Tendency of Scope Changes</td>
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<td>2.17</td>
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<td>RFI Process</td>
<td>1.19</td>
<td>15</td>
<td>0.80</td>
<td>24</td>
<td>1.76</td>
<td>4</td>
</tr>
</tbody>
</table>

The severity or magnitude of buffers due to uncertainty related to scope changes was the #1 most severe cause for foreman and ranked 6th for superintendents and 8th for project managers. Also, required coordination with other trades was again a high emphasis cause for foreman coming in at 4th, while superintendents ranked it 24th and project managers ranked it 15th. Several of these differences are evident in both tables above. Overall the results indicated a perception of larger frequency and severity of uncertainty as you move from project manager to the superintendent to the foreman. One area not highlighted by the top twelve most frequent or severe causes is the much greater emphasis put on materials,
equipment, and labor by the foremen than the superintendents or project managers. For example, foremen ranked the frequency of crew inefficiencies, labor reliability, and labor availability 14th, 15th, and 17th respectively. Superintendents ranked those same three causes 32nd, 31st, and 27th, while project managers ranked them 36th, 40th, and 23rd. Here, those actually doing the work are most concerned about the resources it will take to complete the work. Acknowledging and understanding this different in perceptions is important for construction managers as they plan and carry out their projects.

The next four comparisons are summarized in the following discussions. As discussed previously, the trades were organized into groups of similar nature or scope. The utilities trades include mechanical, electrical, plumbing, and fire protection. The structural trades include steel, concrete, roofing, earthwork, and masonry. The finishes trades include drywall, ceiling, carpentry, painting, and glazing. Hanna (2002) noted that utilities trades, specifically mechanical and electrical contractors, comprise a labor-intensive segment of the construction industry in which labor can account for 50-60% of the construction cost. Additionally, by their nature, mechanical and electrical construction project are complex and small changes can have large project impacts. Therefore, the expectation would be for the utilities trades to have greater frequency of concern for the uncertainty related to the 47 causes and greater magnitude of time buffer in their task durations. Upon examining the survey results by trade group, the utilities trades were found to have the largest frequency and severity for the time buffer causes (13% more frequency and 15% more severity than structural and 32% more frequency and 25% more severity than the finishes). The structural
trade groups were second and the finishes trade had the least frequency and severity of time buffer per the survey results.

The researchers also hypothesized that the experience level of the participants may result in different perceptions. Specifically, the least experienced (grouped by 5 years or less) participants would be concerned about more of the causes more frequently and buffer with greater magnitude. The least experienced group was compared to a group of 5-25 years of experience and a group of greater than 25 years of experience. The survey results found that although there was not a large percentage difference between the least experienced and the more experienced in regards to frequency, the least experienced group buffered with nearly 30% more magnitude (severity) than the more experienced groups.

General contractors as well as subcontractors participated in the survey. The scopes and areas of responsibility are different for these two entities in the completion of construction projects. Much like the levels of management discussed previously, the researchers expected to find a difference in how frequently and how much general contractors and subcontractors buffer due to the uncertainty due to the 47 causes of time buffer. Overall, the frequency for general contractors and subcontractors only differed by about 8% with the subcontractors buffering slightly more frequently. The general contractors buffered more frequently than the subcontractors for all causes in the project characteristics category. This finding is expected as the general contractors are responsible for the entire project scope and all of the involved subcontractors. The subcontractors on the other hand were more frequently concerned about the materials, equipment, labor, and work/jobsite condition related causes than the general contractors. When looking at the amount (severity)
subcontractors buffer compared to general contractors, the results are staggering. Subcontractors perceive the need to buffer against the uncertainty due to time buffer causes with 30% greater magnitude than the general contractors. These results emphasize the subcontractors perceived need to protect themselves against task variation and perhaps from the general contractor.

Howell and Ballard (1996) assert that "improved planning stabilizes the work environment and reduces the need for large buffers.” They promote LPS® as a planning tool that directly attacks the sources of uncertainty and improves performance through improving the reliability of the plan. As a result, a more reliable plan will reduce the amount of variation and the need for large time buffers. The participants of the survey were sorted based on their responses in an effort to make a comparison of construction personnel who use lean construction techniques such as LPS® to those who use traditional construction management techniques. The survey results showed that those using LPS® on their construction projects had a lower frequency of buffer for 72% of the causes and a smaller amount of buffer for 85% of the causes. This result is interesting and merits further investigation into the effects and benefits of using LPS® to achieve reliable planning and reduce buffer amounts in task duration estimates. The results of the survey corroborate at a minimum that the perception of those using LPS® is one of a reduced need for the frequency and magnitude of time buffers and leads to the necessity for further empirical investigation into the amount and allocation of time buffer in projects using LPS®.
Research Objective 4: Compare and contrast the overall most severe causes of time buffer with the most severe causes of duration variation to identify disconnects between the perception of concerns about uncertainty and the reality of what causes task duration variation.

Understanding which causes of uncertainty personnel plan for and do in fact cause variation and understanding those we unnecessarily plan for can be of significant benefit to project managers. Similarly, understanding which cause of buffer construction personnel fail to plan for, perhaps because they do not realize they pose problems, is equally beneficial. As part of his dissertation, Wambeke (2011) researched and identified 50 causes of duration through the use of a questionnaire survey similar to the time buffer survey. The findings of his research serve as the basis for comparison between the perceived need for time buffer and the reality of what causes duration variation in construction project tasks. The author acknowledges a limitation of this research is that the survey groups are not identical. That being said, both surveys were intentionally anonymous and contacting the exact same individuals for the time buffer survey as in the variation survey was not possible. Furthermore, the demographics of the useable survey responses are similar in each survey and representative of the construction industry as a whole.

In order to determine the overall most severe causes for time buffer to be added to construction task durations, the 47 causes contributing to uncertainty in task duration planning were rank ordered based on the average of their severity responses. The same procedure had been carried out on the 50 causes of duration variation to determine the overall
most severe causes of duration variation in construction project tasks (Wambeke 2011). The top twelve (~25%) most severe causes of time buffer and duration variation are summarized in Table 4.5. Results for the 47 buffer causes have units of days/10 day task and the 50 variation causes have units of hrs/week. Before comparisons are made, a few semantics must be discussed as a few of the causes are conceptually the same but have different names. As stated by Wambeke (2011), the question pertaining to turnaround time was included in two areas of the variation survey with one listed as “turnaround time from engineers when there is a question with a drawing” and the other listed as “waiting for answers about the design or drawing”. Those causes were combined and described as the “request for information process (RFI process)” in the time buffer survey. Additionally, based on survey feedback, the buffer cause “project complexity” was strongly related to the interdependency of the tasks and the variation cause “completion of previous work”.

Table 4.5: Overall Top Twelve Most Severe Causes of Time Buffer and Duration Variation

<table>
<thead>
<tr>
<th>Cause of Time Buffer</th>
<th>Avg Severity (days/10 day task)</th>
<th>Cause of Duration Variation</th>
<th>Avg Severity (hrs/wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of Documents</td>
<td>2.14</td>
<td>Turnaround time from engineers on dwg question</td>
<td>2.1</td>
</tr>
<tr>
<td>Project Complexity</td>
<td>1.93</td>
<td>Completion of previous work</td>
<td>1.83</td>
</tr>
<tr>
<td>Complexity of Trade Task</td>
<td>1.91</td>
<td>Rework required</td>
<td>1.81</td>
</tr>
<tr>
<td>Scope Changes</td>
<td>1.61</td>
<td>Waiting for answers about dsn or dwg</td>
<td>1.71</td>
</tr>
<tr>
<td>Weather/Climate</td>
<td>1.56</td>
<td>Quality of documents</td>
<td>1.61</td>
</tr>
<tr>
<td>Design Constructability</td>
<td>1.44</td>
<td>Getting moved to another job/task</td>
<td>1.51</td>
</tr>
<tr>
<td>Size of Project</td>
<td>1.41</td>
<td>Work sequence or method not well planned</td>
<td>1.41</td>
</tr>
<tr>
<td>Work Area Access</td>
<td>1.35</td>
<td>Inadequate instruction</td>
<td>1.41</td>
</tr>
<tr>
<td>Strict Specification Reqrnts</td>
<td>1.34</td>
<td>Weather impacts</td>
<td>1.39</td>
</tr>
<tr>
<td>Quality Control Reqrnts</td>
<td>1.24</td>
<td>Worker/crew lack of skills/experience</td>
<td>1.37</td>
</tr>
<tr>
<td>Low Degree of Repitition</td>
<td>1.24</td>
<td>Poor quality of previous work</td>
<td>1.25</td>
</tr>
<tr>
<td>Late Materials</td>
<td>1.24</td>
<td>Design constructability</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Consistent with previous research by Dai et al. (2009) and Lee et al. (2006), design errors (quality of documents) ranked highly (#1 cause of buffer, #5 cause of variation) as causes significantly contributing to uncertainty and variation in construction tasks. Additionally, other causes found among the most severe in both surveys include design constructability (#6 cause of buffer, #12 cause of variation), weather (#5 cause of buffer, #9 cause of variation), and the request for information process (#13 cause of buffer, #1 & #4 cause of variation). Kimpland (2009) found “slow responses to questions” to be one of the top factors impacting productivity and leading to uncertainty and variation. According to Thomas et al. (2005), undesirable delivery of materials (not at the right time or right place) is one of the most common problems in construction projects. This problem of material delivery is perceived as the #12 top cause of buffer and was the #17 cause of variation, and additional research completed by Wambreke (2011) through a case study found material
delivery to be one of the top three causes of variation. The survey results and case study both point to material delivery as a key concern and problem in construction projects. The case studies completed by the author also reinforce the concerns about materials.

There are several causes highlighted by the results of the buffer survey that are not seen in the variation survey results and vice versa. Scope changes (#4 cause of buffer) is a cause of great concern in allocating buffer to task durations but is not a top twelve cause of duration variation (#36 cause of variation). Further, additional top causes of buffer not included in the top causes of variation are work area access, strict specification requirements, quality control requirements, and low degree of repetition in the tasks. Conversely, rework being required (#3 cause of variation) is not a cause which personnel plan for with great emphasis and perhaps because they feel confident in their workmanship. Other top causes of duration variation which are not a top cause of uncertainty in task duration planning include getting moved to another job/task, inadequate instruction, worker/crew lack of skills/experience, and poor quality of previous work. These causes of variation seem to be more subjective and somewhat unpredictable causes related to human factors that are not being considered thoroughly during task planning.

The time buffer survey and variation survey both asked the participants to rank order their perception of the importance of the categories of causes. Table 4.6 below summarizes the results of the categorical ranking for each survey. Differences exist here too between the perceived need for time buffer and causes of variation. The most severe causes of time buffer coincide strongly with the overall category ranking. The top categorical cause of time buffer accounted for five of the top twelve individual causes of buffer. Additionally, the top
three perceived categorical causes accounted for nine of the top twelve causes of buffer. The most severe causes of variation do not match up as well with their perceived categorical importance. In fact, detailed design and working method, the #7 of eight ranked variation categories, ended up accounting for five of the top twelve causes of variation. The participants taking the variation survey perceived that most of their variation would come from the categories of labor, management/ supervision/ information flow, materials & components, work / jobsite conditions, and equipment & tools; however, only three of the top twelve causes of variation were accounted for by these categories. Another example of disconnect in perception is the #1 perceived categorical cause of variation was labor force, but that same category was ranked 7th as being a categorical cause of buffer. Interestingly, the top categorical causes of buffer (which categories cause the most uncertainty and concern about potential variation) correctly accounted for eight of the top twelve causes of variation.

Table 4.6: Categorical Ranking Comparison

<table>
<thead>
<tr>
<th>Category</th>
<th>Time Buffer Category Rank</th>
<th>Variation Category Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Characteristics</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Prerequisite Work</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Detailed Design/Working Method</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Labor Force</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Equipment &amp; Tools</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Materials &amp; Components</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Work/Jobsite Conditions</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Management/Supervision/Info Flow</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Weather</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>
As discussed in the third objective analysis, the survey results do not allow us to determine a specific buffer or variation amount for each cause as participants were asked to consider the factors one by one and independent of each other. Construction personnel likely consider multiple causes at once when estimating task durations or considering the effect of various causes of variation. However, the survey responses do allow for a comparison of the average severity among different groups. The comparison made here between the buffer survey and variation survey is at two different levels of management – project managers and foremen. The survey responses were sorted by respondents’ job position and then the average severity was taken for each factor. A total of fifteen causes of buffer and variation were included in Table 4.7 to account for the top twelve causes at each level of management.

Table 4.7: Comparison of Causes between Project Managers and Foremen

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Complexity</td>
<td>2.19</td>
<td>1</td>
<td>1.60</td>
<td>6</td>
<td>Turnaround time from engineers on dwg question</td>
<td>1.93</td>
<td>1</td>
<td>1.24</td>
<td>3</td>
</tr>
<tr>
<td>Quality of Documents</td>
<td>2.12</td>
<td>2</td>
<td>2.08</td>
<td>2</td>
<td>Waiting for answers about design or drawing</td>
<td>1.96</td>
<td>2</td>
<td>1.68</td>
<td>1</td>
</tr>
<tr>
<td>Complexity of Trade Task</td>
<td>2.04</td>
<td>3</td>
<td>1.91</td>
<td>3</td>
<td>Prerequisite Work</td>
<td>1.81</td>
<td>3</td>
<td>1.29</td>
<td>2</td>
</tr>
<tr>
<td>Weather/Climate</td>
<td>1.62</td>
<td>4</td>
<td>1.44</td>
<td>11</td>
<td>Worker/crew lack of skills/experience</td>
<td>1.58</td>
<td>4</td>
<td>0.76</td>
<td>17</td>
</tr>
<tr>
<td>Size of Project</td>
<td>1.56</td>
<td>5</td>
<td>1.73</td>
<td>5</td>
<td>Rework Required</td>
<td>1.49</td>
<td>5</td>
<td>1.24</td>
<td>4</td>
</tr>
<tr>
<td>Strict Specification Reqrmnts</td>
<td>1.55</td>
<td>6</td>
<td>1.28</td>
<td>19</td>
<td>Socializing</td>
<td>1.42</td>
<td>6</td>
<td>1.15</td>
<td>8</td>
</tr>
<tr>
<td>Low Degree of Repitition</td>
<td>1.40</td>
<td>7</td>
<td>1.08</td>
<td>27</td>
<td>Inadequate instruction</td>
<td>1.36</td>
<td>7</td>
<td>0.65</td>
<td>23</td>
</tr>
<tr>
<td>Tendency of Scope Changes</td>
<td>1.39</td>
<td>8</td>
<td>2.32</td>
<td>1</td>
<td>Design constructability</td>
<td>1.09</td>
<td>8</td>
<td>0.53</td>
<td>28</td>
</tr>
<tr>
<td>Work Area Access</td>
<td>1.37</td>
<td>9</td>
<td>1.45</td>
<td>9</td>
<td>Getting moved to another job/task</td>
<td>1.31</td>
<td>9</td>
<td>1.18</td>
<td>7</td>
</tr>
<tr>
<td>Design Constructability</td>
<td>1.34</td>
<td>10</td>
<td>1.42</td>
<td>12</td>
<td>Quality of documents</td>
<td>1.31</td>
<td>10</td>
<td>1.18</td>
<td>5</td>
</tr>
<tr>
<td>Quality Control Reqrmnts</td>
<td>1.34</td>
<td>11</td>
<td>1.49</td>
<td>8</td>
<td>Absenteeism</td>
<td>1.30</td>
<td>11</td>
<td>0.97</td>
<td>10</td>
</tr>
<tr>
<td>Prerequisite Work</td>
<td>1.30</td>
<td>12</td>
<td>1.15</td>
<td>24</td>
<td>Weather impacts</td>
<td>1.23</td>
<td>12</td>
<td>1.18</td>
<td>6</td>
</tr>
<tr>
<td>RFI Process</td>
<td>1.04</td>
<td>22</td>
<td>1.49</td>
<td>7</td>
<td>Material to arrive from distributor or supplier</td>
<td>1.09</td>
<td>15</td>
<td>0.88</td>
<td>12</td>
</tr>
<tr>
<td>Required Coordination w/ Other Trades</td>
<td>1.19</td>
<td>15</td>
<td>1.76</td>
<td>4</td>
<td>Error in material type</td>
<td>0.98</td>
<td>18</td>
<td>1.00</td>
<td>9</td>
</tr>
<tr>
<td>Concerns about being pushed into using more manpower</td>
<td>1.19</td>
<td>16</td>
<td>1.44</td>
<td>10</td>
<td>Site Layout - material transfer distance</td>
<td>0.81</td>
<td>24</td>
<td>0.94</td>
<td>11</td>
</tr>
</tbody>
</table>
There are several disconnects between the causes of variation and the perceived need for time buffer to absorb that variation in construction projects. For example, project managers cited causes of variation related to the RFI process as the #1 and #2 cause of variation, but concerns about the RFI process was only the #22 cause of time buffer for project managers. This example raises the question of whether or not personnel are concerned about and address all the right things when planning task durations. In other words, the study results indicate there is a need for management to address the RFI concerns more actively and aggressively prior to the start of construction to avoid the variation that RFI delays cause. Other examples at the project manager level include labor force as a major cause of variation (#4, #6, #7, #9, and #11 are all labor force related), yet labor force concerns are not a top twelve cause of time buffer. Conversely, the survey responses show that during the planning process project managers are overly concerned about the effects of strict specification requirements, the tendency of scope changes, and the trades’ task complexity. There are also areas at the project manager level where the perception does match the reality. These include prerequisite work/project complexity, quality of the design and specification documents, weather impacts, and design constructability.

At the foreman level there are similar disconnects. The #1 planning concern for foremen was the concern about dealing with scope changes; however, the variation results show that scope changes were only the #36 most severe cause of task duration variation. Similarly, foremen expressed significant concern about the required coordination with other trades during a construction project (#4 cause of time buffer for foremen), but that coordination was the 25th most severe cause of variation. These are both potential examples
of misdirected concern. Also, the variation data revealed material related causes of variation (#9 – Error in material type; #11 – Material transfer distance; #12 – Late materials) to be the in top causes group, while foremen did not see any of these material related concerns as a top cause of buffer. Less clear were the areas where foremen’s perception did meet reality. The researchers did notice that many of the top causes of buffer and variation at the foremen level were task specific, meaning those actually performing the work are most concerned about what resources it will require to get the task completed.

*Research Objective 5: Identify the underlying factors that correlate the individual causes of time buffer.*

As previously discussed, task durations are not independent random variables. For example, if problems are encountered in the delivery of concrete for a project, this problem may likely influence the expected duration of numerous activities involving concrete pours on a project. Likewise, this author hypothesized the many individual causes of buffer considered during this research are not independent and multicollinearity exists in the buffer variables (ie., some of those individual causes of buffer are correlated to others). In other words, the author sought to identify which causes are grouped together by construction personnel when planning for uncertainty in construction project task durations.

Factor analysis was used to account for this suspected multicollinearity by grouping the 47 individual causes of buffer into orthogonal factors which represent the underlying structure of the causes of time buffer. This technique is appropriate when measures on a
number of variables have been obtained as through the time buffer survey, and the researcher wants to identify the number and nature of the underlying factors responsible for covariation in the data (Hatcher 1994). Factor analysis is conducted in a sequence of steps, with many of these steps requiring somewhat subjective decisions to be made. The process is lengthy, but a basic flow chart of the factor analysis procedure is depicted in Figure 4.7. Additionally, a more detailed explanation of the technique can be found in Loehlin (1987) and Pett et al. (2003).

First, The Kaiser-Meyer-Olkin (KMO) measure of sampling was used to assess the adequacy of the data sample’s correlation matrix for factor analysis. Kaiser (1974) recommends a KMO value greater than 0.50. The KMO for the buffer data sample was 0.87, suggesting it was acceptable for the factor analysis process. SAS was then used to perform the factor analysis in this research. The data elements are first resolved into their principal components by transforming the data into orthogonal variables using the eigenvectors of the matrices of the original variables. This is an initial extraction of the factors with each extracted factor 1) accounting for a maximum amount of the variance that has not already
been accounted for by other, previously extracted, factors and 2) each factor being uncorrelated with all of the previously extracted factors (Hatcher 1994). Once these principal components are determined and the ”meaningful” factors have been retained, a factor rotation is performed. The maximum variance method (varimax) was used in this research to maximize the loading onto each factor, resulting in more interpretable groupings of factors. Factor loading is the correlation between the factor and the observed variable. The rotated factor loading matrix was created for the causes of time buffer and can be seen in Table 4.8.
Factor analysis resulted in the identification of eleven factors that accounted for 69% of the overall variance of the time buffer data. A threshold of 0.40 was used and was sufficient for the factor loading. Loadings equal to or greater than 0.40 are considered meaningful loadings (Stevens 1986). The eleven factors are described below.
Factor 1: Communication & Labor Force Capabilities. The individual causes loaded on this factor pertained to either the labor force (reliability, availability, skill, morale) or communication between construction personnel.

Factor 2: Jobsite Management. Logistics of the jobsite is essential and the concerns here relate to getting the material to the right place on the jobsite, ensuring construction resources have work area access, and avoiding congestion and overcrowding.

Factor 3: Equipment Management. This factor and the causes loaded on it are directly related to equipment and tools.

Factor 4: Project Characteristics & Prerequisite Work. Most of the causes from the project characteristics category loaded on this factor as well as those related to the interdependency of construction tasks (project complexity and prerequisite work).

Factor 5: Trust and Recognition. Causes related to trust between levels of management and company recognition are included here.

Factor 6: Material Management & Weather. Not receiving materials from suppliers when expected or receiving the wrong or damaged materials can immediately impact the duration of a task. Weather also loaded strongly on this factor.

Factor 7: Design Quality. Design errors and omissions, poor quality of the design documents and the resulting RFIs and changes in scope are all related to design quality.

Factor 8: Constructability. This factor contained the causes unfamiliar scope, low repetition, rework required, and delays due to inspections.
Factor 9: Standards & Quality Control. When there are strict specifications and/or quality control is tight then coordination within and between trades becomes increasingly important.

Factor 10: Management Liability Pressure. There always exists pressure to get things done more quickly and with fewer resources.

Factor 11: Labor Force Allocation. Concerns about being pushed into using more manpower to complete a task in the planned duration are the single cause loaded on this factor.

In addition to the 47 causes of time buffer loading onto these 11 factors, a few other interesting results can be seen in the rotated factor loading matrix. The variable “Owner/Engineer and Project Manager Communication” loaded significantly (0.62) on Factor 1, Communication and Labor Force Capabilities, and also (0.42) on Factor 7, Design Quality. This relationship may highlight the importance of clear and effective communication between the owner and/or engineer and the project manager(s) in regards to issues related to design quality such as errors, omissions, and unclear design documents. Another noteworthy relationship highlighted by the factor analysis results involves the variable “coordination between trades” and its’ strong loading on the factors “communication and labor force capabilities”, “design quality”, “standards and quality control”, and even somewhat significant loading on “trust and recognition”. This occurrence is especially interesting to the authors as they have found those issues to be at the very heart of the complex construction process from discussions with construction personnel in multiple case studies. Personnel continuously point to the direct impact on buffer and variation caused by
the interdependency of tasks and how communication or a lack thereof between the trades in
combination with the quality of the design documents affects whether or not the task is
completed as required.

Table 4.9: Rotated Factor Loading Matrix for Time Buffer Frequency

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
<th>Factor 6</th>
<th>Factor 7</th>
<th>Factor 8</th>
<th>Factor 9</th>
<th>Factor 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication &amp; Trust</td>
<td>0.8</td>
<td>0.11</td>
<td>0.10</td>
<td>0.07</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>Equipment Management</td>
<td>0.09</td>
<td>0.01</td>
<td>0.05</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Labor Force</td>
<td>0.03</td>
<td>0.02</td>
<td>0.09</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>Supplier Characteristics</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Material Management</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Design Quality &amp; Constructability</td>
<td>0.11</td>
<td>0.10</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Management Liability Pressures</td>
<td>0.12</td>
<td>0.10</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>Weather</td>
<td>0.13</td>
<td>0.12</td>
<td>0.08</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The factor analysis was also completed on the time buffer frequency data and there
were 10 factors that accounted for 66% of the overall variance of the data (Table 4.9). The
same 0.40 threshold was used for this analysis. The overall factors were very similar to the
ones identified by the factor analysis of the time buffer severity data. In fact, communication, equipment management, and labor force are top three factors in both analyses.

Research Objective 6: Develop the mental model and associated causal structure used by project managers and field level managers (superintendents and foremen) when buffering and planning for uncertainty.

Construction personnel at every level of management are constantly planning and trying to figure out how to best deal with the uncertainty and variability of construction projects. Construction project managers, superintendents and foremen are faced with the daunting challenge of not only managing trades working on a large number of interdependent tasks but also task duration planning to meet project schedule deadlines set forth by the construction contract. The allocation of time buffer in task planning is one method used to absorb variation caused by the inherent complexity and uncertainty present in construction. Plausibly and arguably, there exists an underlying thought process or mental model that each level of management uses when allocating time buffer and planning for uncertainty. That is to say construction personnel do not consider all the causes at the same time or with the same priority and some hierarchy exists. Further, the organization, priorities, and perhaps nature of the key elements in these models likely differ between the levels of management. Through the use of Structural Equation Modeling (SEM), this portion of the research explored the mental models or hierarchical structures used by field management personnel
(foremen & superintendents) and upper management personnel (project managers) when planning construction tasks. The analysis results discussed serve to fill a gap in the body of knowledge pertaining to the allocation logic used in planning for uncertainty and allocating time buffer to construction project tasks. Additionally, the execution of a model survey serves to strengthen the findings of the data analysis and improve the overall models from a practical standpoint based on real world feedback.

SEM was used to develop models for four different data sets in this research. Models were developed for field management based on both the frequency and severity response data and models were developed for upper management based on both the frequency and severity response data. The SEM method involves two main model components: a measurement component and a structural component (Molenaar et al. 2009). The measurement component specifies how latent variables are measured in terms of observed variables and the structural component expresses relationships among the latent variables (Islam and Faniran 2005).

The measurement component involves using confirmatory factor analysis (CFA) to develop an acceptable measurement model. When a measurement model is tested, the analyst looks for evidence that the indicator variables truly are measuring the underlying constructs (factors) of interest, and that the measurement model demonstrates an acceptable fit to the data (Hatcher 1994). No causal relationships between the latent constructs of interest (factors) are specified by the measurement model. Estimates of errors of measurement of exogenous variables and their intended latent variables are incorporated by the measurement models within a SEM.
Once an acceptable measurement model has been established for the data of interest, these measurement models are modified so that they predict specific causal relationships between the latent variables (Hatcher 1994). These models are the structural component of SEM and enable analysts to “make substantive statements about the relationships between latent variables, and the mechanisms underlying a process or phenomenon” (Molenaar et al. 2009). When these models are tested, the researcher is performing path analysis with latent variables which allows for the testing of hypothesis that certain latent constructs (factors) have causal effects on other latent constructs. This Anderson-Gerbing (1988) two-step approach to causal modeling (CFA followed by path analysis) is used in this research.

The measurement component’s assessment of fit is accomplished using the CFA results from the SAS PROC CALIS analysis. The specific fit indicators used to test the measurement models in this research include the chi-square ratio test, non-normed fit index (NNFI), comparative fit index (CFI), factor loadings significance, and review of the residuals. The informal criterion for $\chi^2$/df (where df is degrees of freedom) is usually less than 2.0 but results less than 5.0 may be acceptable as well (Marsh et al. 1988). The NNFI and CFI are generally preferred to the normed fit index (NFI) as they are less likely to produce biased estimates in small samples (Marsh et al. 1988, Bentler 1989). Typically values over 0.90 on the NNFI and CFI indicate an acceptable fit (Bentler and Bonett 1980, Bentler 1989). When reviewing the factor loading significance, there should be no near zero standard errors, all $t$ values should be greater than 1.960 (significant at $p<0.05$), and the standardized loadings should at least be moderately large (Hatcher 1994). The distribution of the residuals should be centered on zero, relatively symmetrical and contain no or relatively
few large residuals. The model composite reliability and variance extracted also need to be
cHECKed to determine the consistency of the measurement model before final acceptance.
Analogous with coefficient alpha, composite reliability reflects the internal consistency of the
INDicators measuring a given factor and a value of 0.60 or greater is preferable (Fornell and
Larcker 1981). Fornell and Larcker (1981) also discuss a variance extracted index which
Assesses the amount of variance captured by an underlying factor in relation to the amount of
VARiance due to measurement error. Values of 0.50 or larger are desired for the latent
Constructs (factors).

Similarly, the structural component of SEM also undergoes an assessment of fit.
This assessment is accomplished with path analysis completed in SAS using the PROC
CALIS analysis. This path analysis determines whether the combined model (measurement
and structural components), as a whole, provides an acceptable fit to the data (Hatcher 1994).
With the exception of the composite reliability and variance extracted, the same fit indicators
are used in this assessment with the addition of a few useful indices. One additional index is
the parsimonious normed fit index (PNFI). The PNFI simultaneously reflects both the fit and
the parsimony or simplicity of the model. Although there is no firm criterion, 0.50 or 0.60
have been suggested as acceptable levels (Netemeyer et al. 1990; Williams & Hazur 1986;
Mulaik et al. 1989). Another index, the relative normed-fit index (RNFI) reflects the fit in
just the structural portion of the model, and is not influenced by the fit of the measurement
model (Mulaik et al. 1989). This index is important as the other indices only test the fit of
the combined model and may be more influenced by the measurement component. The
Higher values (nearer 1) indicate the hypothesized causal relations between the latent

99
constructs (factors) provide a good fit to the data (Hatcher 1994). A final test is the chi-square difference test comparing the combined or theoretical model to the measurement model. According to Anderson and Gerbing (1988), if the theoretical model is successful in accounting for the observed relations between variables, there will not be a significant difference between the chi-square for the theoretical model and the chi-square for the measurement model. The chi-square distribution critical values table is used to determine whether or not a significant difference exists.

To begin the SEM analysis a rough estimate of the latent factors was developed from a preliminary review of the survey results, discussion with construction personnel and research group members, the literature review, and a factor analysis of the data. Factor analysis was used here in combination with the other initial analysis to analyze the observed variables and help identify a reduced set of underlying factors that summarizes and describes the interrelationships among the variables (Gorsuch 1983).

A base model was developed for each of the four data sets (field management frequency, field management severity, upper management frequency, and upper management severity) by integrating the hypothesized latent constructs with their corresponding measurement variables into an initial theoretical model. Model improvements were performed using a combination of modification indices and sound theoretical backing until the most acceptable and satisfactory measurement model was identified for each of the four data sets (see Table 4.10). Specifically in CFA, factor loading is equivalent to a path coefficient from a latent factor to an indicator variable and therefore, a nonsignificant factor loading means the indicator variable is not doing a good job of measuring the underlying
factor and should possibly be reassigned or dropped (Hatcher 1994). Additionally, variables which load heavily on more than one latent construct are multidimensional and may be considered for exclusion.

The final measurement models’ assessments of fit indices are summarized in Table 4.10. The chi-square ratio is below or nearly below 2.0 for each measurement model. Although none of the measurement models achieve a CFI or NNFI above 0.90, they are relatively high and range from 0.70 to 0.87. All coefficients for the measurement component of the SEM models are nonzero with a 95% confidence level and moderately large standardized loadings. That is to say, the coefficients provide meaningful implications that significant influences exist from observed variables to latent variables (Yang and Ou 2008). Additionally, the composite reliability and variance extracted of each measurement model are above the recommended minimums of 0.60 and 0.50 respectively with the exception of one factor extracted variance in the upper management frequency dataset that was 0.44. Taken as a group, however, the latent constructs (factors) performed well. Overall, each measurement model displayed a generally acceptable fit to the data.
A description of the factors in each of the accepted measurement models is included below. These explanations are based on the observed variables that describe each factor in the four separate data sets:

Factors based on Upper Management Frequency Data:

1. **Supt/Foremen Communication Skills & Trust:** Communication skills of the Superintendent(s) and Foremen on the job and trust in them and their abilities.

2. **Labor & Equipment:** Crew inefficiencies/skill limitations, and availability and reliability of the labor force and construction equipment on site.

3. **Jobsite Organization:** Construction site layout, material yard organization as well as transfer method and distance from receiving or material yard to task location, work area access and overcrowdedness of jobsite.

4. **Project Scope:** Complexity of the project and tasks, project size, delivery method, contract period, and contractor size.
5. **Material Concerns:** Concerns about late material deliveries or material deliveries with incorrect material quantities or damaged materials.

6. **Design Quality:** Quality of the construction drawings & specifications (including design errors/omissions), inspection delays, and the request for information process.

   Factors based on Upper Management Severity Data:

1. **Supt/Foremen Communication Skills & Trust:** Communication skills of the Superintendent(s) and Foremen on the job and trust you have in them and their abilities.

2. **Labor Force & Equipment:** Crew inefficiencies/skill limitations, and availability and reliability of the labor force and construction equipment on site.

3. **Jobsite Organization:** Construction site layout, material yard organization as well as transfer method and distance from receiving or material yard to task location, inspection delays, and work area access and overcrowdedness of jobsite.

4. **Project Complexity:** The complexity of the project and inherent interdependency of trade tasks, the project size, and prerequisite work completion concerns.

5. **Material Concerns:** Concerns about late material deliveries or material deliveries with incorrect material quantities or damaged materials.

6. **Design Quality & Constructability:** Quality of the construction drawings & specifications (including design errors/omissions), constructability, and concerns about low repetition in the work tasks.
Factors based on Field Management Frequency Data:

1. **Coordination & Communication:** Level of trust you have in Superintendent and the quality & amount of communication & coordination with the Superintendent(s) & Project Manager(s) as well as within your trade and between trades for the construction project tasks.

2. **Labor Concerns:** Crew inefficiencies and skill limitations, and availability and reliability of the labor force for your trade as well as any language or morale concerns.

3. **Prerequisite Work:** Concerns about work before you not being completed as scheduled as well as rework required or delays in inspections.

4. **Jobsite Conditions:** Material transfer method and distance from receiving or material yard to task location, as well as level of overcrowdedness of the work area.

5. **Project Scope:** The scope/complexity of the project and inherent interdependency of trade tasks, as well as the project size and contract period.

6. **Material Concerns:** Concerns about late material deliveries or material deliveries with incorrect material quantities or damaged materials.

7. **Design Documents & Constructability:** Quality of the construction drawings & specifications (including design errors & omissions), constructability, and concerns about low repetition in the work tasks.

Factors based on Field Management Severity Data:

1. **Communication & Labor:** Quality/amount of communication & coordination w/ the superintendent(s) and project manager(s) as well as within your trade and between trades for the construction tasks. Also, Crew inefficiencies/skill limitations, and availability and reliability of the labor force for your trade and any language or morale concerns.
2. **Prerequisite Work & Design Quality:** Concerns about work before you not being completed as scheduled as well as rework being required due to quality of prerequisite work. Also, quality of the construction drawings & specifications (including design errors/omissions) and constructability.

3. **Jobsite Conditions:** Material transfer method and distance from receiving or material yard to task location, weather related issues, trade access to the task location and level of overcrowdedness of the work area.

4. **Project Scope:** The scope/complexity of the project and inherent interdependency of trade tasks, as well as the specifications and quality control requirements.

5. **Material & Trust:** Concerns about late material deliveries or material deliveries with incorrect material quantities or damaged materials. Also, level of trust you have in the project team.

6. **Management Liability Pressure:** Level of trust you have in the superintendent(s) as well as liability pressure such as schedule pressure, liquidated damages, contractual deadlines, etc.

7. **Task Concerns:** Planning for uncertainty in the construction tasks themselves. Low repetition in the work tasks for your trade as well as task scope concerns and inspection delays.

Understanding how each of these latent factors has been defined is important as construction managers focus in on certain factors and their placement in the overall SEM. In other words, knowing which individual causes of time buffer and uncertainty contribute to
the overall factors is crucial to addressing the problem areas when discussing the models in practice. Each of the four measurement models was further modified to derive the “best” fitting structural models for the given datasets.

Several iterations of competing models as well as individual model improvements were executed until three relatively acceptable models were identified for each data set. In each data set there was one model which provided a best fit to the data, but three were retained for feedback and external validation through a model survey completed by construction personnel and discussed in the next section of this paper. The path analysis approach used was to evaluate the models in terms of overall fit, interpretability, and then pursue external validation to determine which model or even parts of the model obtained the most support. The latent constructs (factors) identified in the measurement model component remained the same for each dataset, but their interrelationships and hierarchy differed somewhat within each dataset. These different causal structures were repeatedly adjusted and tested, and then their indices compared to determine the model with the best fit. The assessment results of the best model for each dataset are summarized in Table 4.1. Comparing alternative a priori models is an acceptable analysis method per Hatcher (1994). The letter identification of the model (i.e – Field Management C) corresponds to the model diagrams in Table 4.12 (Upper Management Structural Equation Models) and Table 4.13 (Field Management Structural Equation Models).
Table 4.11: Fit Assessment of Proposed Best Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Data Set</th>
<th>$\chi^2$/d.f</th>
<th>NNFI</th>
<th>CFI</th>
<th>PNFI</th>
<th>RNFI</th>
<th>$\chi^2$ difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Management C</td>
<td>Frequency</td>
<td>1.62</td>
<td>0.854</td>
<td>0.869</td>
<td>0.650</td>
<td>1.025</td>
<td>7.80 - Pass</td>
</tr>
<tr>
<td>Field Management F</td>
<td>Severity</td>
<td>2.10</td>
<td>0.710</td>
<td>0.739</td>
<td>0.543</td>
<td>0.981</td>
<td>11.39 - Pass</td>
</tr>
<tr>
<td>Upper Management C</td>
<td>Frequency</td>
<td>1.58</td>
<td>0.824</td>
<td>0.841</td>
<td>0.604</td>
<td>1.034</td>
<td>2.45 - Pass</td>
</tr>
<tr>
<td>Upper Management F</td>
<td>Severity</td>
<td>1.90</td>
<td>0.762</td>
<td>0.784</td>
<td>0.581</td>
<td>0.991</td>
<td>5.39 - Pass</td>
</tr>
</tbody>
</table>

Even though none of the models exhibit a NNFI or CFI above the ideal 0.90 level, a model’s fit does not have to meet all the criteria perfectly in order to be deemed acceptable (Hatcher 1994). In fact, it is quite common with real-world data as used in this research for a strong theoretical model to not meet all the index minimums. Leung et al. (2009) developed an integrated model for the stressors and stresses of construction project managers in Hong Kong with a final model CFI of 0.83. Also, Eybpoosh et al. (2011) used SEM to identify risk paths in international construction projects with a finalized model CFI of 0.744 and NNFI of 0.732. Overall, the models in this research do fit the data well with NNFI values ranging from 0.71 to 0.85 and CFI values ranging from 0.74 to 0.87. The PNFI, which simultaneously reflects both the fit and the parsimony of the model, was above the minimum recommended levels for all four models. Additionally, the RNFI, reflecting the fit in just the structural portion, was very strong in all four models. The frequency data based models performed better than the severity based models, but perhaps the most important test, the chi-square difference test, is passed by each dataset’s best model. The chi-square difference for each model is below the critical values of chi-square obtained from the chi-square distribution table and thus pass this test.
Each model in Table 4.12 (Upper Management Structural Equation Models) and Table 4.13 (Field Management Structural Equation Models) also includes the path coefficients for the causal paths that constitute the structural portion of the model. The coefficients on the straight, single-headed arrows predict unidirectional causal effects between factors. The coefficients on the curved, double headed arrows predict simple correlations between factors.

The structural equation models differ not only between the field management level and upper management level, but also they differ somewhat between the frequency data and the severity data. Upper management such as project managers view the causes of time buffer and the latent factors differently than field management such as superintendents and foremen. As mentioned previously, these differences may be tied to the differences in the levels of understanding and control of the level of management on a construction jobsite. Further, the area or scope or responsibility differs between a project manager and field manager. As a result the type of factors and how they are prioritized when task planning and allocating time buffer differs between these two levels of management. The differences in the frequency and severity based models are perhaps less apparent but result from how personnel think about the frequency of a cause as opposed to the severity of the same cause. The biggest difference between the frequency and severity models is in how the individual causes of time buffer loaded on the different latent factors for the measurement model leading to different naming of the latent factors.

When considering the best fitting upper management models C and F in Table 4.12, it is clear that upper management concerns about potential for variation and causes of
uncertainty stem first from an overall project perspective to include the project scope, project jobsite, and the project team. For project managers, buffer allocation begins here. Next in the left to right thought process flow is the quality of the actual drawings and specifications as well as overall constructability. Grouped at the end of the mental model are the physical resource concerns including labor, equipment, and materials. The most important factors in the upper management model are interestingly related to intangibles such as information, communication, and trust. Galbraith (1977) and others have pointed out the requirement for increased and enhanced information flow under conditions of uncertainty such as those in the construction industry. Howell et al. (1993) noted that construction can be thought of as a process of reducing the aforementioned uncertainty through improved communication and information processing to make effective decisions. There are only slight differences in the latent factors in the frequency and severity dataset for upper management. One difference is project scope in the frequency dataset versus project complexity in the severity dataset. The severity model had more emphasis on the complexity of the project scope and resulting interdependency of trade tasks, while the frequency model latent factor of project scope was more focused on the scope, size, delivery method, contract period, and contractor size. Also, in the severity model, constructability was a complementary component to the design quality latent factor.
Table 4.12: Upper Management Structural Equation Models

Table 4.13 includes the six field management models developed to be used in the model survey. Here again, models C and F represent the best fitting models for the frequency and severity data respectively. The top priorities and concerns in task planning
and buffer allocation for field management personnel are the project scope to include the scope, interdependency of trade tasks, project size, and contract period; prerequisite work to include work before them not being done as well as rework required or inspection delays; and the overall design quality and constructability. Additionally, in the severity based model only, management liability pressure such as upper management schedule pressure, liquidated damages, and contractual deadlines is a top tier factor in the field management mental model. These top tier concerns have some of the same intangible characteristics found in the top tier of the upper management models. Prerequisite work, although not explicitly intangible, is a concern that is out of the field managers hands as they rely heavily on others ability to get their work done as planned. Similarly, the quality of the design is intangible to the field managers in the sense that they rely on the architects and engineers to provide accurate drawings for the work they must complete. Coordination, communication, and planning for uncertainty in the construction task themselves are the next priority in the field management level mental models. Both from the time buffer survey responses and interviews with construction personnel at the field management level, these second tier factors are extremely important to the day to day completion of construction tasks and are crucial to the interrelationships between the different trades and the timely completion of trade tasks. On the back end of the field management models are resource related factors to include jobsite conditions, labor, and materials. These factors’ location at the end of the mental model may be a result of the survey revealing that field personnel are less worried about the things they have direct involvement with, control of and responsibility for.
When comparing the upper management and field management models it is evident there is a big emphasis on information and communication in the top tiers of both levels of management. There is definitely greater emphasis on the design quality and prerequisite...
work in the field management model than the upper level management model. This concern about uncertainty driving time buffer allocation does make sense as both of those factors directly affect the field managers’ task completion. A design error, omission, or unclear design requiring a request for information (RFI) can quickly cause a variation in the work plan. Similarly, other trades not being done with prerequisite work or even the same trade not being done with a prerequisite task can affect the work plan and have a domino effect on the schedule if there is no buffer. Another difference resulting from the different perspective of the two levels of management is between jobsite organization in the upper management models and jobsite conditions in the field management models. Jobsite conditions are focused on the task level physical conditions as opposed to the overall construction site organization. These conditions include ability to access the trade task area (proper equipment, other trade in the way, etc), physical condition of the task due to weather, overcrowdedness of the task area, and material transfer to the task area. Jobsite organization is a factor related to concerns about the overall layout and logistics of the construction site and is considered a top priority by project managers. Another difference is the lack of concern about equipment by the field managers. This may be a result of today’s ease of access to a spare or ability to procure replacement equipment quickly. Equipment was included in the upper management model together with labor, as in their opinion these two elements are what physically get the job done. Materials were a common factor at the end of both management levels thought process, but based on variation research by Wambeke (2012) as well as the ongoing research on time buffer, late materials are a top cause of task variation on a construction project. This may be an area where more attention should be
directed with more communication and coordination between the suppliers and contractors. It is important to note that the final models are based on data-driven model modifications, and must therefore be regarded as tentative until the results are replicated in other samples. The model survey discussed in the next section is an attempt to obtain feedback and a degree of validation of the top models developed for each data set.

4.1.3 Time Buffer Survey Discussion and Conclusions

Discussions were held with a project manager, a superintendent, and a foreman in regards to the time buffer survey results in an attempt to gain validation. The project manager worked for a general contractor, while the superintendent and foreman worked for a trade subcontractor. All three had over 15 years of construction industry experience. None of them had seen the results of the survey. The project manager mentioned that his biggest concerns in task planning related to how complex the project was (“how many subs, activities, and their interactions”), having a complete and accurate set of design drawings and making sure his subs get where they need to be when they need to be there. The Superintendent said he was most worried about “getting the job done right and on time” (liability pressure) while ensuring coordination between the trades on the job in regards to both resources and timing (prerequisite work/interdependency of tasks). The foreman said he worried about change orders, material, labor, and equipment. These responses are fairly consistent with the research findings and provide some validation, but the case studies in
summarized in later sections were conducted to gather additional survey data as well as empirical data pertaining to time buffer in construction task durations.

The time buffer survey results and analysis addressed six main objectives, and the results have led to further questions for investigation. First, the overall top most frequent and severe causes of time buffer were identified. The top twelve most frequent causes of time buffer were: project complexity, complexity of the trade task, quality of documents, size of the project, required coordination with other trades, contract period, design constructability, tendency of scope changes, material transfer distance, material transfer method, work area access, weather/climate. The top twelve most severe causes of time buffer were: quality of documents, project complexity, complexity of trade task, tendency of scope changes, weather/climate, design constructability, size of the project, work area access, strict specification requirements, quality control requirements, low degree of repetition, and late materials.

Next, the results of the research provide construction managers two tools to help target those factors related to uncertainty and resulting in the most frequent and severe time buffer in their construction projects. Depending on available resources, construction managers should target the high frequency/high severity factors first, followed by the low frequency/high severity factors, and finally the high frequency/low severity factors. The low frequency/low severity factors are least likely to require attention. Since the risk profiles do not account for all of the causes, the step graph can be used as a secondary tool to prioritize which causes management and the construction team should focus on first. Regardless which tool is used as a guide, there is great importance for management to address these factors and
develop effective strategies in order to reduce the need for buffer, as reducing the amount of time buffer in construction task durations should improve productivity, and may also reduce both project duration and cost.

The third objective involved comparing the differences in opinion and perception between different survey groups. Overall, the frequency and severity increases as you move from project manager to the superintendent to the foremen. The survey analysis also highlighted larger frequency and severity of time buffer perceived by trades with more complex tasks and greater interdependency such as mechanical, electrical, and plumbing. Experience was also shown to impact how much time buffer is included in construction task durations. Lack or limited experience (5 years or less) resulted in adding a larger amount of time buffer. Due to the differences in scope and responsibilities, general contractors and subcontractors were compared to expose the differences in their perceptions, finding that subcontractors perceive a greater need to protect themselves against uncertainty and variation with time buffer. A final comparison between construction personnel who use lean construction techniques such as the Last Planner System® (LPS®) and those using traditional construction planning techniques was made. The results of the survey corroborate at a minimum that the perception of those using LPS® is one of a reduced need for the frequency and magnitude of time buffers and leads to the need for further empirical investigation into the amount of time buffer in projects using LPS®.

Previous research has not been conducted on how the root causes of time buffer compare to the causes of variation. The literature review noted that one of the primary reasons construction personnel buffer is to absorb variation. The research compared the top
individual causes of time buffer with Wambeke et al.’s (2011) similar investigation of the causes of variation. The time buffer survey documented the perceived need for buffer and what construction personnel are most concerned about when planning task durations. The variation survey carried out by Wambeke et al. (2011) documented the actual causes of variation on construction projects. One would hope to see personnel plan for the right problems, but based on the survey results and the comparisons made between the top overall causes and between different levels of management (project managers and foremen), there exist disconnects in the perception of concerns and uncertainty and the reality of what causes task duration variation. Furthermore, the top five causes (quality of documents, constructability, weather, prerequisite work, and request for information) seen in both the buffer and variation survey results are associated with such intangibles as information and communication. In fact of all the top causes, only late materials in the time buffer results and the labor related causes in the variation survey results are directly a resource (materials, equipment, labor) concern. Galbraith (1977) and others have pointed out the requirement for increased and improved information flow under conditions of uncertainty such as those in the construction industry. Howell et al. (1993) noted that construction can be thought of as a process of reducing the aforementioned uncertainty through effectively communicating and processing information and making decisions. The time buffer survey results and comparison with the variation survey highlight the need for emphasis by management on reducing the uncertainty inherent to the construction process through improved two way communication and efficient information flow.
A quantitative analysis of the underlying structure of time buffer was accomplished through factor analysis. Factor analysis was performed on the 47 individual causes of time buffer and identified eleven factors that account for approximately 69% of the variance in the severity data. Those factors were associated with: Communication and Labor Force Capabilities, Jobsite Management, Equipment Management, Project Characteristics and Prerequisite Work, Trust, Material Management and Weather, Design Quality, Constructability, Standards and Quality Control, Management Liability Pressures, and Labor Force Allocation. Similarly, the frequency data revealed 10 factors accounting for 66% of the variance with very much the same underlying factors.

Identification of the underlying factors along with other survey results analysis drove the interest in exploring the causal structure or mental model used by different levels of management when task planning and considering potential for variation and uncertainty. A total of six best fitting models were developed for both field managers and project managers. These models can be used for decision support through identification of risk areas, and the prioritization, prevention, and mitigation of those risks. Further, comparison of the field management models with the upper management models was conducted to identify both the shared key causes of buffer allocation and the differences in planning priorities. The findings of this research will help construction managers understand what drives the need for buffer in their construction schedules and allow them to focus efforts on strategically addressing the most critical areas of interdependency and uncertainty.

The analysis results for the first six objectives help industry practitioners identify and prioritize the causes of time buffer for construction managers to address. There is a saying
that “a problem well identified is a problem half-solved”. In other words, understanding why time buffer is added and then quantifying the influence of different causes on the way construction personnel at various levels of management buffer and plan for uncertainty will help construction companies take proactive steps towards addressing those causes, managing uncertainty, and reducing the associated time buffer in construction projects. One possible method for understanding the reasons for the disconnects between perception and reality requires companies to allow open and no threat discussion by all levels of management, voicing their concerns and recommended solutions in a group setting. Understanding how the members of a team think, plan, and perform, is critical to the success of a project. Further, Hopp and Spearman (2008) assert that understanding the underlying causes of variability and the buffers it begets is essential to the design and management of efficient production systems. This research is an effort to understand and examine those buffers, specifically time buffers as they relate to construction tasks.

4.2 Case Study 1

4.2.1 Case Study 1 Results

The study involved a mechanical contractor coordinating on average 45 construction personnel working on the new construction of a $33M medical facility. Data was collected on the mechanical contractor case study from January 2012 through February 2013. Overall, task data was collected for their 219 mechanical and plumbing related activities. The eight specific activity types examined in the case study analysis included cast iron pipe and fittings
(CIP & F), copper pipe and fittings (Copper P & F), steel pipe and fittings (Steel P & F), pvc pipe and fittings (PVC P & F), embeds and sleeves, drains and carriers, hangers, and fixtures. Mean or average time buffer, variation, and productivity were calculated on a monthly basis.

4.2.2 Case Study 1 Analysis

Research Objective 7: Examine the effect of traditional management and planning on the allocation of time buffer and the associated impacts on task variation and productivity.

For the purposes of this research case study, traditional project management and planning refers to the current method used by the mechanical contractor as well as the general contractor on the project and is not the Last Planner System. Monthly task time buffer and variation were collected and converted into a percentage for the mechanical contractor’s activities to determine the effect of the general and mechanical contractor’s management and planning. The percentage of time buffer was calculated by dividing the identified time buffer by the scheduled duration. For example, if an activity had a planned duration of 10 days and a best possible duration of 8 days, then the time buffer was 2 days. The percentage was then calculated by dividing the 2 days of buffer by the 10 day scheduled duration for a 20% time buffer. Similarly, the variation was calculated by dividing the days of duration variation by the scheduled duration. The mechanical contractor kept record of the productivity rates for each type of activity on a weekly basis and these rates were calculated by dividing the man hours estimated by the man hours spent for each activity. In
general, a productivity value of 1.0 or greater is favorable, whereas a value less than 1.0 is unfavorable (Oberlender 2000). The results for the duration of the project are displayed in Figure 4.8. Note that the mean productivity rates were multiplied by 100 to put them on the same scale as time buffer and variation.

Figure 4.8: Mechanical contractor project time buffer, variation, and productivity

The first point of discussion for Figure 4.8 is the focus of this research on the allocation of time buffer. During the first few months of the project, the mechanical contractor’s time buffer hovered between twenty and thirty percent. In fact, the time buffer
trended downwards between March and May. However, from May through the end of the project the time buffer increased every month. One reason for this increase may be due to an increase in uncertainty as the number of activities increased and the project progressed. As previously discussed, construction personnel allocate buffer in order to compensate for the uncertainty and potential for variation in construction projects. An interview with the mechanical contractor project manager led to another explanation. Due to fairly large amounts of duration variation in April and May, the general contractor severely reprimanded them multiple times, placing the blame for poor project performance on the mechanical contractor. The mechanical contractor project manager said that thereafter they did not feel they could be truthful or precise with their activity durations and they had to "pad their durations" to avoid "being beat over the head when variation did occur". Interestingly, the amount of variation decreased significantly over the same timeframe that the time buffer increased. The researchers expected this result as time buffer hides the variation and its root causes, giving the appearance of improved project performance by meeting promised schedule dates more consistently. Low variation levels in a project do not alone guarantee good productivity or reduced waste, because the presence of excessive buffers can absorb the variation and adversely impact performance. The productivity in this project was true to this statement. As the time buffer increased and variation decreased, the mean productivity of the mechanical contractor decreased from 0.96 to 0.86, an 11% drop in productivity. The project manager stated that the task complexity did not increase during that period and there were no unexpected difficulties in work area access. The increased time buffer appears to be responsible to some degree for decrease in productivity. Parkinson’s Law explains that this
reduced productivity can occur because people always use the time buffer and allow the task to grow to take as long as the time allotted for it to be done (Lechler et al. 2005). In other words, the work will expand to fill the time allotted by for example working more slowly, or rechecking work multiple times before declaring it complete. Reduced productivity comes at a cost to the mechanical contractor in this case. Seemingly, as long as that cost is not affecting their bottom line, the mechanical contractor would rather incur that cost than risk variation and potentially jeopardize their relationship with the general contractor.

**Objective 9:** Determine construction trades and activities to be targeted by management for time buffer and variation reduction. Further, investigate how the reasons for time buffer allocation compare to the causes of variation in practice for a given construction project.

This particular objective spans both the mechanical contractor case study and the general contractor case study. For the mechanical contractor case study the focus is to determine which mechanical trade activity types encounter the most task uncertainty, how time buffer is allocated to protect against the resulting variation, and the effect on productivity rates of those activity types.

The mechanical contractor performed eight different types of activities for which the researchers were able to collect data. The different activity types for analysis included cast iron pipe and fittings (CI P & F), copper pipe and fittings (Copper P & F), steel pipe and fittings (Steel P & F), pvc pipe and fittings (PVC P & F) embeds and sleeves, drains and
carriers, hangers, and fixtures. Additionally, the contractor was interested in the time buffer and variation trends of their plumbing activities versus their heating, ventilation, and air conditioning (HVAC) activities. A two by two matrix was developed similar to one used by Howell and Ballard (1996) when comparing inventory buffer with budget performance. The matrix for this research is presented in Figure 4.9 with the time buffer percentage along the horizontal axis and the variation percentage along the vertical axis. Each different activity type and the overall plumbing category and HVAC category have a data point which represents the mean time buffer and mean variation performances for this construction project. The lower left box represents the area of best performance with low amounts of both time buffer and variation. The researchers do note that the average time buffer percentage for the project was near 35%, so the term “low” is relative. While 35% time buffer may seem quite high, this result supports Russell et al.’s (2013) finding that complex and labor intensive trades such as the mechanical trade in this project perceive a need for large time buffers. Furthermore, the mechanical trade in the second case study had similarly large time buffers early in their planning and will be discussed in objective 4. Overall for the mechanical contractor, the HVAC activities performed the best and were the only data point to have relatively low time buffer and variation. The embeds and sleeves activities performed the worst out of the HVAC specific activities with below average variation but high time buffer. The fixtures activities had a high average buffer at 44% and high average variation at 22%, making them the worst overall performing activity and worst performing plumbing activity. Drains and carriers activities also performed poorly for the plumbing activity types. On the other hand, steel pipe and fittings were the best overall performing
activity type with low variation but slightly above average variation. The low variation there may be the result of excessive time buffer. The other pipe and fittings activity types as well as hangers all exhibited lower than average buffer, yet suffered from higher than average variation. Where each one of these activity types ended up on the matrix serves to point to which activity types for this mechanical contractor need what sort of attention from management. In other words, where might they need to add time buffer and where can they reduce time buffer and take advantage of that extra time.

![Graph showing the relationship between buffer and variation for different mechanical trade activity types.](image)

**Figure 4.9: Time buffer and variation by mechanical trade activity type**
To further highlight the impact on productivity discussed in objective 1, the time buffer and productivity over the course of the project for the two activity types with the most activities are shown in Figure 4.10. The convergence of time buffer and productivity can be seen in the graphs of both activity types. The increased allocation of time buffer to project task durations is at least complementary in reducing the task productivity for this case study project.

Figure 4.10: Productivity and time buffer comparison for copper and steel activity types

4.3 Case Study 2

4.3.1 Case Study 2 Results

The second case study involved a large general contractor responsible for 18 trade contractors on the new construction of a $211M data facility. The data collection period for the general contractor case study spanned from February 2012 through the end of April 2013.
PPC data was obtained for the entire duration of Phase A/B and the first seven months of Phase C/D. Additionally, data was collected on a total of 640 activities from five trade contractors – mechanical, electrical, plumbing, drywall, and painting. Again, mean time buffer and variation were calculated on a monthly basis to coincide with data collection site visits. Additionally, feedback regarding the use of LPS® and causes of time buffer was documented from interviews and discussions with 21 project managers, superintendents, and general foremen from both the general contractor and the trade contractors on this project.

4.3.2 Case Study 2 Analysis

Objective 8: Examine the effects of lean construction techniques such as LPS® results on the allocation of time buffer to construction project task durations and the implications on project performance.

One of the goals of the Last Planner System® is to reduce the amount of uncertainty which is exists in a construction project through the use of collaborative and pull planning techniques. Based on the findings of Russell et al’s (2013) survey on the frequency and severity of time buffer causes, construction personnel using LPS® had a lower perceived need for time buffer due to uncertainty or potential for variation than those personnel using traditional management and planning methods. The second case study involving a large general contractor was executed in part to test the hypothesis that over the course of a LPS® project the amount of time buffer will be reduced as the plan becomes more reliable and the trades’ communication, coordination, trust, and information flow improves. PPC as
presented in Figure 4.11 is the ratio of the number of tasks 100% completed to the number of tasks planned for the given time period (Wambeke et al. 2012). Time buffer percentage is calculated as previously discussed. Both phases A/B and C/D demonstrated an overall downward trend in the allocation of time buffer over the course of the project, supporting the researchers’ hypothesis regarding LPS® and time buffer. In fact, phase A/B experienced a drop of 15 percentage points between April and September of 2012. Phase C/D experienced a drop of 10 percentage points between the beginning of January and the end of April 2013 and did not experience a single increase in the average time buffer during that timeframe. These drops represent a 54% and 40% reduction in the allocation of time buffer over the course of those time periods. Some may argue that learning curve is responsible for these improvements; however, from experience and discussion with the general contractor, the greatest learning curve effects are typically felt early in the project and both of these sets of data demonstrate the improvement several months into the project phases. Additionally, the previous findings of Ballard (2000b) and Liu and Ballard (2009) are corroborated as the PPC for both phases was over 70% and at times approached 90%. These levels are a significant improvement compared to the findings by Ballard and Howell (1998) that the use of traditional planning methods resulted in an average PPC of 54%. Both phases experienced what the general contractor called the “liars’ hump” in the beginning and then began to see buy-in to the LPS® method of planning, reduced variation, and improved PPC. Phase A/B does have a downward trend in the PPC, especially between May and September of 2012 where it dropped from 80% to 70%. The researchers feel this may be a result of the nature of construction projects. The activities at the beginning and during the later parts of the project
are more piece-meal or fragmented, whereas most of the substantial work occurs during the middle part of the project. Even though the PPC drops slightly in Phase A/B towards the latter stages of the project, it does not drop below 70% and the allocation of time buffer still continues to drop during that timeframe.

![Graph](image)

**Figure 4.11:** General contractor case study PPC versus time buffer percentage

An additional hypothesis was that reduced time buffer and improved PPC will result in shortened project durations which entails cost savings in areas such as general conditions and the ability to move on to another project. Planning is not free and the use of LPS® carries an associated cost for the additional planning to include last planner meetings and phase scheduling meetings. The company estimated they spend about $50K per phase in additional planning costs for the use of LPS®. This project did experience a benefit. Phase A/B was completed 4 weeks early, while phase C/D is still ongoing but is expected to finish
by the end of October 2013. Although Phase C/D is nearly 8 weeks ahead of schedule, the author will not speculate on how early it will actually finish. The general contractor indicated that the estimated cost savings for each phases would be approximately $1.5M per month in general conditions costs. The resulting benefit/cost ratio for this project was 30:1.

**Objective 9:** Determine construction trades and activities to be targeted by management for time buffer and variation reduction. Further, investigate how the reasons for time buffer allocation compare to the causes of variation in practice for a given construction project.

Objective 8 included discussion about the overall time buffer trend but did not specifically look at the different trades involved in this case study. The time buffer trends of the five participating trades are shown in Figure 4.12. The gap in the graph represents the break between phase A/B on the left and phase C/D on the right. The trade contractors were mechanical, electrical, plumbing, drywall, and painting. The allocation of time buffer by the different trade contractors varied depending on the trade, the foremen assigning the task durations, and arguably the effect of LPS® on their planning.

The foreman interviewed and responsible for planning the mechanical tasks was different for phase A/B and phase C/D. Regardless, both mechanical foremen started out with time buffer percentages just above 30% in their respective phases and both exhibited a downward trend in their time buffer allocation for the mechanical trade tasks. The mechanical trade in the general contractor case study was a different company than the
mechanical contractor in the first case study, yet they both had very similar starting points for the time buffer allocated during task planning. The important difference is the trend over the course of the project with the mechanical trade on the LPS® project reducing their time buffer by 10 percentage points on phase A/B and 18 percentage points on phase C/D. Conversely, the mechanical trade on the non-LPS® project increased their time buffer by nearly 30 percentage points. The electrical trade had the same foreman throughout phase A/B but had two different foremen for phase C/D. All three demonstrated a reduction in time buffer allocation over the portion of the project for which they were responsible. The phase A/B electrical foreman dropped consistently over the six month period with a total reduction of 13 percentage points. The first electrical foreman in phase C/D was responsible for planning from October – December and reduced his time buffer allocation by 8 percentage points. The second electrical foreman in phase C/D took over in January and although his time buffer increased the second month, it dropped 4 percentage points over the next two months. The plumbers for phases A/B and C/D were much less predictable. The plumbing foreman in phase A/B made a large increase in time buffer early in the data collection but then dropped significantly over the next four months. Phase C/D had a very experienced plumbing foreman with over 20 years in that position but not a lot of experience using LPS®. From the data results, it is possible he may have been reluctant to completely commit to the process or may have been reacting to task variation as the spikes in time buffer correlated with prior spikes in task delays particularly due to overcommitment. Like the previous trades, the drywall foremen changed between phase A/B and phase C/D. Experience seems to play a role in this dataset. The drywall foreman for the first phase had close to 30 years of
experience, while the foreman in the second phase had 10 years of drywall experience but this project was his first opportunity to be the general foreman and directly responsible for planning. Phase A/B time buffer hovered between 15% and 20% for the entire phase. The buffer was not extreme and perhaps this is an example of LPS® not changing this foreman’s planning mindset. As with all the other trades, additional case studies for comparison of trades on LPS® and non-LPS® projects would be very beneficial. Phase C/D was very different as the time buffer allocation began near 40% and dropped steadily over the next five months. Surely the drywall foreman had some initial learning curve due to inexperience, but one could argue that his increasing confidence in the system also directly impacted his allocation of time buffer as coordination and communication with the other trades improved. The final trade for discussion is the painter who remained the same for both phases. Although there is an overall drop in his time buffer allocation over the course of the two phases, he also exhibited some unpredictability and higher than expected levels of time buffer. One possible reason the researchers note for this is the planned durations of most of the painting tasks were fairly small at 2-4 days. With those durations, even a one day buffer results in a fairly large time buffer percentage.

All participating trade foremen provided feedback in a survey and agreed that lean construction techniques such as LPS® were beneficial to this construction project and the construction industry as a whole. Further they commented that the biggest LPS® benefits resulted from the increased communication, coordination, collaboration, and trust between the trades. With a more reliable plan there were less mistakes and a better work flow. In fact they estimated a reduction in task variation anywhere from 10% to 30%. They said that
moving away from an atmosphere of every trade for themselves and towards a truly team effort was refreshing. In essence, the project effort became more about “what was right” and not “who was right”. In regards to time buffer allocation specifically, one foreman summed up the others’ responses when he stated that “as everyone else stopped sand bagging, I knew I could also be more truthful and precise” when planning task durations. The foremen feel the bottom up planning in LPS®, where the foremen actually help create the schedule rather than having it dictated to them, allows a lot more problems to be resolved and variation to be avoided.

![Figure 4.12: Trade contractor time buffer allocation](image)

Figure 4.12: Trade contractor time buffer allocation
The same two by two matrix introduced in the first case study one and used for comparing time buffer and variation was applied to the trade contractors in the second case study. The results for the five trade contractors are displayed in Figure 4.13. The results definitely identify the electrical contractor as a solid performer and perhaps the trade to be most learned from. Even with low time buffer allocation, they experienced the least task variation. The overall time buffer for mechanical and plumbing was at an expected level around 25% and yet still less overall than the non-LPS® case study mechanical contractor who averaged about 35% for their project. The two mechanical contractors are both well-known companies with a solid performance history. Further, both companies agreed they were fairly comparable even with the differences in scope between the two projects. The drywall contractor’s buffer was unexpectedly high, but the inexperience of the second foreman may have contributed to that. Also, their low level of variation may be a result of the high buffer hiding the causes and occurrences of variation in their work plan. Russell et al.’s (2013) survey results led to the hypothesis that less complex trades such as the finishing trades to include painting had less of a need for time buffer. One reality made evident by this case study is that the painter and likely other finishing trades as well were at the mercy of several of the other trades discussed here. The painter had multiple delays due to prerequisite work not being complete, priorities changing, and the scope of work changing. This may lead to a perceived need for larger time buffers and may help explain why the painter’s buffer behavior was similar in magnitude to the mechanical and electrical trades.
The final purpose of this objective is to compare and contrast the most frequent causes of variation with the most prevalent causes of time buffer to identify disconnects and similarities between the perception of concerns about uncertainty and the reality of what causes task duration delays on a given construction project. Overcommitment by the trade contractors, incomplete prerequisite work, change in work plan or priorities, and unavailability of materials were the top five causes of variation for the general contractor case study. These results confirm previous findings by Wambeke et al. (2011) which identified overcommitment, prerequisite work, and lack of materials as three dominating causes of variation. All the causes responsible for at least one percent of the total variation occurrences are displayed in Figure 4.14. Overcommitment results when a trade foreman overestimates what his crew(s) will accomplish and can result from crew inefficiencies or a lack of skilled labor. Overcommitment by a trade can affect sequential trades behind them.

Figure 4.13: Time buffer and variation by trade contractor
by causing variation due to prerequisite work not being complete. All five trades in this case study identified crew inefficiencies and lack of skilled labor as a concern going into the project and a reason for time buffer allocation. Material concerns (late materials, incorrect quantities, and receiving damaged materials) were a primary driver of time buffer for the mechanical, electrical, plumbing, and drywall trades. Late materials were the most severe cause of duration variation on the project. The electrical and painting trade expressed concerns about prerequisite work going into the project and both had the highest rates of variation due to previous trades not being complete. Changes in scope and priority were a major uncertainty and cause of time buffer for the painter based on previous experience. His trade suffered the most variation from such changes in this project. In all these cases the perception of concerns met the reality of variation. The problem here is if concerns have been correctly identified then they should have been specifically addressed to the best of each trade’s ability in order to reduce the variation caused by them. The reality is that just because a concern exists, inaction can and does occur. Being concerned is not action or preventative in and of itself. On the other hand, sometimes limited resources make it difficult if not impossible to address concerns such as a lack of skilled labor in the area.

Disconnects between perception and reality existed in the results as well. The mechanical, electrical, plumbing, and drywall trades all acknowledged concerns about an overcrowded or cluttered work area as causes of time buffer allocation. Design quality was an uncertainty for all the trades except painting. Also, required coordination with other trades, communication, and information flow were cited by the trades as causes of time buffer prior to this project. In these cases, perception did not meet reality, and they are
examples of areas of concern for which management can reduce time buffer allocation because LPS® reduced the associated uncertainty. Although time buffer was allocated for all these reasons, less than 6% of the variation occurrences were attributed to any one of the discussed reasons. These results support the claimed benefits of LPS® and are further corroborated by feedback from the trade foremen presented earlier. Even in regards to jobsite congestion, the foremen noted that LPS® shows the other trades where you are and where you are going so everyone can coordinate their activities accordingly. The researchers note that the project team used building information modeling (BIM) on this project, which in combination with LPS® seems to prove very effective and likely helped reduce design related issues.
Figure 4.14: General contractor case study causes of task variation

4.4 Case Studies 1 and 2 Discussion and Conclusions

The author acknowledges that the results of these case studies are limited to specific projects and strongly recommend that additional such case studies be completed to strengthen the findings. Each case study is however repeatable and can be applied to any type of project or trade. The research did provide quantitative data collected from two construction project case studies that demonstrated the allocation of time buffer by different trades and to different types of activities. As Howell and Ballard (1996) noted and is applicable in this research to both two by two matrices (Figure 4.9 and Figure 4.13), the size of the time buffer might indicate the extent of uncertainty managers expect to experience. Small time buffers
and variation indicate the construction team had been able to control or reduce uncertainty and save time and money associated with large time buffers or variation in task durations. This low time buffer and low variation combination is the target and is depicted in Figure 4.15 as precise and accurate task durations. Precision here relates to a minimum amount of time buffer and accuracy relates to avoiding task variation. If an activity or trade falls outside of the low time buffer and low variation area, they can and should be targeted by management for improvement. Those areas include task durations which are neither precise nor accurate, precise but not accurate, and accurate but not precise. Generally, project managers would rather be in the bottom right area than the top left or in other words they would rather be “roughly right” than “precisely wrong”. Ultimately, the concept proposed is for management to work towards moving their activity or trade first left (less time buffer) and then down (less variation) in the matrix. Management understanding and addressing the root causes of time buffer will help them reduce it through better planning and allocating it where it is needed most. As time buffer is reduced and the causes of variation are realized (lower the river to reveal the rocks), management can proactively attack the causes of variation. Hopp and Spearman (2008) state, “understanding the underlying causes of variability and the causes of buffers it begets is essential to the design and management of efficient production systems.” More reliable work flows with reduced waste in the form of excessive time buffer will help management improve project performance.
The results of this research corroborated at a minimum that the perception of those using LPS® is one of a more reliable plan and a reduced need for time buffer allocation. Collection of time buffer data in both case studies and the related productivity and PPC demonstrated the effects of collaborative planning compared with traditional planning methods as well as the effect of time buffer on performance. In the mechanical contractor case study this effect was a negative one as productivity decreased as the allocation of time buffer increased. The use of LPS® in the general contractor case study increased information flow through communication, coordination, and building of trust. Information is to reduce uncertainty. Galbraith (1977) introduced this concept of “uncertainty gap,” between the information required to efficiently and effectively complete a project and the information available in the project organization to do so. LPS® helps close the gap and allows for more
precise and accurate task durations. The reduced time buffer and variation in the LPS® project resulted in an increased PPC and productivity as the project was shortened by four weeks at a cost savings of $1.5M and a benefit to cost ratio of 30:1. This cost savings does not include the savings likely experienced by the trade contractors as well and further research into the direct impact of them would be interesting. LPS® is also ultimately about learning and when mistakes are made the project team works to prevent them in the future rather than, as foreman on the LPS® study put it, “throwing a trade or foreman under the bus for busting a schedule date.” The learning must happen at all levels of management and involve all members of the project team to include the architects and engineers, owner, general contractor, trade contractors, and suppliers. The last planners themselves learn how to precisely and accurately plan task durations and coordinate with other trades to remove constraints each time through the process.

The concerns and variation caused by materials highlight the need for management to more directly and more frequently involve suppliers outside of the project site in the last planner meetings and overall effort. As shown by Chinowski et al. (2008), the isolation of key individuals contributed to over centralized decision making, a lack of information and knowledge integration, and a lack of trust. Not involving the suppliers or distributors in the phase scheduling or other last planner meetings can be a major kink in the armor of lean. They must be on board early and throughout the project and communication efforts from both sides must be improved. For example, a late delivery is not necessarily the suppliers’ fault if the contractor notified them the day before it was needed on site.
Overall, the general contractor must provide an environment conducive to benefitting from LPS® where clear two-way communication exists, trust can be built, and all personnel are included in the process and have an opportunity to participate. The researchers as well as the participating companies have been encouraged by the findings of this research and feel they are significant in their demonstration of the value of the LPS® method of collaborative planning.

4.5 Model Survey

4.5.1 Model Survey Results

A total of 63 completed surveys were received and used for analysis. The participation of the construction personnel was appreciated and valuable. There were a total of 34 field management surveys and 29 upper management surveys. Overall, 35 participants either suggested modifications to the best model they had picked (33) or drew their own model (2). The other 28 participants were satisfied with the causal structure of their best of six models they had chosen. All 63 participants completed the model selection, but 20 field managers and only 12 project managers annotated their top three concerns that lead to time buffer allocation. All the feedback was considered in analysis of the model surveys.
4.5.2 Model Survey Analysis

Objective 10: Through the use of a model survey, attempt to validate the SEM developed mental models of how construction personnel plan for uncertainty and allocate time buffer to construction project task durations.

For the field managers, three models best depicted their task planning thought process: models A, C, and F. In the frequency data based subset, model A was the #1 ranked model 16 out of 34 times and model C was the #1 ranked model 17 out of 34 times. Model B was clearly the least favorite. In the severity data based subset, model F was the #1 ranked model 15 out of 34 times. Although F was the favorite, all three severity models were ranked as a top model fairly often. Models A and C also combined for 21 of the 34 overall top rankings with model F receiving 6 votes. Models A and C both emphasize design documents and constructability, project scope, and coordination and communication as top tier factors. Perhaps the biggest difference between the two is the location of prerequisite work. To those who picked model C and F, prerequisite work is a top concern regarding uncertainty and potential for variation. All three models have the more tangible aspects of construction such as labor, materials, and jobsite conditions towards the right side or latter stages of the planning process. This is the same point noted in earlier discussion of the models and is supported by the survey participants whose suggested modifications did not include any changes to the location of labor or materials. That being said, multiple foremen suggested moving jobsite conditions to an earlier position in the model. Additionally, based on the responses regarding the top causes of time buffer, the factors of coordination and
communication, design quality, and prerequisite work were the top three overall concerns. Interestingly, labor related concerns were the next most important based on the feedback. The author notes that no one model convincingly dominated the rankings as the best overall model, but based on the rankings provided and the construction personnel feedback, the three models (A, C, and F) in Table 4.14 were the best portrayals of the field managers task planning thought process.

Table 4.14: Top Three Field Manager Models

The upper management survey results were not overwhelming either, but models B and F were the favorites overall. Model B based on the frequency data received 48% of the
#1 rankings (14/29) and model F based on the severity data received 55% of the #1 rankings (16/29). Overall, model B was picked as the best of all six models 31% of the time. The main difference between the top two models is the switching of jobsite organization and design quality. Two of the top three factors of concerns for project managers were surprisingly labor force and equipment, and material concerns. Even though both those factors were on the far right of the mental model, they were repeatedly pointed out as top concerns in regards to uncertainty and potential for variation. Less surprising was the acknowledgement of superintendent/foremen communication skills and trust as the other top factor. The superintendent of a construction project can often make or break the project and can greatly impact project performance and construction team relationships.
4.5.3 Model Survey Discussion and Conclusions

Although the model survey did not provide an overwhelmingly convincing selection of a single model for either level of management, there were models which stood out to the construction personnel as fitting their task planning process. Conversely, there were models which were clearly not the best representations even though the SEM results reflected otherwise. Most encouraging was that only two participants did not think any of the models fit their planning thought process. In general, the models correctly portrayed the field managers and project managers mental model and their survey participation and feedback supported the models developed using SEM. The participating companies found the surveys
and the discussion they spurred as valuable and beneficial. One field manager even stated to the author how much he enjoyed the survey because he had “never thought about how I think about my planning. This really put some things in perspective.” Upon careful review of the survey results and participant feedback, the author has proposed two models (one for field managers and one for upper management) as the best fitting models from a combination of SEM and survey participant suggested changes. The models are field manager model C and upper management model B. The adjusted final proposed models can be seen in Table 4.16.

Table 4.16: Final Proposed Models

![Diagram showing the final proposed models for field management and upper management.](image-url)
CHAPTER 5

5.0 SUMMARY AND CONCLUSIONS

5.1 Existing Gaps in the Body of Knowledge

Previous construction related research has identified both the causes of task variation as well as factors impacting productivity. Research has also acknowledged the addition of different types of buffer to compensate for these causes of variation and productivity factors. However, the reasons for the use of time buffer specifically in regards to both their frequency and severity have not been studied. This represents the first gap in the body of knowledge addressed by this research.

Although construction personnel involved with a project and the planning of task durations have a natural tendency to add time buffer to task durations, the time buffer deemed necessary varies depending on whom you ask. Here, another gap exists. There was a need to explore the time buffering behavior at different levels of management, different trades, different activities, and amongst other construction related demographics. A comparison had also not been made between the perceived need for time buffer and the reality of what most often causes variation in construction tasks. Management stands to benefit from understanding the disconnects in perception and reality when planning and determining where to focus treatment efforts.

The ever-growing economic demand to deliver projects more quickly while minimizing costs coupled with today’s construction industry environment of limited resources, results in a need for prioritization of the causes of time buffer for mitigation
efforts. Given limited resources, which causes of time buffer should be addressed first? Recent research on variation proposed a systematic means of prioritizing the causes of variation, but such an effort had not been documented regarding the causes of time buffer. Plausibly and arguably, construction personnel do not consider the causes of time buffer independently but rather group them together and prioritize them through the use of a mental model or planning thought process when developing construction plans and assigning task durations. This is another gap in the body of knowledge as no such models existed to describe the causal structures applied by project managers and field managers when planning for uncertainty and allocating time buffer.

While researchers acknowledge the use and necessity of various types of buffer to compensate for the uncertainty and absorb the variation it causes, some Lean Construction researchers argue that the use of buffers is waste. The view here is that it is feasible and necessary to first reduce variability to the extent possible, and then buffer only what cannot yet be eliminated. Others argue that due to the uncertainty and variability inherent in construction, buffer will always be necessary to ensure flexibility in responding to problems. Although opposing views exist, there researchers agree that excessive time buffers mask the sources of uncertainty that make them necessary and overly large time buffers may reduce project performance by extending duration, and reducing work discipline and coordination. The effects of time buffer on project performance and trends of time buffer over the course of a construction project have not been empirically documented and represent another gap in the body of knowledge. Further, the effects of using collaborative planning techniques such as
the Last Planner System on the allocation of time buffer and any associated cost benefit have not been researched.

5.2 Research Summary

The research completed for this dissertation is summarized below to include the research objectives, associated methodology, and conclusions. The table (Table 5.1) is intended to highlight some of the key findings discussed in detail throughout the dissertation.

Table 5.1: Summary of Objectives, Methodology, and Conclusions

<table>
<thead>
<tr>
<th>Research Objectives</th>
<th>Research / Analysis Method</th>
<th>Conclusions / Key Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Identify the causes of time buffer and determine which are the most prevalent and severe in terms of additional time included in construction project task durations</td>
<td>Developed and distributed a time buffer survey to collect data about the most prevalent and severe causes of time buffer (180 useable responses).</td>
<td>Identified overall top 12 most frequent and severe causes of time buffer (Table 4.2). Emphasis on intangibles such as communication and information flow.</td>
</tr>
<tr>
<td>2) Quantitatively develop risk profiles of the causes of time buffer so they may be prioritized for mitigation efforts</td>
<td>Examined different construction related demographics to identify top causes of time buffer as well as differences in perspectives.</td>
<td>Risk Profiles:</td>
</tr>
<tr>
<td>3) Determine the differences in opinion and perception between different levels of management, different trades, different levels of experience, the difference between contractors and subcontractors, and the difference between contractors using traditional management approaches and those using Lean Construction techniques.</td>
<td>Used integrated risk assessment approach to create risk profiles of the causes of time buffer for prioritization of management’s mitigation efforts.</td>
<td>Used Wambeke’s (2011) variation research as a baseline for comparison of perception versus reality in regards to why personnel use time buffer and what actually causes variation.</td>
</tr>
</tbody>
</table>

Difference in perspectives:
- Larger frequency and severity of uncertainty as one moves from project manager to the superintendent to the foreman.
- Utilities trades were found to have the largest frequency and severity for the time buffer causes.
4) Compare and contrast the overall most severe causes of time buffer with the most severe causes of duration variation to identify disconnects between the perception of concerns about uncertainty and the reality of what causes task duration variation.

5) Identify the underlying factors that correlate the individual causes of time buffer.

6) Develop the mental model and associated causal structure used by project managers and field level managers (superintendents and foremen) when buffering and planning for uncertainty.

7) Examine the effect of traditional management and planning on the allocation of time buffer and the associated impacts on task variation and productivity.

8) Examine the effects of Lean Construction techniques such as LPS on the allocation of time buffer to construction project task durations and the implication on project performance.

9) Determine construction trades and activities to be targeted by management for time buffer and variation reduction. Further, investigate how the reasons for time buffer allocation compare to the causes of variation in practice for a given construction project.

Table 5.1 Continued

<table>
<thead>
<tr>
<th>Proposed best model indices for each dataset:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Field Management C</td>
</tr>
<tr>
<td>Field Management F</td>
</tr>
<tr>
<td>Upper Management C</td>
</tr>
<tr>
<td>Upper Management F</td>
</tr>
</tbody>
</table>

Mechanical Trade Contractor Case Study data collection – 12 month duration, 219 activities:
- Average time buffer, productivity, and variation over course of project.
- Average time buffer and variation for different activities.
- Average time buffer and productivity Copper P&F and Steel P&F.

General Contractor Case Study data collection – 14 months, 5 trades, and 640 activities:
- PPC and average time buffer over course of both phases.
- Average time buffer and variation for different trades.
- Comparison of causes of time buffer with actual project causes of variation.
- Cost benefit ratio of using LPS® on this project.

Mechanical Trade Contractor Case Study:
- Time buffer increased over course of project and productivity and variation decreased.
- Steel P&F, PVC P&F and HVAC overall as top three performers (lowest buffer/variation).
- Fixtures, Drains/Carriers, Embeds/Sleeves as worst three performers (highest buffer/variation).
- Copper P&F and Steel P&F productivity decreased significantly as time buffer increased.

General Contractor Case Study (LPS® project):
- PPC increased and time buffer decreased over course of project.
- Electrical as top performing trade (lowest buffer/variation).
- Painting and Plumbing as trades needing most attention from management (highest buffer/variation).
- 4 week early completion on phase A/B resulting in 30:1 cost benefit ratio.
- Use of LPS® promoted open and consistent dialog between trades and resulted in higher predictability and a smoother workflow.
- By using collaborative planning, each phase (A/B and C/D) of the project was delivered ahead of schedule and with zero defects at substantial completion.
10) Through the use of a model survey, attempt to validate the SEM developed mental models of how construction personnel plan for uncertainty and allocate time buffer to construction project task durations.

Model survey to achieve validation and feedback of developed models for project managers and field level managers (64 surveys completed).

### 5.3 Intellectual merit and Broader Impact

This research takes initial steps into the topic of time buffer allocation to construction project task durations. No other research has specifically studied the causes of time buffer or modeled the effects of uncertainty on the allocation of time buffer. This topic is of significant importance in its relation to planning and the inherent complexity, uncertainty, and resulting variation in construction. Construction personnel at every level of management are constantly planning and trying to figure out how best to deal with the uncertainty and variability of construction projects. This research not only explored why time buffer is allocated but also how time buffer is allocated under different planning methods, by different trades, for varying activities, and proposed models to portray the mental thought process and allocation logic used by different levels of management.
The research has added to the body of knowledge pertaining to the allocation of time buffer to construction project task durations. It investigated the important questions of what are the causes of uncertainty or potential problem areas that construction personnel consider when adding time buffer to work plans or task durations and which are the most important from both a frequency and severity standpoint. Ideally, we would like to eliminate all of the uncertainty and variation associated with the different causes of buffer; however, in today’s construction industry environment of limited resources, the use of risk assessment and structural equation modeling in this research helped to prioritize the causes for management to address. Further, the research used a quantitative method to identify both trades and activities requiring management attention on the studied construction projects. The author was not the first to emphasize the need to “lower the river to reveal the rocks” but no other research has empirically provided evidence to the application of that phrase in time buffer and variation research. There is a saying that “a problem well identified is a problem half-solved”. In other words, understanding why time buffer is added and then quantifying the influence of different causes on the way construction personnel at various level of management buffer and plan for uncertainty will help construction companies take effective steps towards addressing those causes, managing uncertainty, and reducing the associated time buffer in construction projects. Understanding how the members of a team think and plan is critical to the success of a project.

Additionally, the use of lean construction planning techniques is one such philosophy aimed at reducing variation and the associated buffer through reliable planning. This
research investigated the effects of this additional planning on the amount of time buffer in construction project task durations as well as the impact on project performance.

The research analysis methods and results will have a broader impact. First of all, one of the author’s primary goals is that the participating companies benefit from the case study research. Several have already expressed the benefit of the continued research done in conjunction with N.C State University. The results of the case study as well as other information revealed during the research will help them focus their improvement efforts and in some cases may confirm suspicions they already had. The research’s applicability to military leadership and management (concerns/priorities at different levels in the chain of command) is of personal significance to the author and his career in the Air Force. The research methods and results have the ability to be applied in multiple other domains to include the military, air transportation, supply chain, and hospitals especially when considering different levels of management.

5.4 Recommended Future Research

In construction there exist multiple types and layers of buffer. The different project participants to include owners, architects and engineers, general contractors, sub or trade contractors, suppliers and all their project managers, superintendents, and foremen use different types of buffer such as money, inventory, capacity, plan, and time to reduce the impacts of uncertainty on a construction project as it transitions from initial owner thoughts into a design and ultimately to construction. Although they are all important areas for
research, the scope of this research was limited to the time buffer added to task durations by the project managers, superintendents, and foremen of general and subcontractors. Given the scope limitations discussed in the following sections, the research results will be relevant and the research method can be applied to other types of projects and trades with appropriate adjustment. While the author feels this research has achieved both breadth and depth in its goal to fill gaps in the body of knowledge related to the allocation of time buffer to construction project task durations, there are findings and related areas that warrant future research. The future research recommendations are:

1. The initial plan was to compare the allocation of time buffer in a project using LPS® to a similar project using traditional planning methods. The contractor for a comparison project fell through. The author feels such a comparison is important and would help to further support the benefits of using LPS®. Further, this research was limited to one general contractor case study and additional case studies with various trades and/or different companies should be conducted to validate or challenge the results of this research.

2. The process suggested for reducing buffer and variation has been illustrated by this research but empirical application of such an iterative process has not been conducted. It is recommended that a case study(ies) be conducted in which the causes and magnitude of time buffer and variation are documented and addressed phase to phase in an attempt to “move” a trade or activity from the upper right portion (high buffer and variation) of the two by two matrix to the lower left portion (low buffer and variation).

3. Further feedback and analysis of the mental models would be valuable and interesting. The research presents a first effort at the development of such planning models
and the author feels further validation is possible. From the data side, execution of the time buffer survey to a larger and new group of construction personnel would help validate or dispute the developed models. Similarly, the potentially adjusted models should be again presented for selection and feedback by construction personnel.

4. Data from LPS® projects has shown PPC levels above 70% but companies have seemingly not been able to go above 90%. Perhaps the additional cost of planning for the individual trades to increase PPC further would be more than the benefit or return on their investment. Even though it would benefit the project overall, trades may not want to make the additional effort, especially if other trades are not doing it either. Further research into the reasons for this limitation would be interesting.

5. This research has demonstrated both the allocation of time buffer as well as its effects on project performance. The research also demonstrated the reduction of time buffer associated with the use of collaborative planning techniques such as LPS®. The research did not determine what level of time buffer reduction is necessary or optimal given that uncertainty and the related variation can likely not be completely eliminated. This goes hand in hand with the question of “how lean is lean enough?” and should be targeted in future research.

5.5 Scholarly Contributions

5.5.1 Journal Papers

Based on this research, four papers have been written and planned for publication in the *Journal of Construction Engineering and Management*. The first paper has been
accepted for publication and the other three are all submitted and under review. The paper titles and publication statuses are provided below:

1. The Application of Time Buffer to Construction Project Task Durations (Accepted for publication)
2. Causes of Time Buffer and Duration Variation in Construction Project Tasks – A Comparison of Perception to Reality (Under revision for re-review)
3. Planning for Uncertainty – Use of Structural Equation Modeling to Determine the Causal Structure of Time Buffer Allocation (Submitted and awaiting reviewer comments)
4. Case Studies into the Allocation of Time Buffer and its reduction through the use of the Last Planner System® (Submitted and awaiting reviewer comments)

5.5.2 Conference Papers / Presentations

Initial versions of two planned journal papers were presented and published in various construction engineering related conference proceedings. They are listed below:

1. 20th Annual Conference for the IGLC (July 2012) in San Diego, California. A paper titled “Causes of Time Buffer in Construction Project Task Durations,” was presented and published in the conference proceedings.
REFERENCES


APPENDIX
Contractor General Information Survey

Thank you for taking the time to complete this survey. It should take you about 5 min to complete. The survey is completely anonymous. Your responses will be returned directly to N.C State University.

This survey should be completed by a superintendent, project manager, or someone else familiar with information regarding company size, project size, etc. The overall intent of this survey is to determine the company demographics associated with the completed contingency surveys. Provide what you feel is the best answer based on your personal knowledge and experience. Your responses will remain anonymous as your name and the name of your company are NOT included in the study. However, if you would like a copy of the survey results please write in your company name on the general information survey and package it with your company's completed contingency surveys. Please contact me via email if you have any questions or concerns. Thank you!

Mark Russell
PhD Graduate Student
Mann Hall - Room 208
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Raleigh, NC 27695-7908
mmrusse2@ncsu.edu
General Information Questions

*1. Please indicate what state you are currently working in.

State: ____________________________

*2. What best describes the type of company you work for?

☐ Subcontractor  ☐ General Contractor

*3. In which trade(s) or area(s) of construction does your company work?

☐ Piping / Plumbing  ☐ Drywall
☐ Mechanical / HVAC  ☐ Ceiling
☐ Electrical  ☐ Flooring
☐ Concrete  ☐ Painting
☐ Steel  ☐ Earthwork / Highway / Road Construction
☐ Roofing  ☐ Fire Protection

Other (please specify) ____________________________

*4. What size would you estimate your company to be (including both permanent and the average number of temporary employees)?

☐ Small (25 employees or less)  ☐ Medium (25-150 employees)  ☐ Large (more than 150 employees)

*5. What would you estimate the overall annual revenue of your company to be?

☐ < $100K  ☐ $5M - $15M  ☐ $100M - $200M
☐ $100K - $500K  ☐ $15M - $25M  ☐ > $200M
☐ $500K - $1M  ☐ $25M - $50M  ☐ I don't know
☐ $1M - $5M  ☐ $50M - $100M

*6. What would you estimate to be the average project size your company typically works on?

☐ < $100K  ☐ $5M - $15M  ☐ $100M - $200M
☐ $100K - $500K  ☐ $15M - $25M  ☐ > $200M
☐ $500K - $1M  ☐ $25M - $50M  ☐ I don't know
☐ $1M - $5M  ☐ $50M - $100M
7. What would you estimate the distribution of your company’s work to be? The total should add up to 100%.

- Public Sector / Government
- Private Sector / Commercial
- I don’t know

8. How would you describe your company’s backlog (i.e., how much pending work does your company have lined up)?

- Large backlog - work lined up for next 1-2 years
- Moderate backlog - work lined up for next 6 months to 1 year
- Little to no backlog - less than 6 months of future work lined up
- I don’t know anything about the company’s backlog

9. Does your company use the Last Planner System (Lean construction management tool) on your projects?

- Always
- Sometimes
- Never

10. If you answered ALWAYS or SOMETIMES in Questions #9, how long has your company been using the Last Planner System?

- < 1 year
- 2 - 5 years
- > 5 years
- I do not know
Wrap Up

******************************************************************THIS CONCLUDES THE SURVEY******************************************************************

Thank you for your time and input. If you would like a copy of the results, please contact me via e-mail. Once again, please return this completed general information survey along with the contingency surveys to me at the address below by 30 Sept 2011.

Sincerely,
Mark Russell
PhD Graduate Student
Mann Hall - Room 208
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Raleigh, NC 27695-7908
mmrussel@ncsu.edu
Survey Introduction

Thank you for taking the time to complete this survey. It should take you about 15-20 min to complete. The survey is completely anonymous and your responses will be placed in the provided self-addressed envelope and returned to N.C State University.

The overall intent of this survey is to determine how the uncertainty and potential for problems due to different factors influence task duration estimates.

The survey addresses the following objectives:

1) Identify the most prevalent types of factors causing uncertainty in task duration estimation

2) Determine differences of opinion/perception between how foremen, superintendents, and project managers view the factors/impacts of uncertainty in task duration estimation.

Instructions are included throughout the survey to clarify what is being asked of you. Simply provide what you feel is the best answer based on your personal experience and/or opinion. Your responses will remain anonymous as your name and the name of your company are NOT included in the study. If you would like a copy of the survey results, simply contact me via email.

Mark Russell
PhD Graduate Student
Mann Hall - Room 208
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Raleigh, NC 27695-7908
mmrusse2@ncsu.edu
Section 1: General Information

1. Please indicate what state you are currently working in.
   State: 

2. What best describes the type of company you work for?
   - Subcontractor
   - General Contractor

3. Which best describes your job position / duty?
   - Supervisor / Foreman / Trade Lead
   - Superintendent
   - Project Manager

4. Which trade(s) or area(s) of construction best describes your work?

<table>
<thead>
<tr>
<th></th>
<th>Piping / Plumbing</th>
<th>Mechanical / HVAC</th>
<th>Electrical</th>
<th>Concrete</th>
<th>Steel</th>
<th>Roofing</th>
<th>Drywall</th>
<th>Ceiling</th>
<th>Flooring</th>
<th>Painting</th>
<th>Earthwork / Highway / Road Construction</th>
<th>Fire Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxes</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other (please specify) 

5. What is your experience level? (Years of experience - round to nearest number of years)

   - In the construction industry 
   - In your current position 

6. What is the minimum and maximum crew size you supervise/manage?

<table>
<thead>
<tr>
<th>Crew Size</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. How many hours of overtime does your crew typically work in a week? Assume 40 hours is a standard week and anything over that is overtime.

   

8. Do you typically work on projects using the Last Planner System (Lean construction management tool)?
   - Always
   - Sometimes
   - Never
Section 2: Overall Category Comparison

The purpose of this page is to compare nine different areas by rank ordering them based upon how uncertainty in each of the areas contributes to how you determine your task duration estimates. Think about when you are making a work plan or estimating the duration of a specific task, and consider the uncertainty or potential issues/problems you face in each of these nine areas in that process. From your experience and in your opinion, uncertainty in which areas is the most critical when budgeting time into a task duration estimate?

The nine areas, along with a general description of each, are:

1) Project Characteristics: Pertains to characteristics specific to the project and your trade such as contract delivery method, contract period, size & complexity of the project, the size of your company, the complexity of the task for your trade.

2) Prerequisite Work: Pertains to items that must be completed before you can start your task. If there is concern the item (permits, a prerequisite task, or rework on a prerequisite task) will not be completed on time, then consider to what extent your duration estimate is affected. Another way to think about this is confidence in the work plan.

3) Detailed Design / Working Method: Pertains to having an accurate and available design/drawing and a feasible working method. Uncertainty here is related to constructability, design errors/omissions, poor performance due to unfamiliarity, specification and quality requirements, and task repitition.

4) Labor Force: Pertains to availability, reliability, and capability of the labor force to complete the required task as well as wanting to avoid using more manpower which could create inefficiencies.

5) Equipment & Tools: Pertains to availability, reliability, and capability of required equipment and tools to complete the task.

6) Material & Components: Pertains to receiving correct and necessary materials from supplier when and where you need them (trust/confidence in your supplier(s)).

7) Work/Josbite Conditions: Pertains to the physical space available to perform your job in regards to overcrowdedness, clutter, required method & distance of material transfer, and access.

8) Management/Supervision/Information Flow: Pertains to your trust in the superintendent, project manager, and owner; communication between the various project players; changes in the scope; the RFI process; liability pressure (LD’s, contractual deadlines, etc.); duration negotiation preparation (knowing management will request task be done in shorter duration); and positive company recognition (i.e. for completing work as promised).

9) Weather: Pertains to the climate at the location of the project and what weather conditions are prevalent such as temperatures, rain, and wind.
1. Please rank order the nine overall categories based upon how much you feel the uncertainty or potential for problems in each area contributes to the duration you estimate a specific task will take.

For example, if your greatest uncertainty or concern compared to the others is with your supplier’s ability to get you the right material in the right amount at the right time, then you would rank materials and components as #1 of the nine areas. #1 will be the area with the highest uncertainty (greatest influence or area you consider the most when developing an activity duration estimate), and #9 will be the area with the lowest uncertainty (least influence or area you consider the least when developing an activity duration estimate).

Note - please only use each number (#1-#9) once when completing the ranking.

<table>
<thead>
<tr>
<th>Rank of Importance</th>
<th>Do you feel the uncertainty associated with this category is under your responsibility to control or mitigate? (Yes or No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Characteristics</td>
<td>☐</td>
</tr>
<tr>
<td>Prerequisite Work</td>
<td>☐</td>
</tr>
<tr>
<td>Detailed Design/Working Method</td>
<td>☐</td>
</tr>
<tr>
<td>Labor Force</td>
<td>☐</td>
</tr>
<tr>
<td>Equipment &amp; Tools</td>
<td>☐</td>
</tr>
<tr>
<td>Material &amp; Components</td>
<td>☐</td>
</tr>
<tr>
<td>Work/Jobsite Conditions</td>
<td>☐</td>
</tr>
<tr>
<td>Management/Supervision/Information Flow</td>
<td>☐</td>
</tr>
<tr>
<td>Weather</td>
<td>☐</td>
</tr>
</tbody>
</table>
**Section 3: Factors Influencing Duration Estimates**

**INTRODUCTION / PURPOSE:**

This final section expands the 9 categories you ranked in section 2 into 47 overall factors which can potentially influence or impact your activity duration estimates. Uncertainty is part of the nature of construction and can lead to variation. Uncertainty or a potential for problems related to these 47 factors can lead to variation in the activity start times and durations. The purpose of this section is to find out which factors influence the way you estimate activity durations and to what degree.

**STEP 1:**

Review the 47 factors broken out by category and determine which factors you've considered or have influenced you in your experiences estimating activity durations as a foreman, superintendent, or project manager.

**STEP 2:**

For the factors which you've considered or have influenced you, consider how often the factor influences your duration estimate by circling one of the seven responses: never, rarely, occasionally, sometimes, frequently, usually, or always.

**STEP 3:**

For each factor you consider, answer the step 3 question for a typical two week (10 day) activity by circling one of the seven responses (0, 0.5, 1, 2, 3, 5, or 7 days). You most likely consider multiple factors at once when estimating your activity duration; however, for the purposes of the step three question, "How much time (days) would you add for this factor?", please consider the factors independent of each other. In other words, assume the factor you are considering is the only source and cause of uncertainty or potential variation in your hypothetical 10 day activity. Given uncertainty or potential for problems in that factor alone, estimate how much time you would include/allocate in your duration estimate to protect against the effects of the uncertainty in that factor.
### 1. Factors Related to Project Characteristics

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does the factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract Delivery Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contrast Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of the Project</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complexity of the Project (Interdependence of Activities)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complexity of the task for your trade (degree of difficulty/inherent nature of your work)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of your company</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2. Factors Related to Prerequisite Work (Confidence in the work plan)

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delays in obtaining permits for a specific part of the task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion of previous work (prerequisite task)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rework being required due to quality of previous work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delays in inspections for previously completed work</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3. Factors Related to Detailed Design and Working Method

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Constructability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of Documents (Design Errors/Omissions/differing site conditions and other design issues requiring additional time or an RFI to resolve)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor performance due to unfamiliarity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strict specification requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality control requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low degree of repetition in your tasks (inability to develop efficient system due to task constantly changing)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 4. Factors Related to Labor

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of your labor force (concerns about absenteeism or people arriving late and/or leaving early due to illness, injury, family, or personal situation)</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Availability of your labor force (crew size limitations due to other tasks/projects)</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Inefficiencies in your crew due to lacking experience/skills</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Concerns about being pushed into using more manpower and creating inefficiencies</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Low morale or lack of motivation</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Language barriers among workers/supervisors</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

### 5. Factors Related to Equipment and Tools

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of your trade’s equipment and/or tools (tendency to breakdown, old/worn out inventory)</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Availability of your trade’s equipment and/or tools (inventory maintained by your company)</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Capability (productivity) of your trade’s equipment and tools</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Time required to repair equipment if breakdown occurs</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Time required to replace equipment if breakdown occurs</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

### 6. Factors Related to Materials and Components

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving incorrect quantity of materials</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Receiving incorrect or damaged materials</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Receiving materials for a task later than expected/planned</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
### 7. Factors Related to Work: Jobsite Conditions

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overcrowded or cluttered work area/jobsite congestion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult access to work area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method of material transfer required from receiving area to task location (i.e., crane, construction elevator, hand carry)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance of material transfer required from receiving area to task location (i.e., one story versus ten story project)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 8. Factors Related to Management, Supervision, and Information Flow

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidence in Request For Information (RFI) process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liability Pressure (liquidated damages, contractual deadlines, etc)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparing for Negotiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive Company Recognition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trust in Superintendent (based on their reputation, experience, knowledge, and/or experience you’ve had with them)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trust in Project Manager (based on their reputation, experience, knowledge, and/or experience you’ve had with them)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trust in Owner (based on their reputation, experience, knowledge, and/or experience you’ve had with them)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required coordination with other trades</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in scope of work (tendency of owner to make changes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication bw Owner/Engineer and Project Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication bw Project Manager and Foreman</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication bw Foreman and Workers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 9. Factors Related to Weather

<table>
<thead>
<tr>
<th>Factor</th>
<th>How often does this factor influence your duration estimate?</th>
<th>How much time (days) would you add to a 2 week (10 day) activity to account for this factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate (weather conditions such as temperature, rain, and wind associated w/ the location of a project)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This concludes the survey.

Thank you for your time and input. If you would like a copy of the results, please contact me via e-mail. Once again, please return the completed survey to me at the address below by 31 August 2011.

Sincerely,
Mark Russell
PhD Graduate Student
Mann Hall - Room 208
Department of Civil, Construction, and Environmental Engineering
North Carolina State University
Raleigh, NC 27695-7908
murusse2@ncsu.edu