A RESEARCH SYNTHESIS ON THE INTERFACE BETWEEN LEAN CONSTRUCTION AND SAFETY MANAGEMENT

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ABSTRACT

Applying lean construction practices to safety management is a promising research area and has been discussed by multiple authors. Some researchers propose that the reduction of occupational hazards is a naturally occurring effect of the implementation of lean practices. To further understand how lean practices affect project safety performance, an interaction matrix between lean construction and safety management practices was developed by performing a research synthesis and validating the synthesis with structured interviews. The variables analyzed in this interaction matrix were elements of the lean production system such as the last planner system, autonomation, and standardization, and the most common safety management practices such as planning and staffing for safety. The interface between lean construction and safety management was systematically analyzed by assessing the conclusions from previous investigations. The results indicate that there is a significant amount of evidence of synergy between lean production practices and safety management practices. For example, project-specific safety objectives can be incorporated in the lookahead planning process, and autonomation could be directly extended to worker involvement in such a way that workers can stop production whenever they feel in danger, among others. This evidence, along with the results obtained from the analysis of the interaction matrix, can also help to develop and integrate future production and safety management models.

KEY WORDS

Lean Construction, Last Planner, Safety Management, Research Synthesis, Interaction Matrix

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INTRODUCTION

The construction industry has long been reputed for its high accident rates when compared with other industries. It is one of the most dangerous industries worldwide consistently accounting for the highest fatality rates. The International Labor Organization (ILO) has made a conservative estimate claiming that at least 60,000 people are being fatally injured every year on building sites worldwide (ILO 2003). Furthermore, in 2005 alone, the construction industry shared 1,243 (21.7 %) of the total 5,734 work-related deaths from injuries in the US, while making up only 8% of the overall workforce (CPWR 2008). Recent investigations have studied how safety performance is affected by the implementation of lean practices and have shown that they both improve the efficiency of production sites and result in favorable safety outcomes (Thomassen et al. 2003; Saurin et al. 2004; Nahmens and Ikuma 2009; Leino et al. 2010).

Minimizing waste in a production system is one of the cornerstones of lean production. Improved safety performance, such as reduced injury and fatality rates, is an example of waste reduction. Accidents result in reduced efficiency of a process, resulting in non-value-adding events in a production system. Since lean principles aim at reducing waste, it would be prudent to assume that the reduction of occupational hazards is a naturally occurring outcome of the implementation of lean construction principles.

The purpose of this paper is to discuss the relationship between lean construction strategies and construction safety management practices. The underlying relationship between the lean practices and safety has yet to be explored. Thus, the topic is still in its infancy and needs to be addressed because it may help the industry to simultaneously improve productivity and safety performance.

LEAN CONSTRUCTION

Lean production emerged from the ongoing development of alternatives to mass production. Its primary foundation, however, has been accredited to the principles of the Toyota Production System (TPS). The term ‘lean’ itself was so given in part to counterpose the new production system to ‘mass’ production (Ballard 2000). Koskela’s ground-breaking report challenged the construction industry to explore and adopt the new concepts and techniques of this new production philosophy in order to examine it as an alternative to the traditional production system for construction (Koskela 1992). Based on the principles of lean production and its implementation in the construction industry, the last planner system has been established as one of the most effective lean construction tools (Ballard 2000).

THE LAST PLANNER SYSTEM

The Last Planner System (LPS) of production control has been established as an effective methodology that improves efficiency by stabilizing the workflow in construction sites. A concise summary and description of the most important elements of LPS identified in this study is provided in Table 1.

Table 1: Elements of the Last Planner System

Element	Description	Key
Lookahead Process	The lookahead process is the second level of planning that expresses what CAN be done after the master plan defines what SHOULD be done.	**T1**
Constraint Analysis	Constraint analysis consists of determining the activities that must be completed so that each assignment can be executed.	**T2**
Backlog of "Ready-Work"	Once all constraints have been removed for each assignment, the activities are then put into the workable backlog from which the last planners can establish the weekly plan.	**T3**
Last Planner Process	The last planner process establishes weekly commitments to production (what WILL be done) based on the workable backlogs produced in the lookahead process.	**T4**
PPC Measurement	The Percent Plan Complete (PPC) consists on systematically comparing the plans committed to the plans executed. This measures the extent to which the front line supervisor's commitment (WILL) was realized and becomes the reliability performance indicator.	**T5**
Root Cause Analysis	The root causes for nonconformance are tracked and analyzed in order to develop a future plan and prevent it from happening in the future, so that improvements can be made.	**T6**

LEAN PRODUCTION

Based on the concepts of lean production several principles, methods, and tools were developed revolving around the primary goal of eliminating all waste. The main objective of TPS is to produce the products that the client demands with the best quality, lowest cost, shortest lead time, best safety and high morale. In order to accomplish such goals, Just-In-Time (JIT) delivery and Jidoka must be implemented in the production process. JIT is a set of tools and techniques that allows a company to produce and deliver products in small quantities, with short lead times, to meet specific customer needs. JIT allows for "the delivery of the right items at the right time in the right amount" (Liker 2004, p. 33). Jidoka, the Japanese term for autonomation is a concept that consists on never letting a defect pass into the next station within a production process and allowing machines or workers to stop production whenever something unusual or defective is detected (Liker 2004). A summary of the most common lean production practices is provided in Table 2.

Table 2: Lean Production Tools

Tool	Description	Key
Just-In-Time	Just-In-Time (JIT) consists on producing and delivering products in small quantities, with short lead times, to meet specific customer needs	**T7**
Autonomation	Autonomation consists on never letting a defect pass into the next station allowing machines or workers to stop production whenever something unusual is detected.	**T8**
Production Leveling	Production leveling reduces variability and inconsistency during production.	**T9**
Standardization	Standardization involves using stable, repeatable methods everywhere to maintain the predictability, regular timing, and regular output of processes.	**T10**
Continuous Improvement	Continuous improvement is the process of making continuous internal, incremental, and iterative improvements to a process.	**T11**

SAFETY MANAGEMENT

In 2008, the US construction industry had a fatality rate of 9.7 per 100,000 workers, while the all-worker average was 3.6. Falls and electrocutions have been identified as the leading causes of fatal injuries in the construction industry, whereas being struck by an object, falls to lower levels, and over exertion in lifting remain the leading causes of nonfatal injuries (CPWR 2008). The dynamic and unpredictable construction tasks and environments, combined with the high production pressures and workload, create a high likelihood of errors, which leads to accidents (Mitropoulos et al. 2007). Safety performance in the construction industry has improved in the past two decades, but it has reached a plateau, as recent statistics suggest (ILO 2003; CPWR 2008).

CII released its report titled Zero Injury Techniques (CII 1993) which presented the results from a safety study that had identified five strategies as the most successful accident prevention techniques being used to achieve the "zero accident" objective. This study was followed by a validation study (Hinze and Wilson 2000) to examine changes made since its publication. The results of this study identified nine key practices, or areas, that contribute to improved safety performance. The most prevalent safety management practices that have been identified to analyzed in this study. The key safety practices are described in Table 3.

Table 3: Safety Management Practices

Practice	Description	Key
Management Commitment	Top managers must be actively involved in worker safety at the project level to exert a strong influence on establishing the project safety culture.	**S1**
Staffing for Safety	Staffing for safety implies that the right people, methods, and resources are used to ensure safety on a construction project. The appropriate staff ensures that safety needs are being satisfied.	**S2**
Planning for Safety: Pre-Project and Pre-Task	Pre-project planning (longer-term) establishes and communicates project-specific safety goals, plans, and policies before the construction phase of the project. Pre-task planning (shorter-term), such as JHA's, ensures that tasks are performed with safety integrated into the daily work routine.	**S3**
Safety Education: Orientation and Specialized Training	Knowledge about performing tasks safely is vital to worker safety. There are a variety of ways that this knowledge can be instilled, but training is perhaps the most effective means. Training covers a wide variety of topics, each of which may directly influence safety performance when performing a given task.	**S4**
Worker Involvement	This is essentially based on the view that workers are not just a valuable resource to be protected but also a resource that can contribute to achieving the goal of zero accidents.	**S5**
Evaluation and Recognition	In order to encourage safety performance, reinforcing such behavior is a key element. If workers are evaluated and/or recognized for safe behavior, then workers will seek to repeat that performance.	**S6**
Subcontractor Management	If a safety program is to be effective, it must involve the subcontractors. They should be included in the orientation training, the drug testing and the safety planning among other activities. All parties must comply with the same safety guidelines including employees of the subcontractors.	**S7**
Accident Investigation	Accident investigations are important for identifying the root causes of injuries in order to devise effective preventative measures. Many companies include near misses also, indicating proactive measures.	**S8**

EMERGING RESEARCH LINKING LEAN AND SAFETY

Nahmens and Ikuma (2009) showed that lean strategies encourage less material in the work area, an orderly and clean workplace, and systematic workflow. Therefore, it could be expected that standardizing, systematizing and regularizing production leads to better safety. Poor safety is considered a form of waste because, from a lean perspective, incidents that disrupt the flow of work or lead to injuries are waste (Howell et al. 2002). Furthermore, injuries are costly not only in terms of human suffering, but also in terms of worker compensation costs, lost time, lost productivity, and higher employee turnover (Saurin et al. 2004). Safety should not be treated as a separate subject from production, for it is an integral part of every production process; safety depends on every action, material, and person used in a work process (Nahmens and Ikuma 2009). Typical production planning decisions, which determine what will be done, when, how and by whom, are the basis to establish preventive measures (Saurin et al. 2004). As Leino et al. (2010) explains, safety shall be treated as another one of the performance variables targeted by production management along with cost, time, and quality. From a lean perspective, safety management is about managing uncertainty given that it enables proactive planning, helping to reduce workflow variability.

POINT OF DEPARTURE

It is evident that many of the new proposed approaches to construction safety within the paradigm of lean need to be further assessed and are topics that are still in their infancy. There is a lack of in-depth conceptual discussions on the interface between lean construction and safety management. This will provide a basis for the discussion of the strong correlation, which may or may not exist, between lean practices and safety performance in construction. A framework that reiterates the interactions between aspects of lean construction and safety management would enable an in-depth conceptual discussion on this interface. The results from this can provide evidence to promote and demonstrate the value of lean construction in construction safety, yet another aspect of significant importance to construction projects, and can also help to develop and integrate future production and safety management models.

METHODOLOGY

A research methodology approach known as a research synthesis has been implemented in this investigation. This approach closely examines previous studies related to the topic at hand and it has been used to combine qualitative data related to the interface between lean construction and safety management. This helped to recognize and understand the interface between lean and safety. Empirical studies were also inferred as supporting evidence for the interactions identified and how the implementation of lean results in improved safety performance. This approach was inspired by two similar studies to the one being undertaken (Martinez et al. 2009; Sacks et al. 2010). Martinez et al. (2009) integrated the principles of sustainable construction (green building) and lean construction to develop a “Green-Lean” conceptual integration, while Sacks et al. (2010) similarly has analyzed the interaction between lean construction and Building Information Modeling (BIM).

DATA COLLECTION AND ANALYSIS

Previous studies that have considered the interaction between lean construction and safety were the focus of this study. The advantages of using these data was that it enabled the possibility of obtaining not just the results from similar studies, but also the language and words of the authors of these studies, which represents data that has given a thoughtful input and a great deal of attention to compile. The data was thoroughly collected in an iterative process to develop a fine framework, more specifically an interaction matrix that encompasses across all of the possible interactions between the lean construction tools and the most common safety management practices (Table 4).

Table 4: Interaction of Lean Construction Tools and Safety Management Practices

Lean Construction Tools		**Last Planner System**						**Lean Production Tools**				
		Lookahead Process	Constraint Analysis	Backlog of Ready-Work	Last Planner Process	PPC Measurement	Root Cause Analysis	JIT	Autonomation	Production Leveling	Standardization	Continuous Improvement
Safety Management Practices		**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**
Management Commitment	**S1**	1	1		5					14	16	18
Staffing for Safety	**S2**	2	3		6			11		11		
Planning for Safety	**S3**	2	3	4	6			11		15	16	20
Safety Education	**S4**								12		17	18
Worker Involvement	**S5**				7	8	9		13		17	19
Evaluation and Recognition	**S6**					8	9					20
Subcontractor Management	**S7**	1	1		5						16	
Accident Investigation	**S8**						10				16	

The extent of this study was rather to identify the most important and obvious interactions, provide the supporting evidence from the research synthesis, and identify the most significant interactions in the interaction matrix developed. Also, it is important to note that this study provides the evidence for the potential synergy between lean construction tools and the most common safety management practices. The term *tools* has been implemented and used throughout the research to describe the lean concepts and practices, given that these are the *means* to accomplish lean construction. The interaction matrix initially identified a total set of 88 possible interactions, from which 41 have supporting evidence, which are the interactions with an index number noted in the matrix. These interactions with supporting evidence were identified from 11 previous studies. Note that the research focuses mainly on evidence available in literature.

DISCUSSION AND RESULTS

Table 4 displays an index number correlated with the interactions found in the evidence, which identify the explanation of each interaction along with its supporting evidence in a separate table. Due to the space limitations of this paper, the following will discuss a few of the most salient interactions identified per tool (T1-T11) with the safety management practices (S1-S8). For a complete discussion of the results of this investigation, including a validation with an expert panel, and the other supporting tables, see Antillón (2010). To maintain brevity, the details of the interviews are not discussed in this paper. In the following text, the publications supporting the statements made are provided in brackets at the end of the section. The reference numbers correspond to the reference section at the end of the paper.

LOOKAHEAD PROCESS - INTERMEDIATE PLANNING (T1)

Several of the strategies implemented by LPS can be easily extended to safety planning, thus directly affecting the effectiveness of safety programs. One of the main goals of the lookahead process is to shape the work flow sequence and rate. In terms of pre-project planning for safety, this allows to establish more reliable project-specific safety resources for a given time period during a project and thus staff for safety accordingly. [13] [21]

CONSTRAINT ANALYSIS (T2)

Constraint analyses determine what must be done for a given work assignment before execution. By freeing any constraints identified, this allows to execute the assigned task. A constraint analysis can systematically include safety constraints, such as job hazard analyses, directly incorporating pre-task planning for safety as part of the constraint analysis process. By performing safety constraint analyses similarly as part of the production planning, risk can also be predicted better, which in turn allows safety management to allocate, or staff, safety resources accordingly. [13] [20] [21]

BACKLOG OF READY-WORK (T3)

A workable backlog consists on having a list of the tasks that have gone through the constraint analysis and are ready to be performed with the assurance that everything is indeed workable. This idea can be easily extended to safety planning. A checklist of soundness requirements that an assignment must go through is usually what determines whether the assignment can be considered workable or not. Safety could be included as part of these preconditions. [21] [24]

LAST PLANNER PROCESS - WEEKLY PLANNING (T4)

At this planning level, the actual workers, such as the foreman and other people working on site (the last planners), play a significant role in planning. Worker involvement is directly incorporated at this level to determine what *can* actually be done (what *will* be done) in terms of the previously defined tasks with the workers' perception of the work reliability. This is often referred to as a bottom-up perceptual approach which can also be extended to safety by allowing the workers to determine whether a task is reliable in terms of safety. [13] [21] [24]

PPC MEASUREMENT (T5)

The Percent Plan Complete (PPC) measurement consists on systematically comparing the plans committed to the plans executed in a project. The safety planning and control (SPC) model proposed by Saurin et al. (2004), which integrates safety management to the production planning and control process extends this concept to safety performance measurement in order to evaluate safety effectiveness. Using a similar measurement for safety the percentage of safe work packages (PSW) carried out is measured, which can directly evaluate worker's safety performance. [21]

ROOT CAUSE ANALYSIS (T6)

Investigating root causes for accidents or near misses, which may or may not be the root causes for nonconformance with the assignments, safety management may proactively devise effective preventive measures. When root cause analyses are carried out, similarly causes for successful performance and safe work behavior, rather than just causes for non-conformance might also influence workers perspective on safety by recognizing "causes for conformance." [21] [22]

JUST-IN-TIME (T7)

The delivery of the right safety resources, such as appropriate safety personnel and personal protective equipment, at the right time, when risk levels are higher for example, and in the right amount, can directly impact safety planning and staffing for safety. Tools implementing the JIT concept help to forecast safety risks and therefore management can allocate safety resources when and where they are needed, leveling safety risk. Instead of allocating safety management efforts with the traditional "push" approach, a more effective and less wasteful "pull" approach implementing JIT can significantly impact planning and staffing for safety. [19] [20]

AUTONOMATION (T8)

Autonomation in itself applies the same concept that worker involvement strategies for safety implement, that is, the use of the worker's perception and input for evaluating the aspects of safety programs. Therefore, autonomation can directly be extended to worker involvement in such a way that workers can stop production whenever they feel in danger. Proper safety training for workers to recognize such hazards is also essential for autonomation to impact safety management. The appropriate training for workers to make the right judgment when they feel in danger would help in maintaining a desired level of risk or risk averseness. [16] [22]

PRODUCTION LEVELING (T9)

Through proper production leveling the appropriate resources can be matched to production demands without exceeding the capabilities of the workers. This reduces the chances of construction accidents while at the same time increasing productivity. This impacts planning and staffing for safety strategies, and also shows management's commitment to try and improve safety performance while at the same time reducing waste from a lean perspective. [7] [17] [19] [20]

STANDARDIZATION (T10)

Standardization implies that procedures may reduce the degrees of freedom of workers and define a space of safe performance where accidents will not happen. The fact that upper level management standardizes safety related procedures communicates the importance of working safely to all workers and improves project safety culture. Similarly, procedures can emphasize the importance of proper safety training, the incorporation of safety plans, expected safety outcomes for the workers and subcontractor procurement based on safety records, among others. Another very important aspect of safety management that can be standardized is accident investigation, which may also include things such as near misses. [16] [22]

CONTINUOUS IMPROVEMENT (T11)

Applying such strategy for many of the safety management practices with the goal of achieving better results every time can significantly improve the effectiveness of many of these safety efforts. It can be reasoned that in order for continuous improvement to be implemented within a company in the first place, it must be expressed from upper management. Associated tools that implement continuous improvement, in addition to many of the other lean production tools, such as 5S and visual management, foster a culture of continual improvement, which is essential for the successful implementation of lean. Visual management can be extended for safety purposes using things such as safety signs and boards displaying current accident rates allowing all workers to identify issues, thus providing an opportunity to be trained, the boundaries for safe performance and compare the expected safety performance. [6] [18] [22]

CONCLUSION

The results demonstrate that several lean construction tools are related, directly or indirectly, to some of the most common safety management practices that are implemented in the industry today. The last planner system shows that, if applied correctly and implementing all of its elements, the principles of lean construction can be successfully accomplished. Furthermore, there are opportunities to include safety management into the system and improve safety performance in the same way that the last planner system improves production performance. In fact, it almost seems unreasonable not to integrate or include safety with production planning, given its importance in today's industry. Along with cost, time, and quality, safety shall be treated as another one of the performance variables targeted by production management. The interaction matrix, along with the explanations of the interactions, can be used to further investigate this specific issue, or help with the realization of the potential synergy that is obviously present between lean construction and safety management.

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