

TOOL FOR ASSESSING LEAN MATURITY IN CONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

The Non-Value Adding Activities (NVAAs) generated in a construction process are recognised as one of its major weaknesses since they adversely affect performance and efficiency and produce unwanted cost. Lean construction applies lean production principles to the construction industry to minimise NVAAs in construction projects and maximise the value provided to clients. Lean is an innovative construction management approach which is linked closely to the overall life of a project to ensure its success. It is vital to measure the extent to which lean techniques have been applied in a certain project in order to implement more suitable lean techniques in future projects. This paper presents such a mechanism developed for assessing lean maturity in construction projects in Sri Lanka. A detailed literature review was carried out to identify the examples of NVAAs and to investigate the widely used lean techniques in construction projects. Quantitative research approach was adopted through three different surveys. Both surveys one and two were based on questionnaires and the data was collected from industry professionals. The first survey for project quantity surveyors, site engineers and construction engineers to identify NVAA, and the second survey for project managers in building construction projects to examine the application of lean techniques. The research technique for the third survey was semi-structured interviews for senior managers in top grade building construction companies. The data was then used to map NVAAs against lean techniques and emphasise the most suitable lean techniques in different stages of construction projects. Finally, a tool for assessing lean maturity of a construction project was developed to measure the lean implementation of completed projects in order to improve the application of lean techniques in future construction projects. The tool was thereafter validated through an expert survey and implemented in few recently completed projects.

Keywords: Assessment Tool; Construction Projects; Lean Implementation; NVAAs.

1. INTRODUCTION

1.1. RESEARCH PROBLEM

Construction Industry has been suffering with low productivity, insufficient quality, time and cost over runs, poor safety, frequent disputes, lack of innovation, project asking so long and always exceeding the client's budget (Latham, 1994; Egan, 1994; Smith et al., 1999; Kagioglou et al., 2000; Salem et al., 2006; Emuze & Smallwood, 2011; Al-Aomar, 2012; Vilashini & Neitzert, 2012). The main reasons are insufficiency and waste with NVAAs within the construction projects not adding any value to the final product. Therefore, the NVVAs incur costs and hinder the performance of the construction projects are required to be minimized. Most construction managers agree that the industry is vulnerable to multiple wastes, overruns, delays, errors, and inefficiencies (Al-Aomar, 2012). Senaratne and Wijesiri (2008) have revealed that a considerable amount of waste lies in the flow processes of construction. The greatest obstacle to waste removal in general is failure to recognize it. This is prevalent in the construction industry because it is not well understood by the construction personnel (Alwi et al., 2002). In summary, the construction sector has a wide range of activities including the

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provision of professional and technical inputs. Activities that do not add value simply result in waste which absorb resources and does not add any value to the final product and therefore these NVVAs need to be eliminated. By eliminating wasteful activities, processes can become 'lean' providing 'more with less' resources (Womack & Jones, 2003). The traditional thinking of most of the construction related organizations is on conversion activities and flow activities and value considerations are ignored. The goal of lean construction is to implement the project while maximizing value, minimizing waste, and pursuing perfection. Hence, the implementation of lean techniques into construction has been identified as one of the best approach to minimize NVVAs in construction projects. However, there is a lack of mechanism to assess the level of implementation of lean techniques in a particular construction project in SLCI and this paper presents a tool for assessing lean maturity of a completed project in order to improve the lean implementation for future projects to minimize the NVVAs and achieving long-term sustainable benefits by becoming lean.

1.2. RESEARCH METHODOLOGY

Firstly, the examples of NVVAs in construction projects were identified through an extant literature synthesis and the existence of these examples in SLCI were surveyed among constructional professional such as engineers, quantity surveyors, construction managers who work in construction projects for more than 5 years' experience in Colombo and suburbs. Findings revealed that all examples of NVVAs are existence at a higher level in SLCI too. Next, the widely used lean techniques developed in manufacturing industry and then applied in lean construction in different other countries were explored through the literature review and the level of implementation of these lean techniques in SLCI was examined via the second survey which was carried among the project managers who has the single point responsibility in building construction projects for more than 10 years. The results revealed that the implementation of lean techniques in SLCI is at a lower level. Thirdly, the examples of NVVAs and Lean techniques were mapped via semi structured interviews conducted for the senior managers of top graded construction companies in SLCI to identify the most suitable lean techniques to minimize NVVAs in SLCI. Furthermore, the most appropriate lean techniques for different stages of construction processes were also identified. Finally, a tool for assessing lean maturity was developed using the data collected from the study and the tool was refined to a software application. The extent of the implementation of lean techniques in a particular construction project is assessed by using this tool and the level of lean maturity of the completed project would assist construction professionals to adopt the implementation of more suitable lean technique in future projects in order to minimize NVVAs in SLCI. The Capability Maturity Model (CMM) conceived by Watts Humphrey, aids in the definition and understanding of an organization's processes. CMM is recommended for describing evolutionary levels of organizations in order to describe the level of value based management that an organization has realized or wants to aim for. Hence, CMM was selected to assess the lean maturity of a construction process as this model provides specific steps and activities to move from one level to the next level. These levels are named as Initial, Repeatable, Defined, Managed and Optimizing. Maturity gained by a construction project through lean implementations could be assessed defining levels of CMM depending on the implementation of particular lean technique. Having described the background of the development of the tool, the next section presents the examples of NVVAs in construction projects.

2. EXAMPLES OF NVVAs

2.1. EXISTENCE OF NVVAs IN CONSTRUCTION PROJECTS

NVVAs have been defined as the activities which does not add any value to the final product are merely a waste (Koskela, 1992). Waste is generally associated with waste of material in the construction process while NVVAs such as delays, transportation of material and others are not recognized as waste. Most of these activities are intangible (Senaratne & Wijesiri, 2008) and invisible. Activities that do not add value are simply wasteful and should be eliminated Taiichi Ohno has identified seven forms of waste that are part of lean manufacturing. In the context of both construction and production, waste is primarily defined under seven categories; defects (errors), delays, over processing, over production, excess inventory, unnecessary transport and conveyance of material and equipment, and unnecessary motions and movement of people (Ohno, 1988). NVVAs are the major cause of schedule delays, cost over runs and other related problems in the construction projects (Emuze & Smallwood, 2011). According to Salem *et al.* (2006), there is considerable waste in the

construction projects which goes unnoticed. Previous studies (Senaratne & Wijesiri, 2008; Vilashini *et al.*, 2011; Rahman *et al.*, 2012) disclose that the workforce in the domestic construction industry is ignorant of these NVAAs that create waste and hinder construction performance. According to Koskela (2004), these wastes in the flow processes of construction such as ‘non-conformance quality costs’ consume 12% of the total project cost, poor material management results in 10-12% of the total labour cost, time used for NVAAs amounts to 2/3 of the total project time and lack of safety measures amounts to 6% of the total project cost. Thus the value hindrance by waste in the flow processes of construction is quite evident and it indicates the necessity to implement a concept such as lean construction. Waste is a major problem in the construction industry and it amounts to 60% of the construction effort (Vilashini *et al.*, 2011). A study focussing on the construction efficiency made by the National Institute of Standards and Technology in the United Kingdom indicates that 25-50% of waste relates to coordinating labour and managing, moving, and installing material. Many researches (Mossman, 2009; Horman & Kenley, 2005; Vilashini *et al.*, 2011) have revealed that a major portion of time in construction is devoted to wasteful activities. Mossman (2009) has stated that 5-10% of the construction effort is for creating value, 30 -35% for supporting value creation and that 55-65% is wasted with much of the activity that supports value creation being logistics. Furthermore, Horman and Kenley (2005) have contended that as much as 49.6% of the construction operative time may be devoted to NVAAs. In addition, NVAAs have been identified as one of the problems negatively impacting on issues relating to variations. Waste that generates in the flow activities is recognized as a major disadvantage, which hinders performance and efficiency of construction activities. According to Rahman (2012) every system contains waste. A link exists between waste in a project and its cost. Vilashini *et al.* (2011) have disclosed that the analysis of the construction process indicates that construction activities can consist of 55% of NVAUA (Non Value Adding Unnecessary Activities). One third of these activities result from factors under the control of management such as rework and errors. More examples of NVVAs are presented in the next section.

2.2. EXAMPLE OF NVAAs

First, the examples of NVAAs were recognized from extant literature review and then, these NVVAs examples were categorized into seven types of waste introduced by Taichi Ohno. The seven types of wastes are; defects or rework, unnecessary waiting, unnecessary motion, inventory, extra procedures, unnecessary transport and overproduction. In addition to the above classification, an eighth category was identified as ‘other’ for waste which does not fall into any of the above mentioned seven categories. Forty nine examples of NVAAs in construction projects were identified from the literature review and these examples are illustrated in figure 2.1 below. Among these examples, thirteen number of examples are in the category of defects and nine and seven of them are in waiting and extra procedure categories respectively. Four number of examples are explored from other four categories.

Defects	D01NA01	Repair Work	Waiting	W01NA14	Delay to schedules	Extra Procedures	E01NA31	Unnecessary processing
	D02NA02	Design errors		W02NA15	Waiting for Instructions		E02NA32	Long approval processes
	D03NA03	Design changes		W03NA16	Waiting for equipment repair		E03NA33	Retests
	D04NA04	Installation errors		W04NA17	arrive		E04NA34	Excessive safety measures
	D05NA05	Vendors errors		W05NA18	Equipment freequently		E05NA35	Excessive supervision
	D06NA06	Damage by other crafts		W06NA19	Waiting for Clarifications		E06NA36	Excess information
	D07NA07	Incomplete Installations		W07NA20	Waiting (for people, material)		E07NA37	Excessive training time
	D08NA08	Rehandling materials		W08NA21	Activitiy Delay		T01NA38	Unnecessay material
	D09NA09	Damaged Materials on site		W09NA22	Idle Time		T02NA39	Travelling time
	D10NA10	Poor material allocation		M01NA23	movement		T03NA40	Unnecessary Transport
	D11NA11	Rework		M02NA24	Unnecessary motion		T04NA41	Long transport time
	D12NA12	Site layout is not carefully planned		M03NA25	Excessive labour movement		OV1NA42	Unwanted Productions
	D13NA13	Uncomplete work		M04NA26	Excessive material movement		OV2NA43	Unnecessary work
Inventory	I01NA27	Material stocks	Inventory	I01NA27	Material stocks	Over production	OV3NA44	Material waste
	I02NA28	Inventory work		I02NA28	Inventory work		OV4NA45	Inefficient work
	I03NA29	Excess material inventory		I03NA29	Excess material inventory		OT1NA46	specification
	I04NA30	Inventories		I04NA30	Inventories		OT2NA47	Taxes
Others						Others	OT3NA48	Pilferage
							OT4NA49	Making - do

Figure 1: Examples of Non-value Adding Activities

2.3. NON-VALUE ADDING ACTIVITIES IN SRI LANKAN CONSTRUCTION INDUSTRY

Data collected from the SLCI through the survey one reveals that almost all examples of NVAAs identified through the literature review have been confirmed by the respondents to the surveys as prevailing in the construction projects. Moreover, the findings showed that NVAAs are generated at a significant level in the construction projects in Sri Lanka. Further it was revealed through the surveys that the most significant categories of NVAAs are ‘Defects’ and ‘Waiting’. It can also be identified that NVAAs occur to an extent of 59% throughout construction projects. Hence, it can be concluded that there is a requirement for minimizing these NVAAs which negatively affect the productivity of construction and its value for money. Data obtained through this survey, was statistically analysed using SPSS software and all NVAAs identified through the literature review were found to be present in the construction projects in Sri Lanka as well. Figure 2.2 illustrates the NVAAs present in the construction projects in Sri Lanka. X axis represents NVAAs while Y axis represents the response rate related to each non-value adding activity. The Figure shows that the minimum level of existence of NVAAs is 35% and that its maximum level is 85%.

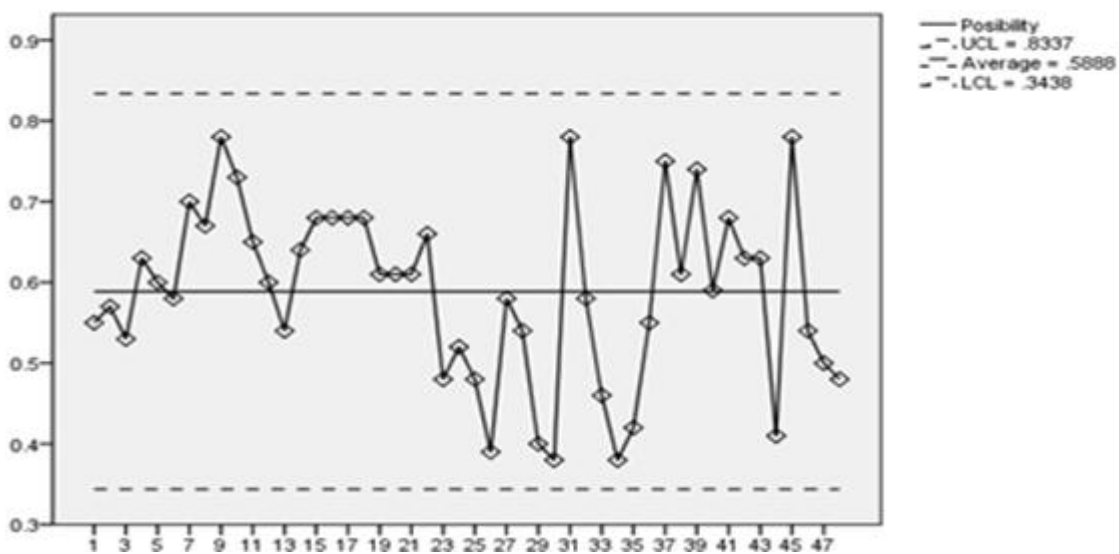


Figure 2: Existence of NVAAs in Construction Projects in Sri Lanka

Findings from Survey one were further analysed to identify the most critical NVAAs in the construction projects in Sri Lanka and each category of waste was considered separately with a view to prioritizing the NVAAs in the construction projects. The most critical examples of NVAAs in construction projects in SLCI is demonstrated in Table 1.

Table 1: The Critical Examples of NVAAs in SLCI

1	Repair Work	9	Waiting for Instructions
2	Design Errors	10	Waiting for Equipment Repair
3	Incomplete Installations	11	Waiting for People and Materials
4	Rehandling Materials	12	Idle Time
5	Damage Materials on site	13	Excessive Labour Movements
6	Poor Material Allocation	14	Retests
7	Delay to Schedules	15	Excessive Safety Measures
8	Delay to Instructions		

3. LEAN CONSTRUCTION IMPLEMENTATION

3.1. LEAN CONSTRUCTION

Lean construction is a new way to manage construction and this concept is still new to many construction industries in the world. Lean production was developed by Toyota and led by Engineer Ohno who was dedicated to eliminating waste. The term 'lean' was coined by the research team working on international auto production to reflect both the waste reduction feature of the Toyota production system and to contrast it with craft and mass forms of production. The lean philosophy can be considered as a new form of design and production that is different from mass and craft forms of production through the objectives and techniques applied on the shop floor, to design and along supply chains. Koskela (1992) has concluded that eleven important principles some of such as reducing waste, variability, cycle and increasing transparency, are essential to the lean philosophy. Ballard (2008) and Womack and Jones (2003) have refined and expanded the lean concept for construction and have outlined the basic lean thinking principles. The lean concept has proven to be effective in increasing environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value (Huovila et al., 1998; Salem et al., 2005). In addition, lean produces an operational and cultural environment that is highly conducive to the minimization of resource depletion and pollution prevention, and that lean provides an excellent platform for environmental management tools such as life cycle assessment and design for environment. Wu and Low (2011) have revealed that the lean production philosophy which originated from the Toyota production system advocates reducing or eliminating NVAAs at the same time as improving the efficiency of value adding activities.

According to Womack and Jones (2003), the five principles of lean thinking are value, value stream, flow, pull and perfection. LC is defined by fundamental concepts, basic practices and a common vocabulary. Together these create a new paradigm for managing work in projects from their conception to completion. The manufacturing industry has been a constant reference point and a source of innovation for the construction industry over many decades. All construction activities can be divided in to two types, the first being conversion activities which produce tangible results. The second type is flow activities which bind conversion activities together during the delivery process of the output. Although all activities incur cost and consume time, according to lean principles only conversion activities add value and these should therefore be made more efficient, where as non- value adding flow activities should be reduced or eliminated (Koskale, 1992). The lean concept is one strategy adopted by the construction industry from the manufacturing industry to improve its own performance (Vilashini & neitzert, 2012). Lean construction is a new way to manage construction implementing the guidelines of Lean Project Delivery System developed by LCI (Ballard, 2008). Moreover, lean construction, assumes that construction is a kind of production process (Bertelsen, 2004). The widely used lean techniques in construction projects are presented in the next section.

3.2. LEAN TECHNIQUES

In summary, lean is a systematic method for waste minimization and several techniques have been developed for the manufacturing industry and then these techniques have been applied for the construction industry and reaped benefits. Egan (1994) has revealed that Lean Construction presents a coherent synthesis of the most effective techniques for eliminating waste and delivering significantly 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). After reviewing the lean implementation cases in the extant literature, the widely used lean techniques in the construction processes were identified as illustrated in figure 3. These LTs were numbered as LT01 to LT20 for easy reference.

LT01	Last Planner System	Planning and control system implemented on construction projects
LT02	Just in Time	Stock of Materials are kept to the bare minimum
LT03	3D Modelling	Computerized 3D design system
LT04	Visualization	Visualization through posting various signs and labels
LT05	Building Information Modelling	Creating a shared knowledge resource for information
LT06	Value Stream Mapping	Maps are prepared at the project level and then decomposed to better understand
LT07	Reverse Phase Scheduling	A schedule that works backwards from the completion date
LT08	Off Site Manufacturing	Manufacturing and assembling process
LT09	Kaizen	Continuous improvement "good change"
LT10	Five S	Approach to housekeeping within Lean
LT11	Poka-yoke	Generation of ideas that alert for potential defects
LT12	Target Value Design	Method that assures customers get what they need.
LT13	First Run Studies	Use video files, photos, or graphics to show the process
LT14	Relational Contracting	Contracts as relations rather than as discrete transactions
LT15	Target Costing	Improve a company's efficiency and effectiveness in cutting costs
LT16	Set based Design	Design alternatives up-front to allow for trade-offs
LT17	Kanban	One-way to do this is to smooth and balance material flows
LT18	Total Quality Management	A combination of quality and management tools and reducing losses
LT19	Work Standardization	Documenting the current best practice
LT20	Work Structuring	Work flow more reliable and quick while delivering value to the customer

Figure 3: Widely Used Lean Techniques in construction projects

3.3. LEAN CONSTRUCTION IMPLEMENTATION

Rahman (2012) has stated that the emerging concept of LC is concerned with the application of lean thinking to the construction industry. During the past ten years, there has been a growing interest in the LC among academics all over the world. These researchers seek to investigate the extent to which the Japanese model of lean production can be applied to the construction industry. From the study of its background, LC appears to have resulted from the adaptation and implementation of the Japanese manufacturing principles in construction practices. LC, assumes that construction is a kind of production process (Bertelsen, 2004). Lean project management is focused on implementing the guidelines of Lean Project Delivery System which includes Lean Project Definition, Lean Design, Lean Supply and Lean Assembly. The Lean Design phase transforms the conceptual design of the project into a lean product and processes the design to be consistent with project scope and design criteria. The lean supply module consists of the detailed engineering of the product design, the fabrication or purchasing of components and material, and the logistics of deliveries and inventories. The Lean Assembly ranges from the delivery of tools, material, and components to commissioning and project delivery to the client (Al-Aomar, 2012). LC keeps an eye on the value added element of the construction process (conversion) as well as the non-value added elements (flow, delay, and errors). A lean delivery emphasizes a cost effective and on-time handover with no delays or rejects or quality issues. According to Salvatierra-Garrido and Pasquire (2011), LC experience commonly connects construction practices with the Transformation-Flow-Value model of Koskela, where value is mainly delivered during the production process at site. Consequently most of the efforts have been made to satisfy the requirements of the paying client. Bertelsen (2004) has argued that the clients represent interests from three main groups; owner, user and the society who value different things at different times through the life cycle of construction projects. Other countries such as 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. Overall, there is sufficient evidence on the implementation of lean techniques in construction (Thilakarathna & Senaratne, 2012). However, some are being implemented without any awareness on 'lean philosophy' and only as a requirement for a quality assurance procedure. Hence, it is important that construction companies rethink about implementing lean techniques consciously to reap the real benefits of lean applications by avoiding general construction issues. Data collected from Survey for this study revealed that the level of implementation is at a lower level. Further it is revealed that almost all lean techniques are implemented in the construction industry in Sri Lanka at different levels and that none of them was at zero

level. All most all 20 lean techniques are being implemented at different levels in the construction industry in Sri Lanka and their average level of implementation is reported to be 40% which is a considerably low figure. Therefore, the construction industry in Sri Lanka is significantly lagging behind in implementing lean techniques in their construction projects (Thilakarathna & De Silva, 2014) and therefore there is substantial scope to improve the implementation of lean techniques in Sri Lanka. Figure 4 indicates the level of implementation of the 20 lean techniques selected along with the number of responses received to illustrate the implementation of lean techniques. The Y axis of the graph shows the cumulative count of the responses received for each of the lean techniques selected for the study. Five S, Total Quality Management, Target Costing, Work Structuring, Work Standardization and Last Planner are techniques that are being implemented at a higher level whereas BIM, kanban, Value stream mapping and 3D modelling are implemented at lower levels.

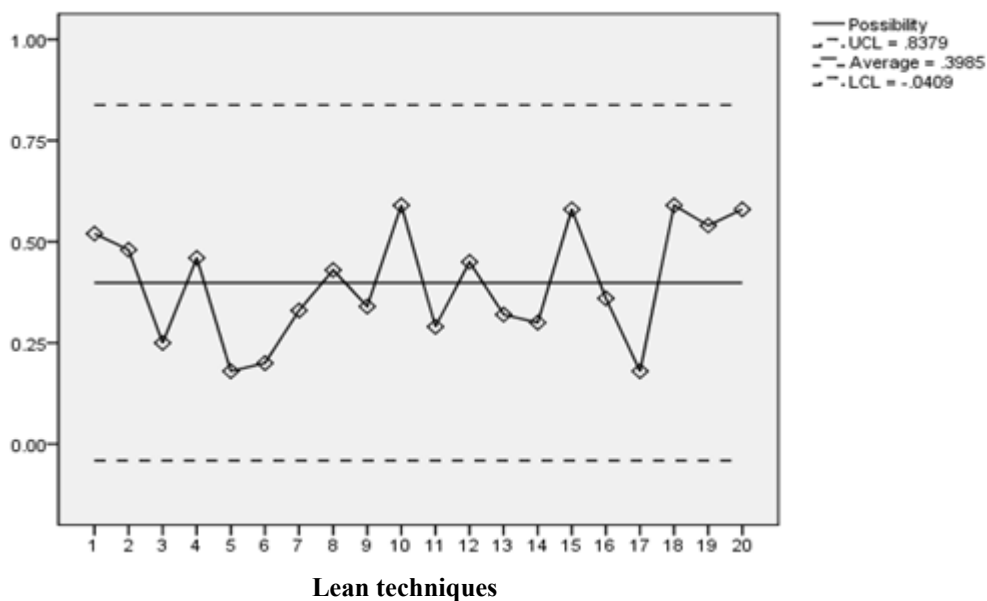


Figure 4: Current Level of Implementing Lean Techniques in The Construction Industry in Sri Lanka

3.4. MAPPING NVAAS WITH LEAN TECHNIQUES

The research findings of the existence of the examples of NVAAs and the level of implementation of LTs in SLCI were presented in the above sections. Next, it is vital to present which LT is most suitable to minimize NVAAs in different stages of construction. Hence, this section discusses the mapping of most critical 15 number of NVAAS with LTs to identify the appropriate LT implementation for construction projects. The third survey based on semi-structured interviews were conducted among twenty number of senior managers of top graded construction companies in order to map NVAAs and LTs. A guideline was designed to map NVAAs against lean techniques and was given to the interviewees to mark their responses a separate description for each lean technique was provided. The data revealed that there is no direct one to one relationship between a particular NVVA and LT. It is a many-to-many relationship which shows a strong relationship among NVAAs and LTs. Therefore it is identified that by implementing LTs, NVAAs can be minimized. It can also be concluded that to minimize each NVVA, several LTs can be utilized. It can therefore be confirmed that (i) to minimize one NVVA several LTs can be utilized and (ii) in utilizing a particular LT, several NVAAs can be minimized. Hence, these findings reveal that there is a strong relationship between LTs and NVAAs. The results of the survey were further analysed and LTs were categorised into 4 groups based on the stage of their implementation, i.e varying from the initial stage of a construction project to its completion align with lean project delivery from lean definition to lean assembly.

The entire life of a construction project can be divided mainly in to five stages (RIBA Plan of work) and the first four of these stages were considered for this study since the last stage comes in only after reaping the benefits of implementation of lean principles. Table 2 illustrates the implementation of the LTs selected for this study in the four different stages of a construction project delivery system. The figure shows that most of LTs can be applied in the Design, Pre-construction and construction stages of a project. Lean techniques such

as Five S, Target value design and Target costing can be implemented from the Preparation stage itself. Set based design technique, LT16, works with design alternatives was identified as not suitable with many alternatives. These data were further analysed and used to develop a tool to measure up to which extent the lean techniques are applied in each stage of a construction project in order to establish the Lean Maturity of that project. If the Project is matured enough with lean implementation, NVAAs are kept minimized and project would gain more benefits with a waste reduction nature.

Table 2: Proposed Lean Techniques Implementation

Lean Techniques	Lean Project Delivery			
	Preparation	Design	Pre-constructio	Construction
LT01 LPS				√
LT02 JIT			√	√
LT03 3DM		√	√	√
LT04 VIS		√	√	√
LT05 BIM		√	√	√
LT06 VSM			√	√
LT07 RPS		√	√	√
LT08 OSM		√	√	√
LT09 KAI		√	√	√
LT10 5S	√	√	√	√
LT11 PY		√	√	√
LT12 TVD	√	√		
LT13 FRS			√	√
LT14 RC		√	√	√
LT15 TC	√	√	√	√
LT17 KNB				√
LT18 TQM		√	√	√
LT19 WSD		√	√	√
LT20 WST		√	√	√

4. A TOOL FOR ASSESSING LEAN MATURITY

4.1. DEVELOPMENT OF THE TOOL

The purpose of this tool is to measure the extent of application of lean techniques in different stages of construction projects and then assess the lean maturity of that particular project. Twenty lean techniques were identified through the literature review and confirmed through the surveys carried out in Sri Lankan construction industry. Moreover, it was revealed that these lean techniques are being implemented at a low level. Further it was revealed that one of the techniques listed among the twenty number of techniques is not appropriate to minimize non value adding activities and that the remaining nineteen techniques can be implemented in construction projects. Therefore, the proposed tool was designed using only these 19 lean technique. Hence, the construction projects were categorized in to four main stages (RIBA plan of work) and the stages were characterised for this study as (i) Preparation stage (Lean Definition), (ii) Design stage (Lean Design), (iii) Pre-construction stage (Lean Supply), and (iv) Construction stage (Lean Assembly) for ease reference to the construction professionals whom may be new to lean project delivery. The weighted average of each lean technique was calculated using the data obtained through Survey and through interviews. It was revealed from the survey that certain lean techniques can be applied in several stages. The weighted average calculated for each lean technique was then distributed among the weighted average allocated for each lean technique in each stage of a construction project. The next step of the data analysis was to calculate the weighted averages of all nineteen lean techniques based on the data collected. The above results reveal that there is a relationship between lean techniques and NVAAs. LT01, LT 02, LT04, LT10, LT18 and LT19 show a strong relationship with a strong weightage when implementing them to minimize NVAAs whereas LT14 with a weighted average of 0.008 and LT17 with a weighted average of 0.016 show a relationship which is less strong when compared with the rest of the lean techniques whose weighted averages range from 0.04 to 0.065. The Capability Maturity Model (CMM) was selected to assess the lean maturity of a construction

process. The scoring system was defined as 1, 2, 3, 4 and 5 for each level, 5 is the maximum or the Optimizing level whereas 1 is for lowest level, the Initial level which needs to be developed. Figure 5 shows the appearance of the tool. The first column indicates the stage of construction whereas the second column refers the LT numbering in each stage. For example, first stage, there are three number of LTs to implement. Next column briefly states the description of each LT and Results are indicated against each LT in each stage.

Stage	No	Lean Techniques implemented in Construction Project Delivery System	Result	Optimization Level	Quantitatively Manged Level	Defined Level	Repeatable Level	Initial Lev
01	1	Five S : Standard approach to housekeeping	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
01	2	Target Value Design : Assures customers get what they need	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
01	3	Target Costing : Assures the target within the established cost	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	1	3D Modelling : computerized 3D design system or physical model to provide better, faster information of components an	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	2	Visualization :communicating key information effectively to the workforce through posting various signs and labels around	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	3	BIM :Building Information Modelling, digital representation of physical and functional characteristics of a building	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	4	Reverse Phase scheduling : a schedule that works backwards from the completion date	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	5	Prefabrication / Off site manufacturing : Manufacturing and assembling process, whereby, construction components are m	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	6	Kaizen / Continuous improvement : "good change". Kaizen refers to philosophy or practices that focus upon continuous im	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	7	Five S : standard approach to housekeeping	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	8	Faille Safe Quality / Poka-yoke : generation of ideas that alert for potential defects	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	9	Target Value Design : method that assures customers get what they need	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	10	Relational Contracting: is characterized by a view of contracts as relations based on trust between parties rather than as di	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	11	Target Costing : Assures the target within the established cost	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
02	12	Total Quality Management : combination of quality and management tools aimed at increasing business and reducing los	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 5: Appearance of the Tool for Assessing Lean Maturity

4.2. USE OF THE TOOL AND ITS OPERATION

The aforementioned tool was further developed to a user friendly software application. The outline of the interface of the tool consists of 19 Lean Techniques into four different stages of construction with a brief description to each techniques against CMM levels with definitions. Each stage of CMM was given a score and the weighted average of each lean technique of each stage of a construction project delivery system was specified in the tool. The user may select the lean technique used in each stage by deciding up to which level it is applied in that particular stage, and the program will produce the scores and display the total score at the end of the exercise. In one construction project, the maximum score displayed was 5 and the minimum 1. Select the construction project which lean maturity to be assessed open the interface of the software with an aid of a suitable electronic device. User may select each lean technique and appropriate level of implementation will be selected his or her knowledge in construction project practice. A brief introduction to each tool is available on the application and it is user friendly with developing a software considering events, objects and behaviour to judge the implementation of each lean technique. The data obtained using the tool was from five construction projects which were all in the stages of being completed. The data in Table 3 shows that these projects are not well matured in lean and that there may be hindrances to their performance which would have made them inefficient. When comparing the scores of the projects, project 5 is the most matured project in lean where project 3 is the least matured project in lean. Therefore, results of the application of tool reveal that further lean implementation is required for future projects in order to become more 'lean' with less NVAAs to solve the productivity issues in construction projects.

Table 3: Lean Maturity of Five Construction Projects

Final Scores after application of the tool		
1	Proposed housing scheme at Athurigiria	2.55
2	Proposed office building at Colombo 08	2.76
3	Proposed apartment complex at Battaramulla	1.78
4	Proposed apartment complex at Rajagiriya	2.95
5	Proposed mix developmet for offices, shops and apartments at colombo 08	3.05

5. CONCLUSIONS AND WAY FORWARD

Inefficiency and waste in construction projects are the main factors that adversely affect the performance of construction activities and NVAAs have been identified as the main cause for this inefficiency and waste. Hence the research problem of this study was the existence of NVAAs in construction projects which have to be minimized if performance is to be improved. The research approach selected to solve this problem was lean implementation. The literature indicates that 'lean' minimizes waste and that lean techniques can be applied to minimize NVAAs in the construction projects. Lean is an innovative construction management approach which is linked closely to the overall life of a project ensuring its success. The background to this study indicates that the significance of developing a mechanism of assessing lean implementation in SLCI in order to implement more lean techniques in future projects. Hence, the aim of this research was to develop a tool for assessing lean maturity of construction projects in SLCI for the implementation of lean techniques so that NVAAs in construction projects could be minimized. The study commenced with a preliminary literature review to identify the basic details of lean implementation and a detailed literature review was carried out to identify the research problem which was the existence of NVAAs in construction projects with examples. The research approach was the implementation of lean techniques that will solve the problem. Several lean techniques which can be implemented in different stages of construction projects were further identified. The quantitative research approach was adopted to collect the data from Sri Lankan construction industry and findings revealed that NVAAs are existence at a higher level in the construction projects and lean implementation is at a lower level. Moreover, examples of NVVAs and the most suitable lean techniques was mapped to identify which LT is most appropriate for each stage of construction. Finally, a tool was developed as a software application and then this tool was applied to five construction projects to make an assessment of their lean maturity. Finally, expert opinions were used to refine the tool that had been developed based on the main findings of the research.

This study was further continued to develop a framework for lean implementation as the last objectives of the study and developed framework would be further refined through expert opinion. The primary goal of this framework is to guide professionals who render their services to clients, contracting organizations, consultants and developers in the construction industry on how to improve the efficiency of construction activities by implementing lean techniques. This will further assist them to identify guidelines to implement lean techniques and the benefits of implementing lean techniques. Further this framework will identify the challenges that exist for implementing lean techniques and the suggestions to overcome these challenges. Moreover, this research could be extended by engaging larger samples to see whether new findings other than the findings already revealed through literature review could be made, especially with regard to the challenges of implementing lean techniques. The application of the tool could also be extended to more cases to reinforce the conclusions made. It will be interesting to know whether new cases would produce the results already obtained through this research study which would strengthen the generalizability of this research.

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