A CRITICAL, THEORETICAL, REVIEW OF THE IMPACTS OF LEAN CONSTRUCTION TOOLS IN REDUCING ACCIDENTS ON CONSTRUCTION SITES

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A number of studies have identified lean construction practices as a strategy for minimising the overall cost and duration of a project by eliminating non-value adding activities and obstacles to a reliable workflow. Although several studies suggest that the Japanese lean production system exposed workers to poor safety conditions and excessive stress in the manufacturing sector, advocates of lean construction argue that the application of lean construction tools could minimise accidents on construction sites. However, there is little or no empirical evidence to support this assertion. A review and synthesis of the literature on lean construction principles and tools reveals a number of ways in which lean can positively impact upon health and safety initiatives on construction sites. The review identifies how their application could improve safety by addressing factors such as poor work methods, physical and mental inability of workers, poor communication and poor planning among other causes of accidents identified by several studies. The review demonstrates the relevance of lean construction tools to key causes of accidents. It concludes by presenting a potential link between the lean construction tools and key causes of accidents, to aid the development of a conceptual framework to empirically investigate this relationship. This study can contribute to developing strategies that can promote improved safety on construction sites.

Keywords: accident causation, construction sites, lean construction tools, safety.

INTRODUCTION

Over the decades, the poor safety record of the construction industry has made it one of the most hazardous industries. This has continued to demotivate workers from working in the industry, posing a great threat to its sustainability and to the economy as well. In an attempt to improve the poor safety records of the UK construction industry, various studies have proposed different methods and practices, besides compliance with the regulations. These include the Corporate Manslaughter and Homicide Act (HSE, 2008), policies like "Revitalising health and safety" (Oloke *et al., 20*08), construction methods like prefabrication (McKay, 2010), government reports such as "One Death is too Many" (Donaghy, 2009) and several research studies on safety improvement (Baxendale and Jones, 2000; Suraji *et al.*, 2001; Haslam *et al.*, 2005; FISCA, 2006; Gambatese *et al.*, 2008; Shalini, 2009). Though the recent statistics showed improvement in the safety records, Hoyle (2009) suggests that

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it may be due to less activities caused by the economic crises. However, these methods considered as best practice have yielded to improvement in the industry safety records (HSE, 2011), but accidents still occur on construction sites, thus, there are still serious safety problems to be addressed. Furthermore, these methods have not considered the potential impact of workers' empowerment and involvement in decision making, the working environment and planning the production processes in reducing accident.

The principles of lean construction consider safety as a significant way improving productivity and minimising cost on construction sites. Based on the principles of lean construction, several tools have been developed to aid its implementation (Abdelhamid and Salem, 2005). The application of these tools appears to promote safety on construction sites. The features of lean construction tools could improve safety by addressing some key causes of accidents on construction sites. However, this need to be further investigated. Based on an analysis of these tools and their relevance to the major causes of accidents on construction sites, the paper demonstrates the relevance of the Last planner system, the 5S (house-keeping) and Error-proofing (poka-yoke) tools to key causes of accidents. The paper is part of a doctoral study aimed at investigating the potential effectiveness and applicability of lean construction principles and tools in promoting safety on construction sites.

LEAN CONSTRUCTION: AN OVERVIEW

Lean construction is a way of designing production systems to minimise waste of materials, time, and effort in order to generate the maximum possible amount of value for the client (Abdelhamid and Salem, 2005). The concept was also defined by Salem and Zimmer (2005) as the continuous process of eliminating waste to meet or exceed customer requirements, while focusing on the value stream and continuously pursuing perfection in the project execution.

The five principles of lean thinking were identified by Womack and Jones (1996) as: value identification from the customer perspective, the value stream identification, achieving value stream flow, achieving customer pull at the right time, and striving for perfection and continuous improvement. In order to achieve a holistic implementation of the concept in the construction sector, Koskela (1992) identified lean construction principles like reduce variability; reduce cycle times; minimise the number of steps, parts and linkages; simplicity; focus control on the complete process; balance flow improvement with conversion improvement; benchmarking; increase output flexibility and increase process transparency. The implementation of lean construction involves developing techniques and tools that conform to lean principles and applying them in project delivery (Abdelhamid and Salem, 2005). Construction academics and professionals have developed and successfully applied Lean construction tools to simple and complex construction projects (Abdelhamid and Salem, 2005). According to Salem *et al.*, (2005), three of the most developed tools are: Last planner system, Error-proofing (poka-yoke), and the 5S (house-keeping). These three tools will now be discussed.

LAST PLANNER SYSTEM (LPS)

This concept was proposed by Glen Ballard based on principles of Lean production to minimize the waste in a system through assignment planning, control and scheduling (Ballard, 2000). Its aim is to improve productivity by eliminating barriers to flow. According to Howell and Ballard (1994), the LPS helps in achieving a reliable workflow. The concept also provides valuable information on workers' abilities that could be used for risk management and effective decision making.

Last planners are usually foremen or site supervisors who decide what work is to be done the following day (Song *et al.,* 2008). The concept is based on Should Can Will analysis (Ballard, 2000). "Should" is a set of all tasks that are required to be carried out in the project master plan. However, due to various constraints not all works may be carried out. Thus, "can" indicates the tasks that can be executed considering the constraint on site. Furthermore, "will" indicates the set of tasks that will be carried out by the last planner based on their abilities (Salem *et al.*, 2005). Therefore, the last planners make commitment on undertaking these particular tasks. Based on this, a weekly work plan is developed (Ballard, 2000; Song *et al.*, 2008). This concept could contribute to a reduction in problems like excessive stress, time pressure, organisational pressure which are considered to be among causes of accidents on site (Suraji *et al.,* 2001; Loughborough and UMIST, 2003; Haslam *et al.,* 2005; FISCA, 2006).

According to studies conducted by Garrahan and Steward (1992) and Green (2001), the lean production system exposed workers to excessive stress, exploitation and very high working hours. Furthermore, Fucini and Fucini (1990) and Kamata (1982) suggest that the system deprive workers of freedom. However, the Last planner system indicates that adopting lean construction rather empowers workers to engage in tasks and methods that correlate to their ability.

LPS emphasises planning and controlling the construction process both at monthly and weekly levels. This could help to eliminate risks and hazards caused by poor planning and control (Nahmens and Ikuma, 2009). At the planning stages, the different risks and hazards are identified and effective decisions are made on how to manage them. There are 3 different planning stages in the LPS: the master plan stage, the Six-Week Look Ahead stage and the Weekly Work plan stage. Safety is incorporated into the production planning and control processes at the three stages (Saurin *et al.,* 2002; Razuri *et al.,* 2007). At the master plan stage, the management select appropriate work methods, make provision for safety equipments, and develop a schedule of tasks based on workers' ability (Sacks *et al.,* 2005). This minimises accidents caused by poor work methods, workers' inability inadequate safety equipments. The selected construction methods are further reviewed, updated and detailed at subsequent planning stages (Saurin *et al.*, 2002).

At the 6- week look ahead stage, works to be carried out in the next one or two months are planned. Safety supervisors develop a plan for supervision schedules to avoid accidents due to poor supervision (Sacks *et al.,* 2005). Furthermore, constraints, risks and hazards associated with the tasks are further identified and minimised to promote safety.

At the weekly work plan stage, works to be carried out the following week are planned and assigned to different workers based on their ability and commitments (Sacks *et al.,* 2005; Sacks *et al.,* 2009). Tasks that could also cause delay or restrict access may be rescheduled (Sacks *et al.,* 2005). This could prevent accidents caused by poor skills among workers. According to Fucini and Fucini (1990), the lean production system exposed workers to poor safety standards. However, the safety measures planned across the three planning stages indicates that safety is an integral part of lean construction practice.

According to Rasmussen *et al.*, (1994), organisational pressure pushes workers to engage themselves in works that are beyond their ability and skills. Therefore, the application of LPS could minimise the likelihood of accidents by correlating workers' skills with the tasks demands in planning the production process (Saurin *et al.*, 2006; Mitropoulos *et al.*, 2007). Furthermore, it empowers the workers to differentiate safe and unsafe work boundaries.

The LPS has certain features that are considered to be helpful in promoting safety. For instance by empowering workers to commit themselves on tasks they could do over a period of time, accidents caused by onsite factors like time pressure, organisational pressure and excessive stress could be minimised. Furthermore, the involvement of the workers in selecting construction methods that match their ability could motivate them and minimise accidents caused by physical and mental disability, excessive stress and exposure to high risks and hazards.

THE 5S (HOUSE-KEEPING)

5S is a lean tool developed from five Japanese words: Seiso (shine), Seiton (straighten), Seiri (sort), Seiketsu (standardise) and Shitsuke (sustain), as a foundation for continuous improvement. Bae and Kim (2007) considered it among the first steps an organisation should take in implementing lean. The 5S process, also known as House-keeping, makes the site conducive for the flow of value-adding activities by maintaining everything in its right place (Abdelhamid and Salem, 2005).

According to Sawacha *et al.*, (1999), Suraji *et al.*, (2001), Haslam *et al.*, (2005) and FISCA (2006), a poorly organised workplace is one of the major causes of accidents on site. The aim of 5S is to systematically achieve cleanliness, organisation and standardisation is a workplace. A well-organised workplace could promote safety and productivity among the workers.

Although Seiso is translated as shine, it means cleaning the site by removing all objects and materials from unwanted places (Abdelhamid and Salem, 2005). It also involves avoiding taking away materials and machines/items that are not required to be used within that period (Bicheno, 2000). The presence of these objects could result in site congestion, obstruction and increase the chances of accidents. Howell *et al.*, (2002) identified failure to see materials placed at wrong location as one of the causes of accidents on site. Therefore, removing such items and maintaining a clean site could minimise the chances of accidents to occur. However, it may be difficult for workers engaged in different trades to be simultaneously involved in cleaning the site.

Seiton involves placing all materials and plants at their optimal location to ease identification and promote orderliness in the workplace (Abdelhamid and Salem, 2005). This reduces congestion, promotes convenience and eases movement and circulation on the site. Hence, the chances of slipping and tripping are minimised.

Seiri involves separating the needed or useful items from the unwanted ones. The concept emphasises that the number of relevant items must also be kept to its absolute minimum to improve productivity as well as safety on the site. The unwanted materials could then be disposed off or removed from the workplace to achieve neatness. This minimises site congestion and makes circulation and movement safer on the site. Besides improving workflow and productivity, Seiri could also assist in minimising accidents on site.

To achieve the maximum productivity and safety on construction sites, a significant level of cleanliness and orderliness is required. Seiketsu involves maintaining the site in such high level of cleanliness and orderliness that will enable the required standard of productivity and safety to be realised (Abdelhamid and Salem, 2005). A poor safety culture among workers on construction sites seems to be another major cause of accidents (Sawacha *et al.*, 1999). Shitsuke emphasises on developing a continuous improvement culture among the workforce (Bicheno, 2000). This would enable the workers to adopt orderliness and cleanliness as a continuous and permanent habit on site.

Studies carried out by Green (1999) and Rehder (1994) associated the lean production system with traffic congestion and environmental pollution. On the other hand, it appears that the application of this concept could help to avoid these problems. Similarly, Fucini and Fucini (1990) suggested that the lean production system expose workers to poor safety standards. However, according to Narang and Abdelhamid (2006), 5S reduces workers exposure to hazards that could lead to injuries and improve ergonomics. Furthermore, according to Bae and Kim (2007), it is a foundation of continuous improvement that could promote productivity and minimise injuries. In addition, Nahmens and Ikuma (2009) suggest that several projects with excellent safety performance adopted house-keeping to minimise trips, falls and other minor accidents on site. Hence, the tool could promote safety on construction sites though there is no empirical evidence to support this assertion.

ERROR-PROOFING (POKA-YOKE)

Poka-yoke is a Japanese word meaning error-proofing (Conner, 2001). It is a lean tool that involves all forms of activities and devices that could prevent an error from occurring (Abdelhamid and Salem, 2005). It is a way of avoiding inadvertent errors in a way that is simple and cost effective. It is a concept that deals with basically what people can do to avoid errors in the workplace. Research conducted by Katsakiori *et al.*, (2009) identified human error among the major causes of accidents on site. Furthermore, Suraji *et al.*, (2001) and Katsakiori *et al.*, (2009) suggests that judgement error among workers is another common cause of accident. Some of these activities include visual inspection, risk assessment and risk analysis among others. Similarly, the error-proofing devices include gadgets that make alarm to alert the occurrence of an unwanted event or automatically shuts down to prevent errors and their impacts. For instance, equipment failure is a major cause of accident (Loughborough and UMIST, 2003; Haslam *et al.*, 2005; Loughborough, 2009). Pokayoke devices could be attached to the equipment and plants to alert workers in case of faults or failures.

In situations where an error occurs, the lean tool could minimise or prevent its impacts on the workers, product or the environment. For instance, the use of safe guards and personal protective devices could absorb the impacts of falling objects which are also among the major causes of accidents (Hughes and Ferret, 2008). Though this concept was used to protect the product under the Toyota manufacturing company, the ideas behind the concept could be used to protect both the product and the workers from the impact of any error. This further indicates the significance of workers' safety in Lean construction. According to Saurin *et al.*, (2006), the devices could also protect workers from excess heat, sound, noise, dust and some other site hazards. In some cases, error-proofing devices could be in the form of fixture, alarms and warning gadgets used to prevent workers from approaching or crossing into unsafe boundaries on site.

FINDINGS

Several studies have identified various causes of accidents on construction sites. A large number of these causes appear to be factors and activities related to the site. By minimising these factors considered to be causes of accidents on site, the rate of accidents could be significantly reduced. Hence, the safety of workers could be improved.

From the above critical analysis of the impacts of implementing various lean construction tools in addressing onsite causes of accidents, a potential relationship can be summarised in table 1 below. The table shows the major onsite causes of accidents identified by various studies and the tools considered to be relevant in minimising such particular causes of accidents. For example, poorly organised workplace has been identified as one of the causes of accidents on construction sites (Sawacha, 1999; Suraji *et al.*, 2001; FISCA, 2006). Lean construction tools such as 5S (workplace organisation or housekeeping) are considered as to have the potentiality of addressing this problem.

Table 1: Lean tools and relevant onsite causes of accidents

Lean construction tools	Tools' Features	Onsite Causes of Accident
Last planner system	workers’ empowerment, correlation of work methods with workers’ skills, correlation of tasks with workers’ ability, pretask hazard analysis, workers’ involvement, weekly work planning, supervision plan.	poor work methods, excessive stress, poor supervision, poor planning and control, poor coordination of workers, poor coordination of simultaneous activities, physical and mental inability, nature of work, Time pressure, organisational pressure
5c/5s, (House-keeping)	clean workplace, improved ergonomics, materials and plants’ organisation, workplace organisation, site neatness, and easy movement, circulation	site congestion, poor working environment, site hazards (dust, noise e.t.c), trips and slips, working in confined space, working at height, falling objects
Error-proofing (Poka-yoke)	visual inspection, personal protective devices, hazards warning and alert systems, equipment failure alert	judgement error, human error, equipment failure, falling objects

DISCUSSIONS

The principles of Lean thinking emphasise on delivering value to the client while continuously improving the production process to eliminate non-value adding activities and any interruption to the flow of value, which are collectively considered as waste. Hence, Lean construction considers occupational accidents as sources of waste. The prevention of accidents could prevent the waste of productive hours and compensation costs which could otherwise add to overall project cost and duration (Sacks *et al.*, 2005). In order to realise this, lean plans the production process and the working environment in a way that reduce workers' exposure to hazards. However, several critical observers of lean production suggest that the system, which originates from the Japanese Toyota automobile company, has a poor approach to human resource management (Green, 2001). Studies such as Fucini and Fucini (1990); Garrahan and Steward (1992); Rehder (1994) and Turnbull (1998) associated the system with excessive stress, exploitation, surveillance and poor quality of life.

Similarly, Fucini and Fucini (1990) and Rehder (1994) suggest that the system expose workers to poor safety standards and lack of freedom in the automobile industries. Furthermore, according to Green (1999) and Rehder (1994) the system resulted in traffic congestion and environmental pollution in the manufacturing sector. On the other hand, Howell and Ballard (1999) argued that lean is a step toward accident reduction on construction sites. Furthermore, a number of studies (Thomassen *et al.*, 2003; Saurin *et al.*, 2004; Saurin *et al.*, 2006; Mitropoulous *et al.*, 2007) suggest that the application of lean construction tools could improve safety on construction sites. However, Nahmens and Ikuma (2009) argued that there is no empirical evidence to support the relationship.

The doctoral study investigates the existence of this relationship. In order to satisfy its aim, the review demonstrates that lean construction tools have certain features that could contribute to reducing causes of accidents. A matrix will be used to demonstrate areas of possible interaction between lean construction features and the onsite causes of accident. Furthermore, a conceptual framework is being developed to wholistically show how the various key lean concepts could promote safety on site by identifying lean construction tools whose application is considered to have the potential in contributing to reduce onsite causes of accidents identified by various studies (Suraji et al, 2001; Haslam *et al.*, 2005; Loughborough, 2009 and Donaghy, 2009). An exploratory study will be conducted among lean experts, health and safety experts and site managers working in the UK construction organisations to investigate the relationship based on their experience with site activities and causes of accidents.

CONCLUSION

Several critical observers of lean production associated the system with excessive stress, exploitation, surveillance, poor quality of life, lack of freedom and poor safety standards. However, the features of Lean construction tools pose a strong argument to these views.

The review indicates that Lean construction tools have certain features like house-keeping, workers empowerment and error-proofing which could be used to reduce accidents caused by trips, slips, congestion, excessive stress and site hazards. Lean construction tools could also help to address factors such as poor work methods, physical and mental inability of workers, poor communication and poor planning.

The application of these tools could help to minimise hazards, prevent errors, promote workers' involvement, develop decision making skills and reduce exposure to risks and hazards. Therefore, the implementation of lean construction tools in project delivery could besides reducing cost and time, also help to promote workers' safety. However, there is little or no empirical evidence to support this assertion, which is what this research seeks to collect in the future.

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