

Intersection between Lean Construction and Safety Research: A Review of the Literature

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Abstract

Occupational accidents are wasteful and non-value-adding (NVA) events in any form of production system. Since Lean principles aim to reduce NVA elements of work processes, it follows that safeguarding construction workers from occupational hazards would be a natural outcome of the Lean Construction ideal of waste elimination. A literature review of the conference proceedings of the International Group for Lean Construction (IGLC), from 1998 to 2008, was conducted to summarize the research pertaining to safety management. A search of key words pertaining to safety was employed to identify seventeen articles that addressed safety management and its relationship to lean construction principles and practices.

Keywords

Safety, lean construction, production planning, cognitive systems engineering.

1. Introduction

Improving occupational safety in the construction industry is essential, not only because enlightened clients demand excellent safety performance from contractors/builders, but also due to continuous search for more economic benefit and increased productivity. Economic pressures on construction firms to increase productivity can lead to increased exposure to new risks, such as increased accident and injury rates [16]. Coupled with the organizational pressure for productivity, the individual motivation of the workers to minimize effort, push them to the brink of safe working zone [6]. Furthermore, the dynamic, complex, and often unpredictable construction tasks and environment add to the risks. Thus, improving safety in construction remains a priority in almost every country around the world, because the construction industry stands out among all other industries as the main contributor to severe and fatal accidents [16]. While there have been improvements in occupational safety outcomes over the last few decades, the construction industry remains the sector with the greatest number of fatalities. A Center to Protect Workers' Rights [5] report states that the fatality rate in construction industry accounts for an annual total in excess of 1,000, which is more than three times the fatality rate of the manufacturing sector. The report also states that there are more than 182,000 serious injuries annually in construction.

The loss or injury of trained and experienced workers, and the resulting disruption to progress of work, undeniably represent waste in the performance of construction. When left uncontrolled, these factors can create disruption due to many cost related factors; such as escalating workers' compensation insurance costs, high cost of medical treatment and rehabilitation program. The economic losses also include indirect losses such as administrative cost, productivity losses and low morale. It follows, then, that safeguarding construction workers from occupational hazards would be a natural outcome of Lean Construction ideal of waste elimination [2].

2. Lean Construction

In the past two decades, researchers have been investigating the impact of Lean Construction principles on the construction industry. In 1992, Lauri Koskela expressed the need for a production management theory in construction and put forth the TFM theory of production to overcome the shortcomings in existing planning, execution, and control paradigms as advocated by contemporary project management theory [7].

The lack of stability in the construction processes which is a project based production system, began to fade away as a result of search into the production paradigms utilized in the manufacturing industries such as craft, mass, lean production paradigms as well as value management perspectives. Koskela conceptualized production system “simultaneously from these three points of view: transformation, flow, and value.” [9]. The TFM theory of production encompasses the attributes of various production paradigms and considers transformation, flow and value generation as complementary rather than competing theories of production [8]. Specifically, craft production embodied the transformation view, while mass and lean production embodied the flow view and the value generation of production process was inspired by the transformation and flow paradigms [3].

Koskela and Howell found that project management is based on a theory of project and a theory of management. “Project management seems to be based on three theories of management: management as planning, the dispatching model, and the thermostat model.” [9]. They mentioned that the existing constructs of management theory namely, planning, execution and control were deficient for managing project-based production system and thus suggested the New Project Management theory. The management theory (of the New Project Management theory) encompasses management as organizing along with management as planning, language/action perspective along with dispatching model, and scientific experimentation model along with thermostat model. Following this, the TFM theory and the New Project Management theory are combined which resulted in the constructs of the paradigms for Lean Construction in terms of new production and management theories as shown in Figure 1.

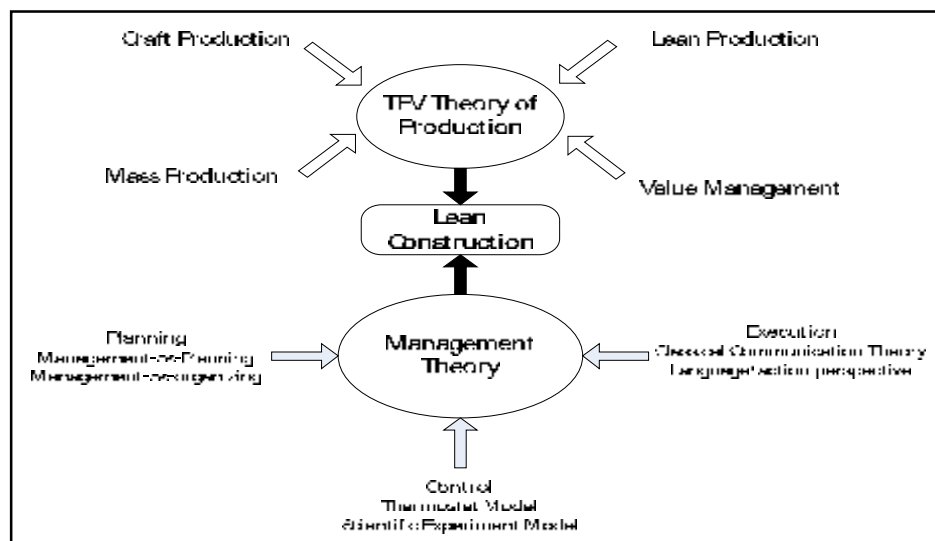


Figure 1: Lean Construction theory in terms of new production and management theories [3]

3. Safety and Lean Construction

Since the initiation by Koskela in 1992, researchers working closely with practitioners have been investigating the theory, principles, and techniques of Lean Construction. These efforts cover a wide range of topics and the International Group for Lean Construction (IGLC) has become a platform to showcase all these research efforts. This paper reviews the conference proceedings for IGLC from 1998 to 2008 with the objective to find out how researchers have looked into managing safety within Lean Construction paradigm. The keywords indicated by the

authors of IGLC conference papers are selected as recording unit to identify papers pertaining to safety of construction. Since IGLC allows authors to define keywords on their own, study of keywords will provide a sufficient perspective into the papers that have investigated various aspects of safety in construction. However this approach of filtering literature on the basis of keywords, takes into account the bias established by the authors while selecting the keywords. Alves and Tsao [4] have clustered the keywords used in the papers published in IGLC conference proceedings under major research topics that interest the Lean Construction community. The same set of keywords with slight modification was used in this paper. A total of seventeen papers were identified from the IGLC conference proceedings within the time frame of 1998 to 2008 through the keyword search as shown in Table 1. Four themes emerged, upon review of the papers: safety through production planning, performance measurement of safety, forecasting risk levels, and new approach to construction safety.

Table 1: Papers related to safety in construction from IGLC Conference proceedings (1998 to 2008)

		List of Keywords												
Year	Authors	accident	accident theory	boundaries	construction safety	hazard	hazard identification	macro-ergonomics	occupational ergonomics	occupational safety	safety in constr.	safety mgt.	safety training	risk/ risk tolerance
2001	Saurin, T. A., Formoso, C. T., and Guimaraes, L. B. M. [26]							x		x				
2002	Howell, G. A., Ballard, G., Abdelhamid, T. S., and Mitropoulos, P. [10]	x	x			x				x				x
2002	Saurin, T. A., Formoso, C. T., Guimaraes, L. B. M., and Soares, A. C. [27]									x				
2002	Abdelhamid, T. S., and Everett, J. G. [1]								x		x			
2003	Mitropoulos, P., Howell, G. A., and Reiser, P. [16]										x			
2003	Abdelhamid, T. S., Patel, B., Howell, G. A., and Mitropoulos, P. [2]	x								x	x		x	
2004	Saurin, T. A., Formoso, C. T., and Cambria, F. B. [28]												x	
2004	Marosszeky, M., Karim, K., Davis, S., and Naik, N. [15]										x			
2004	Walsh, K. D., and Sawhney, A. [33]										x			x
2005	Sacks, R., Rozenfeld, O., and Rosenfeld, Y. [24]					x							x	x
2005	Saurin, T. A., Formoso, C. T., Cambraia, F. B., and Howell, G. [29]			x									x	
2006	Saurin, T. A., Formoso, C. T., and Cambraia, F. B. [30]											x		
2006	Narang, P., and Abdelhamid, T. S. [19]	x			x		x			x				
2007	Salem, O., Lothlikar, H., Genaidy, A., and Abdelhamid, T. S. [25]	x												
2007	Razuri, C., Alarcón, L. F., and Diethelm, S. [23]												x	
2007	Mitropoulos, P., Cupido, G., and Namboodiri, M. [17]											x		
2008	Schafer, D., Abdelhamid, T. S., Mitropoulos, P., and Howell, G. A. [31]	x			x					x				

3.1 Safety through production planning

One group of investigators has looked into managing safety through production planning and control. Saurin et al. [18] found in their exploratory study that some lean production concepts and methods, such as the Last Planner Method, which have been used for production planning and control, can be easily extended to safety planning. Integration of production principles into safety planning would help in overcoming the inherent shortcomings of construction safety planning. The study suggested an integrated safety planning and control model with four essential functions: anticipating safety resources which are necessary to control risks, identifying and controlling risks originated in production planning decisions, evaluating safety performance (based on both proactive and reactive indicators), and enabling workers to identify risks and make suggestions to control them. Following this, Saurin et al. [19] established the main features and tools of the integrated safety planning and control model. The results indicated that some of the successfully used concepts in production planning can be easily extended to safety planning in construction. Saurin et al. [20] took this safety planning and control model further and evaluated the impact of the model on human error. Human error is defined as an inappropriate or undesirable human behavior that

reduces (or has the potential for reducing) the effectiveness, safety or system performance. In dynamic work systems, such as construction projects, the workers have freedom for adaptive modifications of procedures which leads to human errors [14]. Three design mechanisms identified to reduce human errors are to ensure visibility of boundaries to failures, to ensure those boundaries are respected and to make the production system error-tolerant. Six elements of the model which have contribution in terms of both making the boundaries of safe work visible and respected are safety planning, near miss reporting, training, percentage of safe work packages indicator, participatory cycle, and planning and control diffusion. A study by Saurin et al. [22] identified two typical lean approaches namely automation and visual management, which can be used to detect variability. In a separate study, Razuri et al. [15] tried to develop a project management system that integrates production and safety management. The study found that there is a positive correlation between the safety best practices implemented and project injury rate. Moreover, the high-impact practices identified by this study are suggested for the development of an integrated management model of production and safety management. Mitropoulos et al. [12] took a different perspective in their study to find out how production practices, particularly lean practices, affect the chances of construction accidents. The production practices were examined by an exploratory field study which indicates that reducing uncertainty, errors (and resulting rework), and matching ability to task demand reduces the chances of accident and also increases the productivity.

3.2 Performance measurement for safety

Increasing safety is critical in the context of improving productivity and efficiency in construction industry. Thus, the development of valid safety performance metrics is an important first step towards improving safety. Unfortunately, most conventional metrics of safety performance deals with rates of accident or incident occurrence. This type of metric has inherent limitations: it is reactive in nature, causal relationships cannot be established, and it does not include positive aspects of safety performance [10]. Development and implementation of safety-related performance measures within the lean construction paradigm can be classified into two broad categories. The first is related to safety process improvement [19] and other at the detailed operational level [10]. The study by Marosszeky et al. [10] employed an iterative process analysis: identifying potential performance measures, prioritizing and selecting measures, and finally the development of key performance indicators and the feedback mechanism.

3.3 Forecasting risk levels

It has been stated that a proactive safety policy is a more efficient way of managing safety in order to prevent accidents than a reactive policy [19]. Sacks et al. [16] presents a conceptually advanced model to support proactive safety management. The authors argue that most common factors that have a substantial influence on most construction projects are time dependent such as human factors, physical hazards, environmental factors, etc. Thus, knowing the level of risk as it changes with time would help in identifying high risk construction activities and allocate precautions accordingly. The model put forth by Sacks et al. [16] enables forecasting risk levels for teams as well as individual workers as a function of time. This time dependent model can be used to implement management strategies that focus efforts where needed and reduce efforts where it is wasted, in contrast to safety activities that are planned with constant effort.

3.4 New approach to construction safety

In spite of all these efforts to improve the poor safety record of the construction industry, the rate of fatalities in the construction industry has forced researchers to look for new approaches for construction safety. Attempts have been made to introduce behavior-based safety approaches for construction projects. Salem et al. [17] provided a decision support system to assist construction companies (especially small and medium sized) in implementing behavior-based safety. Although behavior-based safety has been widely accepted in other industries, it cannot be exactly replicated in the construction industry and it also involves a huge amount of money to implement full fledged behavior based safety [17]. Another approach of identifying contributing factors of accidents, other than human errors and machine malfunction, is to look into organizational factors through resilience engineering. Resilience

engineering emphasizes how organizations manage unexpected events and how people in these organizations become prepared to cope with unplanned and unforeseen events [23].

3.4.1 Cognitive systems engineering approach

Thus far, most efforts to understand the accident process have failed to recognize the dynamic and dependent nature of construction work [6]. Rasmussen's [14] model of 'migration to accidents' within the paradigm of cognitive systems engineering offers a broader and more powerful view of the relationship between individual and work environment, and of the factors that lead to incidents. In this model as shown in Figure 2, laborers work away from the organization's boundary of economic failure and individual's boundary of excessive effort. Accidents occur when workers migrate towards the boundary of functionally acceptable behavior and lose control. 'Migration to accidents' model contradicts current practices by recognizing that both individual tendencies and organizational factors push people to work in risky circumstances [6]. The ideas of Rasmussen [14] have been advocated both in construction [2, 6] as well as in other industries as an effective basis for designing adaptive work systems that take into account the inevitable migration of workers towards the boundary of loss of control.

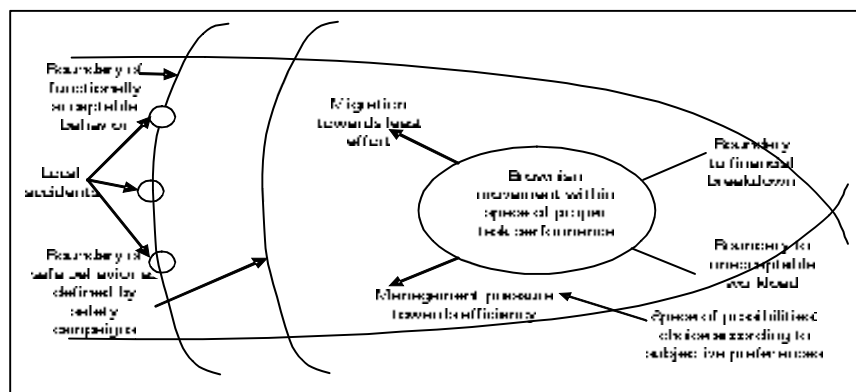


Figure 2: The migration of work toward loss of control [14]

4. Conclusion

This paper summarizes lean construction theoretical framework and the literature pertaining to intersection of lean construction and safety management. We reviewed papers published in the International Group for Lean Construction conference proceedings from 1998 to 2008 and summarized the main themes that have been addressed: production planning and control, performance measures to improve safety, forecasting risk levels as a function of time and developing new approaches to construction safety. Considering the stage of plateau that safety in construction industry has reached using the best practices, perhaps the new approach based on the work of Rasmussen can provide the breakthrough to propose a new model for the way construction accidents originate and propagate to injury.

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