Literature Review on Lean Implementation Cases in the Construction Process

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Abstract

Lean construction is a concept still new to many in the construction industry around the world. All construction activities can be divided into two; conversion activities which produce tangibles and flow activities which bind such conversion activities during the delivery process of the output. Although all activities expend cost and consume time, Lean Principles states that only conversion activities add value and these should be made more efficient, whereas non value-adding flow activities should be reduced or eliminated. By eliminating wasteful non value-adding activities, processes can become 'lean' which provide 'more with less' resources.

Research into these lean principles in construction has found that considerable waste lies in flow activities of the construction process. However, construction contractors are mainly aware of the waste associated with material usage during the construction process and are ignorant on wastes associated with flow activities. Previous research has found major causes and types of wastes in flow activities and also that they significantly hinder performance and efficiency in the Sri Lankan construction industry. Hence, it is high time that the Sri Lankan construction industry start considering lean construction to improve its overall performance. However, the Sri Lankan construction industry lacks an implementation framework to implement lean principles into construction processes. The research study, on which this paper is based on, ultimately aims to develop such an implementation framework through an action research study for Sri Lankan construction contractors.

Other countries such as the United Kingdom, United States of America, and Singapore have reaped sustainable benefits through proper implementation of lean construction. Extant literature offers several case studies on such lean construction implementations. Hence, this paper offers a critique on these case studies, as an initial step to develop an implementation framework for Sri Lanka. Accordingly, few case studies are critically compared with their construction settings. The findings reveal several similarities in the lean implementation in different settings and deviations are also identified. The paper finally, identifies the most commonly applied lean techniques for implementing lean principles in construction processes and its benefits. It is hoped that the key literature findings arising from this stage, will ultimately assist to develop a conceptual implementation framework using lean principles for the construction process.

Key words: Lean Implementation, Construction Process, Review of case studies

1.0 Introduction

1.1 Lean Principles

Lean production was developed by Toyota led by Engineer Ohno who was dedicated to eliminate waste (Howell, 1999). The term 'lean' was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production (Womack et al., 1991). Waste is defined by the performance criteria for the production system. Failure to meet the unique requirements of a client is waste. Moving towards zero waste shifts the improvement focus from the activity to the delivery system. (Howell, 1999). Similarly, Koskela (2004) determined that lean production is 'lean' because it uses less of everything when compared with mass production**.** Howell and Ballard (1998) redefined the goals of lean thinking as performance against three dimensions of perfection: i) a unique custom product, ii) delivered instantly, with iii) nothing in stores. This is an ideal that maximizes value and minimizes waste.

1.2 Lean Construction

Lean construction is a concept still new to many in the construction industries around the world (Senaratna and Wijesiri, 2008). All construction activities can be divided into two; conversion activities which produce tangibles and flow activities which bind such conversion activities during the delivery process of the output. Although all activities expend cost and consume time, Lean Principles state that only conversion activities add value and these should be made efficient, whereas non value adding flow activities should be reduced or eliminated (Koskale,1993). Research into these lean principles in construction has revealed that considerable waste lies in flow processes of construction. By eliminating waste activities, processes can become 'lean' which provide 'more with less' resources (Womack and Jones, 2003).

1.3 Background of the Research

Recent findings (Senaratne and Wijesiri, 2008; Senaratne & Nissanka, 2009) have revealed some of the frequent flow activities that generate waste and their causes in the Sri Lankan Construction Industry. Traditional thinking in most Construction organisations focuses on conversion activities and tend to *ignore flow and value considerations*. Waste is generally associated with waste of material in the construction process, while activities such as inspection, delays, transportation of materials and others are *not recognized* as non value-adding flow activities *that may lead to waste.* Common wastages include; waste due to wait periods, defects, waste due to design errors, transport/ handling time, activity delays, waste due to operations, excessive space / stock, and rework. The causes of wastes include; late information, environmental causes, poor management control, poor planning, poor quality of resources, shortage of resources, defective information, and unclear information. The majority of flow wastes and their causes are identified as controllable.

These flow wastes are recognized as a major weakness, which hinder the performance and efficiency of the Sri Lankan construction industry (Senaratne and Wijesiri 2008). Previous studies (Senaratne and Wijesiri (2008), Senaratne and Nissanka (2009) conclude that the domestic construction industry workforce is ignorant of these flow activities that create waste and hinder construction performance. Through an opinion survey of the construction workforce, Senaratne and Wijesiri (2008) establish that lean construction is suitable and acceptable in the Sri Lankan context. This research aims to develop an implementation framework through an action research study of the Sri Lankan construction industry and achieve long-term, sustainable benefits by adopting lean construction.

Extant literature offers several case studies on such lean construction implementations. Hence, this paper offers a critique on these case studies, as an initial step to develop an implementation framework for Sri Lanka. Accordingly, a few case studies are critically compared with their construction settings. The findings reveal several similarities in the lean implementation in different settings as well as deviations that are also identified. Finally, the paper identifies the most commonly applied lean techniques for implementing lean principles in the construction process and its benefits. It is hoped that the key literature findings that arise from this stage, will ultimately assist to develop a conceptual implementation framework using lean principles for the construction process.

1.4 Lean Techniques

Egan (1998) revealed that Lean Construction presents a coherent synthesis of the most effective techniques for eliminating waste and delivering significant sustained improvements. The philosophy of lean is an umbrella that covers a multitude of tools and techniques commonly used within the industry (Salem et al, 2005). Several lean techniques were developed for the manufacturing industry by many authors, and Table 1.1 summarizes some of the lean techniques that relate to the construction industry. This paper will not describe all the techniques mentioned in Table1.1 in detail as the focus is on analysing lean implementation cases. However, more details on the given techniques could be found in Thilakarathna & Senaratne (2012).

Table 1.1: Lean Construction Techniques

Lean Techniques	**Definition**
Last Planner (LP)	Last Planner system is a technique that shapes workflow and addresses project variability in construction. LP has been created to maximize reliability of the work /material / information flow to minimize waste in time / money in project processes and to maximize customer value (Ballard, 2006).
Just In Time	JIT manufacturing has the capacity, when properly adapted to the organisation, to strengthen the organisation's competitiveness in the marketplace substantially by reducing wastes and improving product quality and efficiency of production. (Cheng and Podolsky, 1993)
3D Models	3D modelling is the process of developing a mathematical representation of any three-dimensional surface of object via specialized software. The model can also be physically created. The use of 3D models for improving constructability has typically included model based design and coordination by combining multiple models into one and running clash detection (Staub-French and Khanzode, 2003)

Lean Techniques	Definition
Increased Visualization	The increased visualization lean tool is about communicating key information effectively to the workforce through posting various signs and labels around the construction site. Workers can remember elements such as workflow, performance targets, and specific required actions if they visualize them (Moser and Santos 2003).
Value stream mapping	A value stream map is a comprehensive model of the project that reveals issues hidden in current approaches (Howell and Ballard, 1998). Value stream maps can be identified as Process Flow Charts that identify what action releases work to the next operation
Stopping the line	Stopping the line in manufacturing prevents the release of defective work downstream. Planning at the assignment level is the place to "stop the line" in construction to assure a reliable flow of work and no defective assignments are released downstream (Howell and Ballard, 1998)
Reverse Phase Scheduling (RPS)	RPS is a pull technique is used to develop a schedule that works backwards from the completion date by team planning (Ballard and Howell 2003). Phase scheduling is the link between work structuring and production control, and the purpose of the phase schedule is to produce a plan for the integration and coordination of various specialists' operations.
Huddle Meetings	Two-way communication is the key of the daily huddle meeting process in order to achieve employee involvement. As part of the improvement cycle, a brief daily start-up meeting was conducted where team members quickly give the status of what they had been working on since the previous day's meeting, especially if an issue might prevent the completion of an assignment (Schwaber, 1995).
Make it flow	Product components should be in constant motion, that is without stopping. In construction, this may mean repackaging work so that parts of the project can proceed without completion of others (Howell and Ballard, 1998)
Kaizen	Kaizen is a system of continuous improvement in quality, technology, processes, company culture, productivity, safety and leadership. Kaizen implicates cost reduction and zero defects in the final product
Five S	Five S is a set of techniques providing a standard approach to housekeeping within lean (Kobayashi 1989; Hirano 1998) visual work place: a place for everything and everything in its place. It has five levels of housekeeping that can help in eliminating wasteful resources
Fail Safe Quality	Shingo (1986) introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process. Fail safe for quality relies on the generation of ideas that alert for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected.
Off site manufacturing (OSM) Prefabrication	OSM is largely seen as offering the ability to produce high-volume, high-quality products based on the efficiencies of general manufacturing principles common to many industries (Cooperative Research Centre for Construction Innovation, 2007). Manufacturing and assembling process, whereby, construction components are made at a location different from the place of final assembly, under specialized facilities with different materials. May lead to better control of the inherent complexity within the construction process

Lean Techniques	Definition
Target Value Design	TVD is a management practice that seeks to make customer constraints drivers of design for the sake of value delivery (Ballard, 2011). TVD is a method that assures customers get what they need (where it is valued by customers) and also a method for continuous improvement and waste reduction

2. Lean Implementation

2.1 Lean Project Delivery in Phases

Ballard (2000a) divides the lean Project Delivery System into four interconnected phases; Project Definition, Lean Design, Lean Supply, and Lean Assembly. Addressing sustainable issues such as economic, social, and environmental values as the requirement of an owner, Lean may act from the project definition to the construction phase.

Project Definition: Defining value and waste is critical and value management in lean production is an attempt to maximize value and eliminate waste (Bae and Kim, 2007). Ballard (2011) revealed that cost, time, location and other constraints are conditions that must be met in order to deliver value to customers. Target Value Design is a management practice that seeks to make customer constraints drivers of design for the sake of value delivery. According to Zimina et al (2012), target costing stands for a range of techniques and methods as part of traditional cost management, such as contract and cost management and target cost contract. It includes several phases: client brief, procurement advice and budget; cost planning and control of the design stage.

Lean Design: The building design process involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, under a highly uncertain environment (Tzortzopoulos and Formoso,1999). Moreover, it is a very difficult process to manage and usually lacks effective planning and control to minimize the effects of complexity and uncertainty. Therefore, Huovila et al (1997) proposed a conceptual frame work for managing the design process in which three different views of this process are considered; a) design as a conversion of inputs into outputs; b) design as a flow of materials and information; and c) design as value generating process for the clients. Hence, recent researchers (Bae and Kim, 2007; Formoso et al, 1998; Tzortzopoulos and Formoso,1999) discussed the application of some lean principles to design management.

Lean Supply: Pasquire and Connolly (2002) revealed that Lean production has made significant improvements within the manufacturing sector and there is a simple argument that increasing the amount of factory based manufacturing of building, their components, sections and elements would form one logical method for incorporating lean production into construction project delivery. Lean techniques such as Just in time (JIT), off site manufacturing (OSM) reduce damages and materials. Moreover, these methods may reduce the various sources of extra inventory. Further, Pasquire and Connolly (2002) concluded that lean manufacturing has a direct application in construction through the pre-assembly of building components and considerable benefits are available as a result of off-site manufacturing.

Lean assembly: Lean supply is the phase beginning with the first delivery of resources to the site and ending with project turnover (Salem et al, 2006). Moreover, it is particularly important to general contractors in the construction implementation stage. Further Salem et al (2006) expressed that there are approaches to Lean Assembly and these are flow variability, process variability, transparency, and continuous improvement.

Having identified the different phases in lean construction and related lean techniques that can be developed in lean construction, this paper summarizes different lean implementation cases implemented in different parts of the world with their main findings.

2.2 Lean Implementation Examples in Different Phases in a Construction Project

Over the last ten years an increasing number of companies have implemented lean construction practices in an attempt to improve the performance in construction projects. Most companies and researches have reported satisfactory results from their implementation (Alarcon et al, 2005). However, there is still a need to provide more extensive analysis of the empirical evidence available, to assess the impact of the implementation of lean construction. Extant literature offers several case studies on such lean construction implementations, and details of the research studies are summarized in Table 2.1.

Table 2.1: Lean Implementation cases

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Project Definition and Lean Design				
Target Value Design: using collaboration and a lean approach to reduce construction cost ***Zimina,D., Ballard, G., Pasquire, C.,2012***	To find out how to cure the shortcomings of mainstream costs and contract management approach that result in regular cost over runs and client dissatisfaction	Action Research carried out on 12 construction projects in USA with a number of clients and construction industry companies	Target Value Design	Systematic application of target value design leads to significant improvement of project performances. The final cost of each project was on average 15% less than market cost. It was noticed that the positive effects of lean principles and methods on project management become more obvious as project complexity and the corresponding level of risk increase.
Sustainable Value on Construction project and Application of lean construction Methods ***Bae,J.W., and Kim, Y.W., 2007***	To examine how current lean construction tools and methods impact the construction and operation of sustainable facilities	Literature Synthesis	Target Costing, Just-in-time Prefabrication, Value Stream Mapping kaizen	**Economic perspective**; possible upfront cost reduction, resource saving, operating cost reduction, and high performance capability **Social perspective**; work place safety, occupant health, community wellbeing, loyalty among stakeholders, and external image improvement **Environmental Perspective**; reduce resource depletion, pollution prevention by eliminating wastes, and resource preservation

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Considerations on Application of Lean Construction Principles to Design Management ***Tzortzopoulos, P. and Formoso, T. (1999)***	To analyse on the application of some lean construction principles to design management	Two Case Studies developed in Brazil with the development of a model for managing the design process for a small-sized house building company	Modelling the process using Flow Charts and Input-output chart	There are some gaps in the knowledge concerning the application of the theory in design. The development and implementation of models for managing the design process in practice is an important source of reflection and as such a discussion approach should be carried out in the future.
Lean Supply				
Leaner construction through off-site manufacturing ***Christine L Pasquire****, C. L.,* ***and Connolly, G.E.,*** *2002*	To examine the integration of lean production into the pre-assembly of building components	Case studies supported with multidisciplinary workshops managed by an industrial steering group with the support of major construction, consultants and client organizations	Off-site Manufacturing. Kaizen Kaizen Formula One Just-In-Time	Lean manufacturing has a direct application in construction through the pre-assembly of building components and considerable benefits; *reduction of on-site labour, welfare cost, health & safety risk, coordination interface, just in time delivery, reduce opportunities for waste, improved cost certainty, zero defects* as a result of off-site manufacturing
Lean Production, value chain and sustainability in precast concrete factory –a case study in Singapore ***Peng, W. And Pheng, S. 2010***	To identify the contribution of the lean concept to achieve sustainability in Precast Concrete Factories. By using appropriate lean principles, the precast concrete industry can move closer towards sustainability	Quantitative assessment of each non-value adding activity and qualitative assessment of activities that cannot be quantitative though semi-structured interviews of 17 pre-casters	Lean Production philosophy Value Chain	Lean Production philosophy can provide a lean benchmark for construction materials. It offers relative measurements of the sustainability factors for construction materials based on the best operations that can be achieved for long term comparison. Lean Production philosophy has practical contributions to sustainable development. By eliminating non-vale activities pre-casters can achieve more environmentally friendly construction materials

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Lean Assembly				
Site Implementation and Assessment of Lean Construction Techniques ***Salem.O., Solomon.J, Genaidy,A. and. Luegring, M. 2005***	To test the effectiveness of some lean construction tools that can be applied in medium size construction firms	Direct observations, interviews, questionnaires and documentary analysis through the lean implementation measurements standards and performance criteria.	Last planner, Increased Visualization, Daily Huddle Meetings, First run studies, the 5S process, Fail safe for Quality.	Last Planner, Increased Visualization, Daily Huddle Meetings and First Run Studies achieved more effective outcomes whereas, 5S and Fail Safe for Quality did not meet the expectations of the tool champion and the research team. Last Planner is ready to be implemented where Visualization, daily huddle meetings, First Run Studies and 5S process are to be implemented with some modifications. Fail safe for quality to be re-examined.
Assessing the impact of implementation lean construction ***Alarcon,L.F, Diethelm, S., Rojo, O., and Caldero, R., 2005***	To analyze some of the main impacts and lessons learned from the Lean Implementation.	Data obtained from the authors own experience and case studies found in the Lean Construction Literature ***(Koskela 2000, Ballard 2000, Bernardes 2001)***	Last Planner System (LPS)	The poor use of information generated during the implementation of Last Planner System was identified as the main barrier for a more complete implementation. Early in the project, the research team had attempted to introduce Work Plan, a computer system developed by Choo (Choo et al 1999) for Last Planner System implementation. However, the companies did not feel comfortable using this system
Last planner and Integrated Project Delivery ***Cho, S, and Ballard, G., 2011***	To figure out the relationship between Integrated Project Delivery, Last Planner and Project Performance	Survey of 'Lean' projects known to adopt Last Planner	Last Planner System (LPS)	There is a significant correlation between the implementation of Last Planner and project performance; the sum of cost and schedule reduction percentage. If a project implements Last Planner more, it achieves project performance better than those employing Last Planner

Overall, the above findings reveal that lean techniques used in the manufacturing industry can be adapted in the construction industry in different phases of construction. Moreover, many researchers such as Salem et al, 2005, Ballard (2011) and Singleton and Hamzeh(2011) concluded that in construction projects where more lean techniques are applied, project performance and effectiveness are high. This paper will select lean implementation cases in lean assembly phase for a detailed review. Lean assembly phase is found to be more relevant when compared to other phases, considering the ultimate aim of the this research is to develop a lean implementation framework for the construction processes for Sri Lankan construction contractors.

3. Lean Assembly Implementation

Lean Assembly is particularly important to general contractors who develop human and technical structure for construction activity (Salem et al (2006). Previous studies such as Senartna and Wijesiri (2008), Ekanayake and Senartne (2010) conclude that the domestic construction industry workforce is ignorant of the flow activities that create waste and hinder construction performance. Hence, it is vital to develop an implementation framework in the context of Lean Assembly for the Sri Lankan Construction Industry. The aim of this study is to develop such an implementation framework through an action research study for Sri Lankan construction contractors and achieve long-term sustainable benefits by becoming lean. As such it is important to critically evaluate the above three studies carried out in the phase of Lean Assembly in Table 2.1. The next section of this paper will discuss the similarities and deviations of the lean implementation of the above three studies and finally a summary will be given in Table 3.1.

3.1 Evaluation of Lean Assembly Implementation Cases

Case A: Site Implementation and Assessment of Lean Construction Techniques O. Salem, J. Solomon, A. Genaidy, and M. Luegring Lean Construction Journal 2005

The aim of this study was to test the effectiveness of some lean construction tools; Last Planner, Increased visualization, Daily huddle meetings, First run studies, the 5S process, Fail safe for quality that can be applied in medium size construction firms. Data was collected through direct observations, interviews, questionnaires and documentary analysis. The effectiveness of lean construction was evaluated through the lean implementation measurements standards and performance criteria.

The study focused on the first phase of a four-floor university garage project. This garage was a cast-in-place reinforced concrete structure which is to be built on top of the garage. This is a five story building that consists of a steel frame and reinforced masonry walls designed for retail shops and dormitories. The size of the garage is about 133,500 sq.ft. Participants in the lean construction implementation study were limited to the general contractor, the formwork subcontractor and the rebar subcontractor.

The findings revealed that Last Planner, Increased visualization, Daily huddle meetings and First run studies achieved more effective outcomes than 5S and Fail Safe for Quality, which did not meet the expectations of the tool champion and the research team. Further, the study disclosed that Lean construction is not widely implemented in US construction industry yet, as Lean concepts are relatively unfamiliar. For both General Contractor staff and sub contractors this project was the first opportunity to use lean techniques for operational purposes. Moreover, the findings divulged that initially in this project, changing mind sets and behaviour with lean thinking became a challenge, and this had a great impact on the 5S process implementation. The

unfamiliarity with or misunderstanding of lean concepts and implementation were the greatest barriers at the beginning of the project.
To eliminate this barrier, the general contractor had offered training classes, provided recognition to promote behavioural change, encouraged employee involvement and rewarded real improvement. As a result, the work force showed a tremendous amount of learning and improvement with regards to lean thinking and implementation. The findings suggest further training will be a key aspect of implementation and success of the Last Planner on the construction site. The staff and workers will need to be trained to use this tool effectively. This training may result in an increased burden in the early stages of implementation but over the long term it will serve to increase the efficiency of construction companies and more than make up for the initial investment in training.

The authors had also found that the lean manufacturing tools can be modified for specific use in construction projects and successfully implemented. The commitment of the top management for implementation of these tools may prove to be the most important factor for the successful implementation of these tools. The authors observed a complete attitude shift among project participants for this project; initially, the project manager questioned the applicability of these lean tools at the site, however, by the end of the project, everyone on site participated in the implementation of these tools. The workers enjoyed being a part of a structured planning and decision making process.

Finally the study concluded that Last Planner is ready to be implemented whereas Visualization, Daily Huddle Meetings, First Run Studies and 5S process are to be implemented with some modifications, and Fail safe for quality should be re-examined.

Case B: Assessing the Impact of Implementation Lean Construction
Luis F. Alarcon, Sven Diethelm, Oscar Rojo and Rodrigo Calderon
Proceedings IGLC, July 2005, Sydney, Australia

The aim of this study was to analyze some of the main impacts and lessons learned from the implementation. This study discusses difficulties and barriers for implementation, productivity improvements, variability reduction and effectiveness of implementation strategies. The study declares that the production Management Centre (GEPUC) from the Catholic University of Chile, promotes long term research and implementation alliances among companies to pursue common goals. The companies undertake their improvement programs working as a group. This allows collaborative sharing of problems and solutions to the individual process improvement. Some of the important activities developed under this scheme are; periodic meeting, Workshops, Preliminary Sessions and Site visits by the researchers. More details can be found in these methodological aspects in Alarcon et al 2002a and 2002b)

Data was obtained from the authors own experience and case studies found in the Lean Construction Literature (Koskela 2000, Ballard 2000, Bernardes 2001). A data base of 77 Chilean projects from 12 companies was used to analyze the impact of the introduction of the Last Planner System on different aspects of project performance. The project sample included: 39 low rise building projects, 15 high rise building projects, 11 heavy industrial projects, 12 light industrial constructions. Data was collected during the research process carried out to develop implementation strategies for Lean Construction and to measure the impacts of those strategies. The analysis considered implementation of projects over three years.

Projects were classified in to two groups according to the level of implementation of the Last Planner System. The first group consisted of 10 projects with a basic level of implementation with an emphasis on the Weekly Work Plan, and only informal look-ahead planning. The second group included 6 projects that had formal look-ahead planning processes and one case of formal workable backlog and learning processes.

The findings revealed that the poor use of information generated during the implementation of Last Planner System was identified as the main barrier for a more complete implementation. Early in the project, the research team had attempted to introduce Work Plan, a computer system developed by Choo for Last Planner System implementation (Choo et al 1999). However, the companies did not feel comfortable using this system. Therefore, the research team had to develop a prototype computer system named "Plan Control", working closely with the companies and maintaining a continuous interaction with them during the system design. One of the main impacts of this tool was a more completed implementation of the LPS in projects that used" Plan Control". These resulted in higher PPC performance for those projects that used IT support compared with projects without IT support.

This study explored the benefits in implementing Last Planner System; this included working in a collaborative approach, with different training actions, sharing experiences and information among companies. This system produced a number of benefits, such as the development of skills for implementation, development of healthy competition among companies that are working together, and fast learning from successes and failures. Further, participating companies have realized that things are possible because there is always a project that can be done and that they can learn how to do it better the next time. Some implementation barriers were also identified in this study with regard to the implementation of LPS. These barriers include; a) Time: Lack of time for implementing new practices in the projects, b) Lack of training c) lack of organizational elements to respond to LPS, d) Lack of Self Criticism and limited the capacity to learn from errors, e) Low understanding of the concepts (production unit, work flow, screening, shielding, and pulling in LPS), f) Inadequate administration of the necessary information to generate a learning cycle and to take corrective action, g) Weak communication and transparency among participants, and h)Lack of integration of Client, Subcontractors and suppliers.

Finally this study recommended that Last Planner System is an effective tool to improve reliability of planning in projects and IT tools can support a more complete and standard implementation of the LPS in projects.

Case C: Last Planner and Integrated Project Delivery
Seongkyun Cho and Glenn Ballard
Lean Construction Journal 2011

The aim of this study was to figure out the relationship between Integrated Project Delivery (IPD), Last Planner (LP), and project performance. Three research questions were designed; i)

Does the use of Last Planner improve project performance? ii) Does Integrated Project Delivery show different project performance? iii) Do IPD projects use LP? Only Research question 1 is considered for this discussion since the other two do not directly relate with lean implementation.

The research methodology was adopted as survey of 'Lean' projects known to adopt LP, including IPD projects, to determine the correlation between LP implementation and project performance. Three hypotheses were assumed for this study, the first hypothesis being, "*if a project implements last Planner more, it achieves better project performance better than those employing LP less". Th*is hypothesis was considered for this evaluation since the other two hypotheses were only related to the research question II and III. This study identified the independent variable of the hypothesis as the degree of implementation of Last Planer (LP). To measure this concept, the authors have developed indicators to be scored based on the following elements.

i. *Pulling Production*: each worker investigates the readiness of the next workers before execution of tasks (Tommelein, 1998)
ii. *Lookahead process*: each front line supervisor removes constraints such as prerequisite work, contractual approvals, sequential inappropriateness, insufficient resource, inadequate duration, funding problems and problems found in first run study before execution of its tasks. Constraints tasks are not eligible for inclusion on daily or weekly work plans (Ballard, 2000).
iii. *Learning from breakdowns*: failures to complete planned tasks are analyzed to root causes and actions are taken to prevent reoccurrence (Ballard, 2000).
iv. *Phase scheduling*: every handoff in a phase should be defined by collaboration of all relevant specialists in the phase before the handoff is produced (Ballard et al, 2003).
v. *Distributed Control*: work is planned in greater detail as you get closer to execution, and planning is done collaboratively by those who are to do the work (Ballard et al, 2003).

The above five indicators were transformed into survey questions and answer type with scoring rules were established. The sum of scores of the survey questions is the total degree of Last Planner implementation of a project. Moreover, in this study, the dependent variable, project performance was identified and the measure of the project performance was; sum of the cost reduction ration (actual cost under final approved budget) + duration reduction ratio (%) (actual duration relative to final approved schedule). Data was analyzed in the regression model and presented as a scattered plotting and a linear regression line.

Findings revealed that there is a significant correlation between the implementation of Last Planner (LP) and project performance and the authors successfully supported the hypothesis "*if a project implements last Planner more, it achieves better project performance better than those employing LP less"*

3.2 Comparison of above three cases

Three studies conducted for implementing lean techniques in the Lean Assembly phase were summarized as Case A, Case B, and Case C and Table 3.1 presents the comparison of these three studies evaluating their similarities and deviations.

Table 3.1 : Comparison of lean Assembly Cases

Criteria	**Case A**	**Case B**	**Case C**
Phase of construction	Lean Assembly	Lean Assembly	Lean Assembly
Main Lean Technique applied	Last Planner System	Last Planner System	Last Planner System
Lean Implementation	Last Planner is ready to be implemented	Last Planner System is an effective tool to improve reliability of planning in projects	Last Planner achieves better project performance
Observations			
Attitude shift in the project participants	changing mind sets and behaviour with lean thinking became a challenge initially	development of skills for implementation	Not observed
Use of Information generated	Not observed	poor use of information generated during the implementation	Not observed
Time Factor	Not observed	Lack of time for implementing new practices in the projects	Not observed
communication and transparency	Not observed	Weak communication and transparency among participants	Not observed
integration	Not observed	Lack of integration of Client, Subcontractors and suppliers.	Not observed
Understanding of Lean concepts	Lean concepts are relatively unfamiliar	Low understanding of the concepts	Not observed
Requirement of Training	Training will be a key aspect and the staff and workers will need to be trained	Lack of training	Not observed
Behavioural Change	Changing mind sets and behaviour with lean thinking became a challenge initially	Not observed	Not observed
The commitment of the top management	The commitment of the top management for implementation of these tools may prove to be the most important factor in successful implementation	lack of organizational elements to respond to LPS	Not observed

The Last Planner lean technique is commonly applied in all cases and it was identified as an effective lean technique in construction processes. Findings revealed further that, changing mind sets, low understanding of the concepts and behaviour with lean thinking are the challenges faced in implementing lean technique and as such training will be a key aspect to overcome most of these barriers.

4.0 Conclusions and Way Forward

This paper reports on the literature review of Lean Implementation cases in the construction process in order to develop a lean implementation framework through an action research study for Sri Lankan construction contractors. Initial discussions in this paper was on Lean Principles, Lean Construction and Lean Techniques that can be applied in the construction projects identifying different phases such as Project Definition, Lean Design, Lean Supply and Lean Assembly. Lean Techniques especially applied in Lean Assembly were also disclosed in order to develop a framework for the Sri Lankan Construction Industry. Lean Implementation cases, obtained from a literature review, were first identified with their main observations. Subsequently, three studies that relate to lean assembly phase were critically evaluated to identify their similarities and deviations in implementing lean techniques in the construction process.

Preliminary literature review into lean construction implementation was carried out (Thilakarathna and Senaratne, 2012) to explore the lean techniques and their applications with benefits and barriers. Following which, this paper presented the lean implementation cases through literature survey to identify the most commonly applied lean techniques and their implications in the construction process in different project settings. The next objective of the research was to explore the current status of implementation of Lean techniques within construction projects in Sri Lanka through a preliminary survey by interviewing C1 contractors in Sri Lanka. Following this survey results, a conceptual framework would be developed which is expected to be tested through an action research phase.

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Use of Mathematical Modelling for Planning Municipal Solid Waste Collection

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Abstract

When people hear the term "Solid waste management" they immediately think of recycling. But it is not the aspect that requires the greatest expenditure, or has the greatest impact on the urban environment and public health. It is the "collection" of municipal solid waste that has a significant impact on both municipal expenditure and public health.

The decisions pertaining to solid waste collection and transportation are basically based on the perception and experience of drivers and other minor staff working at the municipalities. The optimum utilization of available resources within the municipalities for day to day collection of waste is essential as it makes the biggest demand on the Municipal budget.

Therefore the main objective of this research is to develop a mathematical model as a tool for decision making in municipal solid waste collection. This research has utilized two mathematical models known as "Network Analysis" and "Transportation problem method" to achieve the aforementioned objective.

The case study of this research is based on the proposed project of implementing three Integrated Resource Recovery Centres (IRRC) in the Matale Municipal Council (MC) to manage the solid waste by means of producing compost and recycling. By applying the two mathematical models, the research has shown the possibility of reducing the daily solid waste collection cost within the Matale MC Area.

Keywords: Solid Waste Collection, Network Analysis, Transportation Problem Method

1.0. Introduction

Cost analyzed by Ludwig and Black (1968) reveal that 85% of the solid waste system cost is due to collection, and only 15% to disposal. Therefore there is an increasing demand for greater efficiency, so as to minimize the solid waste collection costs, while providing an adequate and regular service to all of the target area.

This research is based on a proposed project of establishing three Integrated Resource Recovery Centres (IRRCs) at Matale Municipal Council (MC) for the purpose of Municipal Solid Waste (MSW) Management. IRRC is the place where the collected solid waste is further managed to produce compost and recycled. Therefore applying mathematical models to solid waste collection can lead to a significant saving in the overall cost, once the project is implemented. The collection system proposed through this research is based on solid waste collection points, road network, location of Integrated Resources Recovery Centres (IRRCs), capacity of the tractors and the population in the area under study.

First, the theoretical and methodological aspect of Municipal Solid Waste Collection, mathematical models and several past case studies of