Framework for Understanding the Relationship between Lean and Safety in Construction

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Abstract

Safety and lean aim at similar goals in making the construction process faster, better and safer (Main et al. 2008). This research intends to answer the basic question: "Is there a relationship between lean and safety principles to help in reduction of waste and incidents?" The primary objective of this research is to understand the relationship of lean and safety through risk and uncertainty reduction. A qualitative analysis of lean methods and safety practices in the construction industry will be derived. Relationships between lean methods and safety practices will also be studied and the impacts of safety on lean methods will be analyzed. A framework that expresses the relationship of lean and safety theories will yield an understanding of the relations. The proposed framework will provide a larger picture of the association of lean and safety will explore the common grounds used in the minimization of waste and risk.

The limitation of this research lies in qualitative findings from the data collected. A quantitative analysis involving the documentation of project processes and safety data would further strengthen the relationships identified. On the contrary, a quantitative approach would not provide a perspective on a larger scale.

The principles of lean and safety are aligned and the construction industry could benefit by their integration

A relationship has been established between lean methods and safety programs. Lean methods add value and eliminate waste, and safety helps in risk mitigation. Thus, it is widely evident that lean and safety have a synergy that can be harnessed to create a safe, productive workplace.

Keywords: Lean Construction, Last Planner System, Safety Management

Introduction

Lean construction borrows lean manufacturing and Toyota Production System concepts (Koskela 1992) in order to eliminate waste and add value to the construction process. Manufacturing processes utilizing lean principles have matured and developed a clear understanding of the relationship between lean and safety (Williams and Robert 2005). In construction, safety is related to reducing the number of accidents on a job site and is now tending to achieve zero accidents on construction sites (Liska et al. 1993). This is seen as a way to reduce the waste in resources and time that accidents cause, which

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must be eliminated in order to function effectively. Hence, it is necessary to discover the possibility of integrating lean and safety principles at all levels of construction.

Historically, safety has been treated as a separate subject that could be improved in isolation from production. However, safety is an integral part of every production process, not something thought of later or seen as an add-in. Safety is important as it depends on every action, material and person involved (Nahmens and Ikuma 2009). The implementation of lean thinking and techniques encourages minimizing material in the work area, an orderly, clean workplace and systematic work flow. In the industry, the use of lean construction tools like Last Planner System claims to reduce accident rates (Ballard and Howell 1994).

Dynamic, unpredictable and often hostile construction tasks and environments, combined with high production pressures and workload, create a high likelihood for errors. For these mentioned reasons, coordination amongst crew and communication are essential for effective and safe performance of construction crews (Mitropoulos et al. 2007). In one study, crews that used lean construction tools, including Last Planner, had about 45 % lower accident rates than did crews in the same organization performing similar work who did not use the Last Planner system. (Thomassen et al. 2003). These examples suggest that when the principles of safety and lean are combined, they enhance improvement of the workplace. The significant characteristics revealed by the lean tools and safety practices are instrumental in finding a common factor to establish a relationship between the two theories.

Lean in construction is a relative new phenomenon introduced by Koskela in the UK (1992), while Ballard (2000) pioneered it in the U.S. However, unlike in manufacturing, construction does not have a completely developed understanding of how lean practices affect safety. The Lean Construction Institute and the Academic Forum for Lean Construction has recently targeted this area for focused research (Lean Construction Institute Academic Forum 2009).

The systemic nature of the construction industry (Fernandez-Solis 2009) of the United States is characterized by employing high technology in design and planning, but in field practices, it is characterized by low productivity, cost overruns, schedule overruns, shortage of skilled labor and high incident of safety issues (when compared with other industries) (Nahmens and Ikuma 2009). In particular, the lack of safety is seen as one of the chronic problems in construction.

The total injury and illness incidence rates for prefabricated wood manufacturing in the U.S. has ranged from 9.5 to 14.3 per 100 workers over the past 5 years. The residential construction incidence rate is approximately 5 per 100 workers (Bureau of labor statistics 2008). Injury rates for both sectors are higher than the national average of 4.2 injuries per 100 workers (Nahmens and Ikuma 2009). The traditional construction process of the industry pushes the client into an often prolonged development process where risk and uncertainty are prevalent (Garnett et al. 1998). This justifies an increased focus on improving safety in all facets of construction.

Problems in the construction industry also include poor communication between teams, lack of documentation, deficiency in making timely decisions and negative iterations of design (Ballard and Koskela 1998). This implies that a work system needs to be developed to achieve high levels of productivity and safety, as Mitropoulos et al. (2005) state. Standardizing, systematizing and regularizing production can be expected to lead to better safety as side effects (Kobayashi 1990). Nahmens and Ikuma (2009), in their research findings, question if “implementation of lean principles result in improved safety.” It also leads to the question of whether these theories can be combined to develop a framework. Main et al. (2008) state that it is important to “demonstrate why safety and lean concepts need to be addressed concurrently.”

Risk in construction is the probability of the occurrence of an incident in the form of an accident like fatality, injury and the severity of expected outcome (ISI 2000). Hazard is a condition, which, if released, can lead to injury unless the worker is able to detect and avoid it without increasing exposure (Howell et al. 2002).

Lean thinking suggests that activities undertaken to promote occupational safety and health in construction can be improved – that the waste produced or generated can be identified and removed and the negative impacts on process flow can be minimized. Since all safety incidents imply waste in time and resources, lean and safety have a common ground in the minimization of waste and risk. The Occupational Safety and Health Administration (OSHA) documented workers' health in different occupations and thus laid down guidelines and specifications that must be followed on the jobsite. Through this, it is understood that the elements of risk and uncertainty act in cohesion with both lean and safety. Lean is defined as reduction of waste in processes (Koskela 1992) and the goal of safety is to reduce incidents on the jobsite, which are a form of waste in terms of resources like time and material. Therefore, a common relationship can be identified amongst the four related elements of lean, safety, waste reduction and safety reduction. The relationship defining the reliance of lean, safety, waste reduction and incidence reduction on each other is represented in Fig 1.

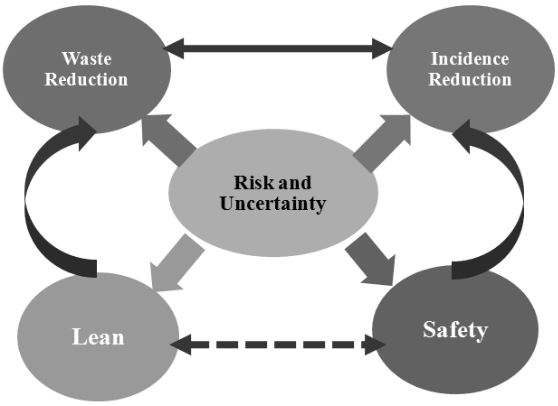

Figure 1: Common element between Lean and Safety

Research Questions and Objectives

Safety and lean aim at similar goals in making the construction process faster, better and safer (Main et al. 2008). This research intends to answer the basic question: "Is there a relationship between lean and safety principles to help in reduction of waste and incidents?" Lean thinking is based on the elimination of waste and value addition. The primary objective of this research is to understand the relationship of lean and safety through risk and uncertainty reduction. To represent this, a qualitative analysis of lean methods and safety practices in the construction industry will be derived.

Relationships between lean methods and safety practices will also be studied and the impacts of safety on lean methods will be analyzed. A framework that expresses the relationship of lean and safety theories will yield an understanding of the relations. This will provide a larger picture of the association of lean and safety will explore the common grounds used in the minimization of waste and risk.

Literature Review

Extensive studies have explored the synergy between safety and lean in construction. Prior to combining these two principles, it is important to know the significance and the properties each bring to the common module. Therefore, the literature review examines topics of lean principles, how they came into existence, the methods used in lean construction/manufacturing, safety, accidents, and safety programs.

Recent papers have discussed opportunities for applying Cognitive Systems Engineering (CSE) with a perspective on safety ideas in the construction industry. Cognitive Systems Engineering is based on flexibility, learning and awareness (Saurin et al. 2008), which are symbiotic with lean as they add value to the process. Owing to the dynamism and complexity of construction sites, also provides high level guidelines on work system design which makes it easier to adapt in different industries.

Based on behavior based approaches, Howell et al. (2002) and Salem et al. (2007) reviewed traditional safety management best practices, and concluded that they are ineffective to make workers capable of performing in situations of high risk (loss of control zone). This theory is represented in Figure 2 where there are three zones of risk; safe zone, hazard zone and a loss of control zone. This model suggests that the safe zone may be increased by planning and operations. The hazard zone is where workers can identify the risk and latent hazard beyond which the boundaries of work become unsafe. Loss of control zones direct management to take measures to minimize its risk, thus minimizing the zone.

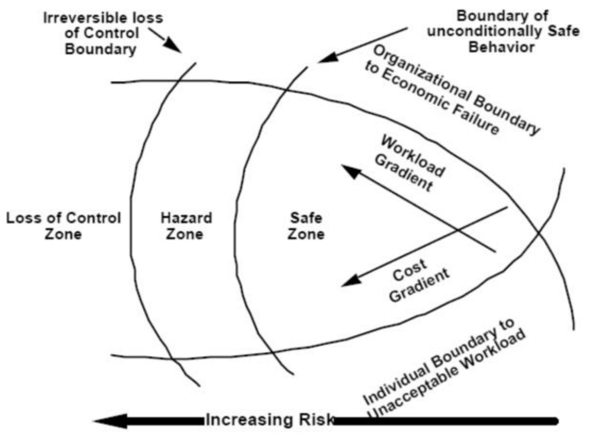

Figure 2: Three zones of risk (Howell et al. 2002)

Abdelhamid et al. (2003) conducted an application of signal detection theory as a mechanism to sharpen workers' sensitivity to hazard identification – this is particularly important at the edge of the loss of control zone. Saurin et al. (2006) carried out an analysis of the frequency of errors and violations in five construction sites. Also, Saurin et al. (2008) extended the discussion of Howell et al. (2002) on the applicability of CSE to construction safety based on empirical data. CSE theory, in Saurian's paper, is seen as helpful in improving safety practices related to process transparency, planning, performance migrations, accident investigations and identifying risks.

These five practices were chosen as they are important in construction safety and the empirical data available in applying the Safety, Planning and Control (SPC) model in six construction sites. This paper also provides insight on autonomation, since it supports the CSE principles discussed in the paper. The overview of the SPC model is shown in Fig. 3.

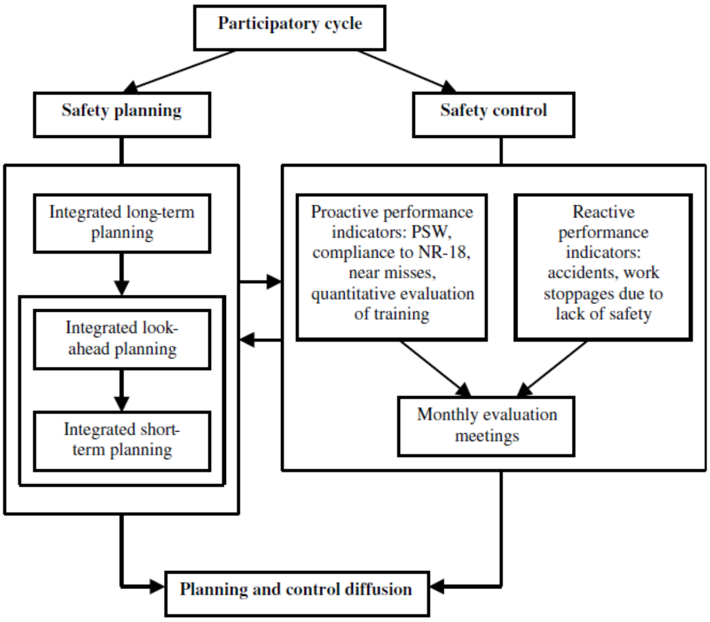

Figure 3: Overview of the safety, planning and control process (Saurin et al. 2008)

Safety

Nahmens and Ikuma (2009) note that safety has been improved separately from production. Safety cannot be viewed as an afterthought to a construction process as it is an integral part (Nahmens and Ikuma 2009). Both organizational pressures to increase productivity and individual workers' drives to decrease effort, push workers to the edge of safe performance (Mitropoulos et al. 2003). Workers in the building, renovation, demolition and commercial industry in the US suffer a disproportionate share of occupational fatalities and lost-time injuries.

Safety and health problems are tied largely to the construction industry's organization and work performance (Ringen et al. 1995). Safety depends on the workers, equipment, site, management, administration and materials; therefore, safety performance depends on the nature of the job and must be continuously monitored, maintained and improved (Koskela 1992). By understanding the nature of risk and hazard, processes can be planned to minimize safety risks and reduce workplace hazars. Construction project processes have the tedious task of overcoming injuries; thus, priority must be given to safety program implementation.

In a study by Aksorn and Hadikusumo (2008), the critical success factors were grouped into five categories for safety management: worker involvement, safety prevention, control systems, safety arrangement and management commitment. Koskela (1993) concluded that the implementation of lean production concepts into construction seems to be a major factor in eliminating accidents. The strategies identified to improve construction safety through lean concepts are:

- Designing, controlling and improving engineering and construction processes to ensure predictable material and work flow on site.

- Improving safety management and planning processes to systematically consider hazards and their counter measures
- Improving safety related behaviours – instituting procedures that aim at minimizing unsafe acts.

Production procedures often include alerts on safety hazards in their content. Another frequent approach is to develop specific procedures for safety, through techniques such as preliminary hazard analysis and failure mode and effect analysis.

Based on the literature (Ringen et al. 1995, Mitropoulos et al. 2005), safety programs can be identified as follows: comprehensive safety policies, safety committees, safety inductions, new employee trainings, jobsite inspections, accident investigations, first aid programs, in-house safety rules, safety incentive schemes, control of subcontractors, selection of employees, personal protection programs, emergency preparedness planning, safety related promotions, safety auditing, safety record keeping and job hazard analysis. Workers are the most common cause of accidents when considering behavior models. A zero accident (Liska et al. 1993) workplace that is founded on health and safety increases morale and builds employee loyalty. When an employee is injured, the company loses time and productivity. By having minimal accidents, the company maintains productivity and morale, causing a decrease in the overall injury rates and the premium rates.

Few safety programs created to reduce costs and add value to the construction process address site safety. A critical element of assigning responsibility for safety and health, while at the same time improving coordination among subcontractors and the trades, is education and training: for example, site orientation and topics of rigging, trenching, etc., are included in the OSHA hazard communication standard. New technologies are coming into place, which reduce the risk of accidents, both minor and major, and other health problems. Examples of these would be wet-blasting, not using asbestos products, and using bricklayers with holes and handles (Ringen et al. 1995). Federal regulations have incorporated certain regulations that are giving new direction to the construction industry, a few of which are:

- Hazardous waste operations and emergency response standard (29 CFR 1926.65)
- Process safety management of highly hazardous chemicals standard
- Lead exposure in construction

Workers' compensation law, which permits compensation agreements, higher benefits, care arrangements and alternative dispute resolutions, may reduce time spent in certain litigation procedures that occur post injury incident. Other health care and medical monitoring discerned through regular checkups provide information to workers that can be used to improve workplace conditions (Ringen et al.1995).

Research Methods

This research reviews publications in journals, databases and the Lean Construction Institute website. The objective of the research is to provide insights on lean, and safety, along with their processes. Data collected on lean, lean methods and from literature case studies reveal the application of lean in construction projects.

The safety data reviewed in the literature explores safety programs implemented by companies and their relationship with lean methods. A relationship between a lean tool and safety practice was seen to exist when a lean tool and safety practice have a common objective or when the implementation of a lean tool helps to drive the implementation of a safety practice. The relationship was conflicting if the implementation of the lean tool hindered the implementation of the safety objective. Based on the “how-can” approach of deductive reasoning (Popovic and Vasic 2008), the analysis may identify overlaps between lean and safety. Deductive reasoning uses a general to specific approach that is found apt for analysis of these theories, moving from a generalized theory to a specific tool / practice.

Further strengthening the definition of a relationship used in this analysis, a tabulated list of the primary goals or driving factors for each lean tool was deduced. This helped in establishing the relationships between two entities. A framework that relates lean tools and safety practices was developed to visually demonstrate the existence of strong, conflicting or non-existent relationships between the identified lean tools and safety practices. Six case studies of construction firms and projects that used lean and had a safety implication verified the application of the lean and safety theories in use. The case studies were used to answer the research questions of “how or why” (Yin 2009) and the extent of control over construction events was minimal or not present.

Data Collection

Data collection focused on understanding the implications of each lean tool and safety practice. A mixed method of data collection was used to collect data for the study (Axinn and Pearce 2006). The definitions and explanations of each lean tool were instrumental in guiding the filtration process of determining where the tool affects safety.

Lean Tools

Common lean methods widely used in the industry were selected through literature. These tools were categorized based on the lean project delivery methods (Khanzode et al. 2005) of lean project definition, design, supply, construction and the general tools that are used. The objectives of these tools were studied and they are stated below.

Lean Methods

Performance based contracting (PBC) organizes project delivery methods to accommodate implementing lean or any other innovative methods to be used in the construction project in the initial phases of project delivery (Bae and Kim 2008). PBC is a technique that defines the facets of acquisition around the purpose and required performance of facilities (Horman et al.2004).

Integrated Project Delivery

Integrated project delivery (IPD) is also known as a lean project delivery system that involves project definition, lean design, supply and assembly. It was used in DPR Construction’s healthcare project, as quoted by Reed (2005). Integrated project delivery also maximizes collaboration among the stakeholders from the early phases. This method binds stakeholders in a single contract with the IPD team and the primary team members are responsible for the primary contract.

Integrated Design

Integrated design is a design phase in the initial phase of the project, whereby stakeholders are involved in the decision to use different synergies of construction techniques and processes in the construction project (e.g. decisions related to using lean, sustainability and building information modeling). The stakeholders involved in a project decide whether to adopt this method in the project delivery process (Bae and Kim 2008).

Target Costing

The financial impacts on the project are tracked using this tool. It states that the building should be built within the budget specified (Ballard 2006). The implementation of target costing is practiced by allocating the larger amount of the budget for the sub phases of a facility's functions. The team responsible for realizing this expectation is comprised of the architect, owner, contractor, specialty contractors and functional agents (Bae and Kim 2008).

Poka-yoke

Poka-yoke is a tool to make any process error-proof, or error tolerant (Rasmussen et al. 1994), and it works within the objectives of safe work systems and lean. Poka-yokes take the form of safeguards and personal protective equipment that have a wide set of functions (Saurin et al. 2006).

Just- in-time

As the nomenclature states, this is the concept of having the right amount of product at the right time, in the right place. Just-in-time reduces potential damage to inventory and the consumption of material (Riley et al. 2005).

Prefabrication

Prefabrication is a technique where the components required for construction are assembled/manufactured off-site and transported to the site for final assembly (Toole and Gambatese 2007). This, in terms of lean, provides speedy construction phases and eliminates waste from the process and materials. Better manageability and reduction of overall lifecycle costs are among the features of using prefabrication. Contractors and owners must proactively decide to use this approach during construction/prior to construction, as the design must complement the prefabrication process.

Value Stream Mapping

Value stream mapping is a lean production philosophy that detects hidden waste in a project by mapping the process of task completion during construction (Main et al. 2008). This helps in detecting errors that cause waste, including waste related to time and resources.

Kaizen

Kaizen means continuous improvement in a work process/task. Kaizens are characterized as short periods of intense activity driven toward resolving a specific problem or achieving a specific goal in a short period of time (Bae and Kim 2008). It is one of the primary ways to implement lean in the construction phase.

Kaikaku

Kaikaku targets rapid process improvement. It is designed to eliminate waste and make rapid changes for product and process improvement in the workplace. This unites the workforce from different organizational levels, addresses problems and improves processes (Bae and Kim 2008).

Last planner system™ (LPS)

Introduced by Ballard (2000), LPS simultaneously shows improvements in the cost, schedule, quality and safety aspects of a construction project. Last planner system involves planning, estimating and scheduling of a construction project. Having weekly schedules and look-ahead schedules simplifies the schedule and holds the people in charge accountable. The validity for this method can be based on a method known as "Percent Plan Complete" that measures the percent of work completed.

Visual Management

Visual management in lean production detects deviations from standards. Visual devices are typically adopted in the construction process to increase safety among workers. Visual communication targets a wide range of users. It is used on site by putting up banners and other visual aid signs for the employees to follow (Saurin et al. 2006).

5S

This tool, 5S, is expanded as Set, Sort, Shine, Standardize and Sustain. Another "S" is added in the present scenario that includes "safety." 5S mechanisms overall help in the house\keeping aspect of construction. This helps contractors increase productivity while protecting laborers from hazards and injuries by providing clean and accident-free work areas (Bae and Kim 2008). The objectives of 5S are to improve profits, management and achieve a safe jobsite.

Autonomation

Shingo (1986) and Filho et al. (2007) have suggested that during a manufacturing process the operators or the machines must be provided with the autonomy to stop production whenever something abnormal is detected. This method calls for immediate action by the project manager/engineer/superintendent as to the further course of the project. In the long term, companies that apply this principle would have fewer hindrances than would companies that do not apply it (Womack et al. 1990).

Safety Programs

For this framework, safety programs or practices were based on hierarchical application levels, i.e., organizational level practices standardized across the organization for all projects. These involve techniques such as Poka-yokes, incentive programs, etc. On a project level, accident prevention techniques and job hazard analysis would be examples. These tools were compared against lean tools and interrelationships were found.

Accident Predictive Techniques (APT)

Accident predictive technique is a safety program that motivates the worker to identify a possible hazard by analyzing his work practices. The main purpose of APT is to habituate hazard recognition and eliminate errors that may lead to incidents. An APT report consisting of the description of the hazard identified and its recommended corrective action is reviewed by the work team during the department's sequential safety meetings (Air Products 2002). APT's can be applied to all phases of construction where the worker is responsible for the safety of his work practices. APT's lend a predictive tool to the safety management system, permeating through the worker level processes involved in construction.

Safety Sampling / Inspection

Safety sampling is a technique that uses the observational skills of an experienced worker to monitor a set of workers and enumerate their at-risk and safe work practices. This method leverages the expertise of the personnel who are familiar with the work process under study and are well trained in identifying hazards. (Manuele 2003).

Worker Shielding / Personal Protective Equipment (PPE)

This safety program is enforced by management to ensure that workers are safe from hazards that cannot be eliminated and to focus on worker health (Landsberigs et al. 1999). Hard hats, protective glasses are a few examples of PPE. An example of worker shielding is workers handling hazardous chemicals being trained to shield themselves before an accident occurs (Air Products 2002).

Safety Metrics

Safety metrics form an integral part of a safety management system, whereby management reviews safety metrics, along with performance metrics of a construction project. This forms an important feedback process of the safety system of the construction firm. Safety metrics are classified as reactive and proactive measure of safety (Hinze and Godfrey 2003). Incident rate, a reactive measure, is a common safety metric that helps the firm establish the credibility of its safety program.

Accident Sequence Guide

An accident sequence guide is designed to analyze how accidents occur and determine their severity (Air Products 2002). The sequence guide helps management understand the sequence of steps from a worker violating an accident prevention measure to the incident being classified as a near miss or an injury.

Accident Investigations / Root Cause Analysis

Accident investigations and root cause analysis are important techniques to help management understand the causes for an incident and suggest preventive measures for the future (Boldt 2001). This practice provides feedback to the construction workflow and prevents similar incidents from happening in the future. Following an incident, management constitutes a team of well experienced personnel to perform an accident investigation.

Site / Job Hazard Analysis

Site hazard analysis is a safety program that evaluates the construction site for safety performance and helps identify possible hazards. The safety team evaluates factors affecting site safety, then develops and submits a plan to management as part of the analysis (Mohamed 2002). Job Hazard Analysis identifies hazards within the construction of a particular task where workers on various teams utilize the same construction site. The analysis is performed by the safety team associated with the project and a report is submitted to safety lead to take prevention measures for the hazards identified (Popovic and Vasic 2008).

Training (OSHA/IFE/FIRST AID)

Training educates workers on the importance of safety and helps them deal with incidents on site. Safety training provides the means for making accidents more predictable (Vredenburgh 2002). The safety team is responsible for conducting training for all workers in the construction firm.

Daily Pre-task Safety Planning

Pre-task safety planning consists of a worksheet that enumerates general aspects of a task, which helps workers identify hazards before a task is performed. Pre-task planning is also known as Pre-task Analysis (PTA). PTA helps identify all hazards associated with a task and makes recommendations for eliminating and controlling them (Walbridge Aldinger 2002).

Safety Incentive Program

A safety incentive program is initiated by management as a proactive measure to rapidly identify hazards as they are noticed. The incentives act as a motivating factor for workers to identify and report possible hazards to the safety team, and generally run alongside safety education and training (Vredenburgh 2002).

Safety Alerts / STOP Program

Safety alerts are practiced as a precautionary measure by workers who have had a near miss or have identified a possible hazard. The STOP program (See, Train, Observation, and Program) motivates workers to use their observational skills and their training experience to identify possible hazards in their work practices.

Material Safety Data Sheets

Material safety data sheets comprise a safety measure that helps workers handling a chemical to be aware of the risks of the task. Data sheets educate workers on proper handling and disposal of certain chemicals.

Safety Orientation

Safety Orientation sessions are conducted by the safety team or senior management to educate the inexperienced new workers about common hazards at a construction site.

Record Keeping / Logs

Record keeping is a traditional safety practice with the objective of storing critical project information which might become useful for further safety analysis. Most of the data for accident investigations are taken from these records for further analysis.

Litigation

Litigation is an important process undertaken by management to provide aid to the victims of an accident. Safety teams and management coordinate to develop the structure of the litigation program.

Data Analysis

Based on the data retrieved from literature, a reasoning that relates theories of lean and safety is necessary. To relate the theories and deduce implications, deductive reasoning was used, as explained by Popovic and Vasic (2008). The term deductive reasoning technique is a form of logic and analysis. The logical process draws conclusions from a set of premises and contains collective information on the premises (Popovic and Vasic 2008). The analysis characteristics of deductive reasoning are based on a set of parameters that question the premise on “how-can” – explaining how a lean method can have an implication on safety practice. This form of analysis moves from a larger scale to specific cases. This is possible after the nature of the element under scrutiny is identified.

This research culminates in the selection of 14 lean methods and a specific safety impact of each lean method is studied in detail. These explanations are based on a time factor in the lean project delivery system. With lean project definition, design, supply, construction and general methods, the methods were categorized by the phase on which they provide the maximum impact. Along with this study, it was also implied through literature that each lean method has a specific driving factor. This was developed into a table that shows each lean method against the objective or driving factor (see Table 1).

Table 1: Exploration of lean methods objectives

No.	Lean Methods	Driving Factor
1.	Performance Based Contracting	Performance
2.	Integrated Project Delivery	Communication
3.	Integrated Design	Design
4.	Target Costing	Economics
5.	Poka Yoke	Errors
6.	Just In Time	Inventory
7.	Prefabrication	Flexibility
8.	Value Stream Mapping	Process
9.	Kaizen	Continuous Improvement
10.	Kaikaku	Rapid Improvement
11.	Last Planner System	Schedule
12.	Visual Management	Visual Aid
13.	5S	Housekeeping
14.	Autonomation	Autonomy

Performance based contracting is specific to performance and a contract that measures the performance of a project or process. Project delivery integration attempts to eliminate miss-information among the various teams, hence, it is communication driven. Integrated design involves all stakeholders from the phase of project initiation, thus providing better design strategies. Target costing is a means to work within a stipulated budget; essentially, it is economically motivated. Poka-yoke is a failsafe mechanism adapted in many industries along with construction. Just-in-time concentrates on the inventory and safety stocks. Flexibility is provided through pre-fabrication. Value stream mapping makes the process transparent, which helps in identifying hidden waste. Kaizen and Kaikaku are improvement driven; they focus on continuous and rapid improvement respectively. Ballard's (2000) Last Planner system™ works on schedules both immediate and long term and validates performance through percent plan complete. Visual management provides effective signage in the jobsite and 5S enhances housekeeping. Autonomation equips workers with the autonomy to decide when to halt a process and seek assistance.

Understanding the driving factors for each method helps in relating safety with lean. This also helps to identify the intersections with either strong or conflicting impacts. The safety impact of each lean method can be analyzed based on the driving factor. Based on a time factor of "when" in the lean project delivery phases, each method has been explored.

Lean Project Definition

Performance based contracting affects safety positively by defining safety metrics as a measure of performance. Training, pre-task planning and orientation also are productive; they reduce waste, thus reducing incidents in wasteful processes. Innovative technologies can be used in safety planning, training, etc. Performance is an indicator and helps decide the incentives or policies to be implemented. Integrated project delivery ensures that all stakeholders share the risks and profit of project performance. Decision making is enhanced regarding practices and risks, owing to effective communication amongst the teams.

Lean Design

Integrated design of a safety system involves trade-offs. Safety requirements may conflict with other requirements like material availability and performance. Identifying safety conflicts within a construction process and solving them could be the central focus of a design process. Thus, integrated design helps set priorities for a process in order to make it safer (Becker 2009). Target costing strategy makes planning more crucial, as a result of which there could be times when safety is a compromised factor; therefore, it increases risk. Poka-yoke contributes to making the boundaries of performance error-tolerant, which is a major principle both of safe work system design and also of lean production (Rasmussen et al. 1994).

Lean Supply

Just-in-time provides the right amount of material and resources needed at the right time, which removes the idea of safety stock (Ballard and Howell 2003). By following just-in-time, there is a reduction of waste and variations.

Lean Construction

Prefabrication provides safer work conditions, as the processes are standardized and automated. The site or the task is more easily manageable since it is divided into small bits. This, in turn, provides better work conditions. Value stream mapping makes the process more predictable and transparent. This eliminates risk and increases value by enhancing safety in the work environment. It is easy to indentify an unsafe work environment around a process. Kaizen programs reduce opportunities for accidents through reduced waste in material motions and processes steps, thereby reducing safety hazards. Kaizen programs include safety initiatives as one category of improvement projects undertaken.

General Methods

Kaikaku is a rapid improvement process; there are times when safety aspects are overlooked. Through this radical change process, it is possible to identify the risk. This syncs with value stream mapping, but Kaikaku applies to a larger interface; therefore, these safety measures reflect impacts over a longer period of time. Last Planner system™ increases predictability of the project by inventing task based scheduling. This has immediate and long term goals for the project; owing to this, the work environment is stabilized. Look-ahead schedules prepare for estimated risk. Visual management applies to safety in signage, demarcations, barricades, boards, and ramps--all measures that visually instruct workers to prevent accidents.

5S methods clean and maintain the workspace by sorting, since organizing items reduces the risk of accidents from trips and falls. Having a specific place for storage provides clarity. Timely cleaning also makes equipment related safety problems visible immediately. Standardizing the processes translates to a clear safety program. Sustaining these efforts includes safety inspections and audits in order to maintain a safe work environment.

Autonomation contributes to safety when a process can be halted before any accident or mishap occurs, since it provides the autonomy to identify risks and take appropriate measures. Thus, all these lean methods actively identify safety as a necessity in the process of construction and also pave the way for a better work environment if both are implemented concurrently. Table 2 summarizes the safety impacts of the lean methods studied and explained in this chapter, based on the classification of the lean project delivery systems.

Table 2: Safety impact of lean methods during lean project delivery phases

Lean Project Delivery Phases	Lean Methods	Safety Impacts

Lean Project Definition	Performance Based Contracting	Innovates safety planning Motivates Safety metrics Provides a better framework for safety related incentives
	Integrated Project Delivery	Enhanced communication helps establish safety standards Coordinates for risk management Faster decision making
Lean Design	Integrated Design	Integrates safety in design Identifies safety-design conflicts Sets safety standards early
	Target Costing	Increases risk as economic objective gain priority Allocates safety budget within the target constraints
	Poka Yoke	Develops error proof processes Prevents incidents before hand Results in a safe work environment
Lean Supply	Just In Time	Reduced excess inventory at site Increases risk by narrow time window for delivery
Lean Construction	Prefabrication	Applies use of automation Eases management by creating smaller tasks Standardizes safety practices
	Value Stream Mapping	Processes are transparent Identifies risk within a process Recognizes hazards
	Kaizen	Sustains safety by continuous improvement Safety team collaborates with other teams Focuses on safety metrics Innovates safety initiatives
General Tools	Kaikaku	Rapid improvement increases the need to collaborate with the safety team Increases risk by shifting orientation to financial objectives
	Last Planner System	Schedules processes , defines relation Encourages task based safety planning helps risk estimation Stabilizes safe work environment
	Visual Management	Communicates safety information effectively Recognizes hazards Eliminates repetitive errors
	5S	Enforces equipment and work area safety by efficient housekeeping Standardizes safety by organizing item within a workspace Decreases risk of hazards
	Autonomation	Identifies and stop unsafe work practices Enhances visibility of safe work practices

Data Interpretation

Based on the literature reviewed and analyzed, data was interpreted in a way where a relationship between safety and lean theories was illuminated. The lean methods and safety programs can have a strong relationship, a conflicting relationship or no relationship. A strong relationship ties the two theories and expresses that if used, they work in synergy. A relationship is seen as strong when a lean method suggests betterment in a safety practice. A compromised correlation expresses no symbiotic relationship between the tools at present, likely owing to properties of one of the theories.

Safety metrics play an important role in quantifying the performance of contractors. Metrics related to safety also contribute to performance and hence, may be instrumental in obtaining contracts with firms practicing performance based contracting (PBC). Thus, the role of safety metrics is enhanced by the implementation of PBC. These metrics also help drive other safety mechanisms like training, task-based safety planning, safety orientation and record keeping. Management can encourage safe work practices from contractors by introducing a safety incentive program. Thus, PBC helps drive safety mechanisms, which leads to a safe, lean work environment. Alternatively, PBC hinders the progress of accident investigations, since construction activities are monitored by contractors.

The main idea behind integrated project delivery (IPD) is forming a core team which will result in better communication between the stakeholders of the construction project. The IPD team has the authority to ensure uniform compliance of safety procedures (Matthews and Howell 2005). Enhanced communication aids in accident investigations and safety analysis of the job/site involved. The safety incentive program can be uniformly applied across all stages of construction through the IPD team.

Knowledge about safety can be leveraged in the design phase of a construction project (Hasan et al., 2003). Integrated Design (ID) helps develop this synergy in the design phases of the project, which aids the overall process of safety analysis. Further, the safety incentive program can be tuned to facilitate integration. Designers may take part in safety orientation; thus, several hazards that develop due to an incorrect design method can be removed at an early stage. Target costing has a conflicting impact on the safety incentive program, since is a rigid constraint for with which all safety mechanisms must comply.

Safety Poka-yokes prevent errors in the construction process, with the central idea being to avoid hazards by developing error prevention techniques. Poka-yokes can be devised to either prevent accidents or react to the consequences of errors (Saurin et al., 2008). Just in time systems reduce inventory at the construction site. Lower inventory enahnces the manageability of tasks, which facilitates the safety analysis process and pre-task safety planning. On the other hand, Koukoulaki (2009) argues that systems like just-in-time increase material handling due to a narrow window for service or delivery, which leads to increased chances of incidents and undermines the effect of accident prevention techniques.

The advantage of prefabrication lies in the fact that tasks are broken down into easier, more manageable tasks. This has a positive effect on safety mechanisms that work on the idea of hazard recognition. Bae and Kim (2008) state that prefabrication leads to overall safer working conditions. Value stream mapping (VSM) shares the main idea of identifying value and hazards through numerous safety mechanisms and helps facilitate their implementation. VSM identifies processes that safety mechanisms like safety analysis can leverage for easier implementation.

Kaizen and safety are regarded as two sides of the same coin. Kaizen, being a continuous improvement procedure, can be easily leveraged to facilitate implementation of any safety mechanism. However, this has detrimental effects on many safety mechanisms. Thus, without the presence of safety personnel in a rapid improvement team, the lean method may have negative effects on safety mechanisms (Bae and Kim 2008).

The Last Planner system's focus on scheduling activities required for the completion of a task aids in the implementation of task-based safety mechanisms. Visual management's central idea lies in the observation skills of workers and trained personnel on site. Likewise, many safety methods rely on observation skills of the personnel involved.

5S's main objective focuses on workplace management. An efficient workplace management enforces a safer environment as the work practices are more manageable and easier to perform. It also helps identify possible dangers in the surrounding workplace, thus indirectly implementing most safety mechanisms. Autonomation shares its objective with the concepts of the STOP program and safety alerts. This enforces a safer work environment as each unsafe work practice is identified and a remedy is developed before proceeding with the construction. Most safety mechanisms that rely on hazard recognition are aided by the implementation of autonomation.

Case Studies Reviewed

Case studies of companies that have used lean tools and that expressed a safety implication were identified through literature. These case studies provided a significant verification regarding lean methods applied to their projects or used in the company; if there was a safety impact, those were stated. These case studies summarize the lean methods used, the benefits of these lean methods, and their safety impacts.

Autodesk Inc. AEC Solutions division headquarters, Waltham MA (2009)

This case study was featured in the American Institute of Architects report by Cohen describing the successful implementation of integrated project delivery. Risk and reward were shared among the core team members, architects and builder through an incentive compensation layer.

- Lean tools used: Integrated Project Delivery
- Benefits: Faster decision making through an integrated core team
- Safety impacts: Risk and reward shared through an incentive program

Office development project in UK

Johansen and Porter (2003) studied the experience of introducing Last Planner into a UK construction project and describe its impact. Rework was reduced significantly due to the implementations and hence it helped in reducing ”overrun” time.

- Lean tools used: Last Planner
- Benefits: Reduced rework
- Safety impacts: Lower risk due to reduced waste

Implementing lean construction in MT Hojgaard

Thomassen et. al. (2003) reviews the implementation of lean construction in MT Hojgaard, a large Danish construction firm. This case study states that it is 95% certain that accident rates are lower for projects using lean tools as compared to projects that do not use lean. The Last Planner system and the look ahead schedules are extensively used in its projects. It is suggested that lean principles should be used in the design phase of the project.

- Lean tools used: Last Planner, integrated design
- Benefits: Lower disruption of work, lower accident rates
- Safety impacts: 95% chance of lower accidents in lean construction projects

Implementation of Lean construction in Messer (Oak Ridge High School Construction)

Messer utilizes lean construction principles in its projects as they realize that strategies and communication are its two main benefits. Reduced stress, reduced rework, less project chaos and more predictability in projects were defined as key learning.

- Lean tools used: Last Planner, visual management, poka-yoke, continuous improvement
- Benefits: Less chaos, more predictability
- Safety impact: Increased awareness and training about work practices

DPR Construction - Camino Medical Center

The lean design workshop held by DPR illustrates the use of lean tools to help facilitate faster design and to develop safe work practices. A core group of the owner, architect and contractor was formed as the integrated project delivery team. This team found that the implementation of the Last Planner system resulted in reliable workflow as the foreman's knowledge was utilized in the design. Hence, quality becomes the responsibility of all stakeholders in the project.

- Lean tools used: Kaizen, Value Stream Mapping, Last Planner, Integrated Project Delivery (IPD), Integrated Design
- Benefits: Greater collective understanding, reliable workflow, efficient sequence of design work
- Safety Impact: IPD team monitors safety in design, safe work practices, look ahead schedule aids in establishing safety standards

Figure 4 represents the relationship framework between lean methods and safety programs; black boxes in the figure represent a strong impact of the lean method on the safety program. A grey box indicates a conflicting impact of the lean method on the safety program. The white box represents no impact of the lean method on the safety programs.

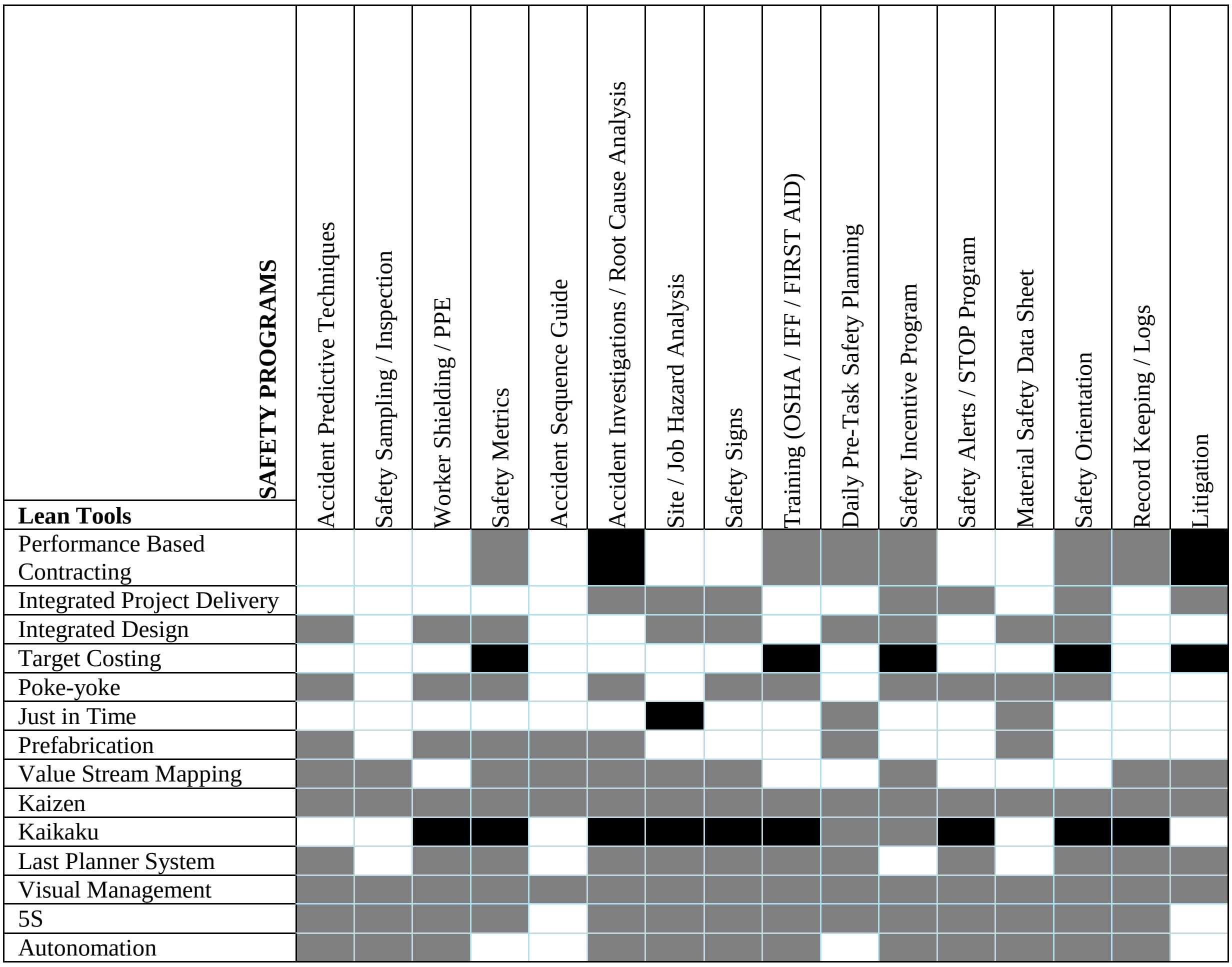

Figure 4: Overview of the safety, planning and control process (Saurin et al. 2008)

Findings

Inferring from the analysis and interpretation of the two theories, it is seen that lean methods impact safety programs strongly 54.91% of the time, represented in Fig. 4 by black boxes. It is also seen that lean methods have 7.6% conflicting impact on safety programs. Figure 5 shows the relationship framework percentage breakdown of the impacts. Thus, the framework is indicative of the synergy between lean and safety.

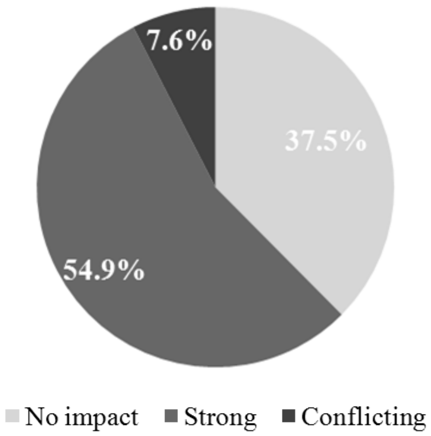

Figure 5: Chart showing the relationship framework percentage breakdown

Figure 6 shows the impact of the respective lean methods on safety programs. Here it is noted that Kaizen, 5S and visual management have the most impact on safety, while Kaikaku and target costing have conflicting impacts on safety programs.

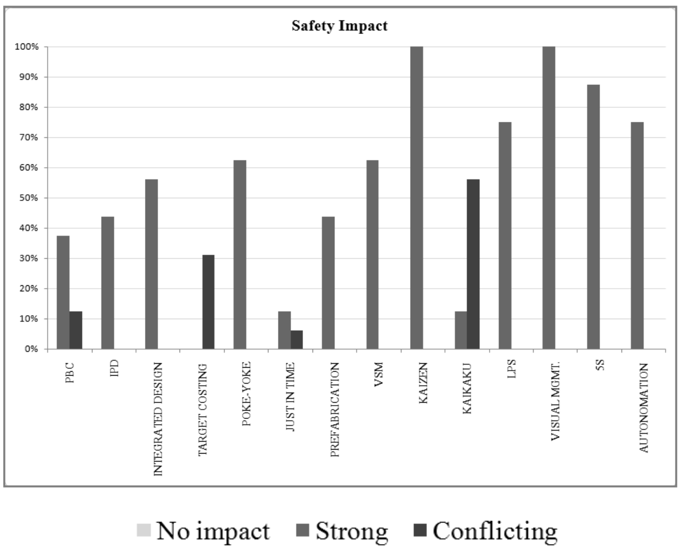

Figure 6: Safety impact

Figure 7 explains the utilization of lean methods by safety programs; the safety incentive program makes maximum use of lean methods. Programs like accident predictive techniques, safety metrics, accident investigation / root cause analysis, and daily pre-task planning, and safety incentive program and orientation utilize lean over 60% of the time. Conflicting impact is less than 15 % for safety programs such as PPE, safety metrics and root cause analysis.

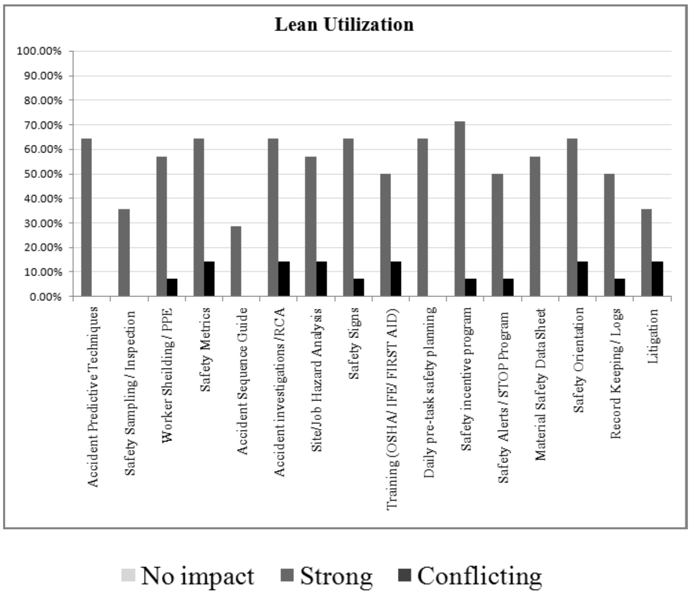

Figure 7: Lean utilization

Discussions

In this study, a relationship has been established between lean methods and safety programs. Lean methods add value and eliminate waste, and safety helps in risk mitigation. Thus, it is widely evident that lean and safety have a synergy that can be harnessed to create a safe, productive workplace. The principles of lean and safety are aligned and the construction industry could benefit by their integration. Research methods involved in this thesis extracted data of lean tools and safety practices through literature and case studies.

Deductive reasoning has been used as a data analysis technique to establish a relationship between the identified lean tools and safety practices. Deductive reasoning defines the cause and effect of each principle. The framework was drawn to facilitate the interpretation of the data collected and visually depict the relationships established. The tools and practices used in the construction industry present a conceptual overlap, which is the primary advantage of deductive reasoning.

Conclusions

The major finding of this research is that there is a 54.9% strong impact of lean tools on safety practices. It was also found that there is a 7.9% conflicting impact of lean tools on the safety practices studied. Kaizen, 5S, visual management and autonomation were found to have the maximum conceptual overlap with safety practices. These findings can be utilized to implement the lean tools that will correspond to the safety practices enforced by the construction company. Lean tools can be implemented easily to support safety practices. The limitation of this research lies in qualitative findings from the data collected. A quantitative analysis involving the documentation of project processes and safety data would further strengthen the relationships identified. On the contrary, a quantitative approach would not provide a perspective on a larger scale.

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