FRAMEWORK FOR LEAN IMPLEMENTATION IN CONSTRUCTION PROCESSES

Nilmini Ruwan Kumari Thilakarathna

(118042D)

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Department of Building Economics

University of Moratuwa

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Nilmini Ruwan Kumari Thilakarathna

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DECLARATION

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ABSTRACT

Framework for Lean Implementation in Construction Processes

Non Value Adding Activities (NVAAs) generated in a construction process are recognized as one of its major weaknesses since they adversely affect its performance and efficiency and produce unwanted cost. Activities that do not add value to the final product are merely a waste and need to be minimized or eliminated altogether. The major reason for our inability to minimize NVAAs is our failure to recognize them. Most of the NVAAs are intangible and invisible. Only a few attempts have so far been made to minimize the NVAAs in construction processes. Lean construction is one of the attempts made to apply lean production principles to the construction industry to minimize NVAAs in its construction processes and maximize 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. Lean construction is still new to many in the construction industry in the world. There is no implementation framework in the construction industry in Sri Lanka to minimize NVAAs and this research aims to develop such a framework for implementing lean techniques in the construction industry in the country in order to minimize its non-value adding activities. It will also propose a tool for determining the lean maturity of a construction project by assessing the extent to which lean techniques have been applied in that project.

A detailed literature review was carried out to investigate lean implementation in construction processes towards developing a conceptual framework by identifying the research gap and the approach that has to be used to fill the gap by implementing lean techniques. This conceptual framework was improved through an opinion survey. Quantitative research techniques were adopted to collect data from three different surveys. Findings of the first survey revealed with examples, the existence of non-value adding activities in construction processes in the construction industry in Sri Lanka with the second survey revealing their level of implementing the lean techniques. The findings of the third survey map non-value adding activities against lean techniques and emphasize the need for developing a framework for implementing lean techniques that will minimize NVAAs in the construction processes. Based on the data collected from the three surveys, a framework for implementing lean techniques and a tool for assessing lean maturity of a construction project were developed. The framework and the tool were thereafter validated through an expert survey. The study concludes by identifying the significance of implementing the most suitable lean techniques in different stages of construction processes that will make them lean with minimum waste thereby ensuring their long term sustainability.

Keywords: *Non-value adding activities, Lean Techniques, Implementing Framework, Construction processes*

DEDICATION

To

my adoring daughter

Ranmalee

for

the special bond

spans the years

through

smiles and tears

sense of trust

can't be broken

depth of love

sometimes unspoken

the gift

I have ever received

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LIST OF ABBREVIATIONS

LT	–	Lean Techniques
NVAAs	–	Non Value-Adding Activities
LC	–	Lean Construction
LP	–	Last Planner
JIT	–	Just In Time
RPS	–	Reverse Phase Scheduling
TVD	–	Target Value Design
TQM	–	Total Quality Management
WBS	–	Work Breakdown Structures
BIM	–	Building Information Modeling
IQSSL	–	Institute of Quantity Surveyors in Sri Lanka
IESL	–	Institute of Engineers in Sri Lanka
AISL	–	Institute of Architects in Sri Lanka
ICTAD	–	Institute of Construction, Training And Development
SLCI	–	Sri Lankan Construction Industry

Chapter – 1

Introduction to the Research

1.0 INTRODUCTION TO THE RESEARCH

1.1 Background

The Construction Industry is project centric and operates within an environment of considerable complexity and uncertainty (Koskela,2000) due to the fragmented structure of the supply chain (Picchi.2011) and short term adversarial trading relationships (Barret,2005). In construction, the final product has its very own nature because construction projects are unique, static and big in size (Koskela,2000).In the construction industry, the job security is low and workers perform a range of tasks during the implementation of a project (Salem et al,2006). The quality of construction is primarily related to conformance of the product with the specifications and drawings. Further Salem et al (2006) have stated that the construction industry has three main features which distinguish it from other industries, i.e on-site production, one-of-a-kind of project, and complexity. Within the typical project structure, the parties involved in a project such as the client, contractor and designer are generally concern with their own interests and communication usually occurs along contractual lines. The construction sector encompasses a wide spectrum of activities including the provision of professional and technical services and the construction process involves the making of thousands of decisions, at times taken over a period of years with numerous interdependencies and under a highly uncertain environment (Tzortzopoulos and Formoso, 1999). Problems in the construction processes, i.e. low productivity, insufficient quality, time and cost over-runs, and poor safety have been illustrated in several studies (Latham, 1994; Egan, 1998) and their findings are familiar to the industry which is still striving for improvements in several areas, although apparently with little success. (Kagioglou et al 2000).

The construction Industry is often regarded as confrontational, risking averse and lacking vision and trust (Barret, 2005). It is viewed as a uniform supply chain operating under inappropriate contractual arrangements with poor communications and widespread organizational issues (MecIntyre, 2008). Halpin (1990) has suggested that high competition accounts for these peculiarities. Consequently, the construction industry is still backward while other industries have modernized their practices (Vilashini et al, 2011). The construction industry still maintains its craft methods of operation, and continues to lag behind in productivity and quality and in delivering value for money to its clientele (Alinaitwe, 2008; Pheng & Li, 2011; Howell& Ballard, 1997; Koskela, 2000). Further, Lichtig (2006) has indicated that construction owners are dissatisfied in different ways, i.e projects take too long, cost is too much, and expected quality standards are not met. The construction industry has been suffering from low productivity and poor performance compared to other industries. However in reality, the construction industry has an unfortunate reputation of delivering projects that are unpredictable in terms of delivery on time, within the budget and to the pre-specified quality, whilst concurrently attempting to ensure a zero accident rate (Smith et al, 1999).

Project delivery systems related to construction consist of three domains, i.e project organization or the way parties to the contract are organized, project operating system or the way the project is managed on an overall and day-to-day basis and the commercial terms of the project or the contract (Thomsen et al., 2010). Singleton and Hamzeh (2011) have revealed that over the past twenty years, innovations have brought major changes to project organization and commercial terms, such as Design and Build and Partnering. However, these changes have done very little to improve construction in terms efficient use of labour, equipment, and material. The project operating system has been largely neglected in construction. This situation contributes significantly to inefficiency and waste and lead to construction's low productivity rates. (Thomsen et al., 2010).According to Emuze and Smallwood (2011), studies carried out in South Africa indicate that clients were neutral or dissatisfied with the performance of contractors on 18% of the projects Surveyed in 2009 and around 12% of the projects so Surveyed had levels of defects that are regarded as inappropriate with health and safety on construction sites remaining a concern. Further, Thomsen et al (2010) have argued that construction projects frequently suffer from adversarial relationships, low rates of productivity, high rates of inefficiency and rework, frequent disputes, and lack of innovation, injury or fatalities among workers. Similarly, Rahman (2012) has stressed that the main reasons for the low performance of the construction industry were the temporary organizational structure of the construction team and the inefficient construction process.

In the building sector, it has been customary for architects to work with clients to understand what they want, then produce facility designs intended to deliver what was wanted (Ballard 2011). The cost of those designs has been estimated, and too often, it is found to be greater than what the client is willing or able to bear, requiring the revision of the design and thereby leading to re-costing and so on. This cycle of design-estimate-rework is wasteful and will reduce the value the clients get for their money. Most construction managers agree that the industry is vulnerable to multiple wastes, overruns, delays, errors, and inefficiency (Al-Aomar (2012). In manufacturing, defective parts are largely discarded rather than reworked due to the simplicity and flexibility of the product whereas in construction, rework is a common practice with only one final product being delivered. Moreover, the labour intensity increases the risk of human errors and quality issues are widespread in the industry. In manufacturing, manufacturer-supplier relationships are clear, more manageable and open to repetition. However, in construction, these relations are more dynamic and complex. Waste is generally associated with waste of material in the construction process while activities such as inspections, delays, transportation of material and others are not recognized as non-value- adding flow activities that may lead to waste. Common wastages are the waste due to waiting periods, defects, design errors, transport / handling time, activity delays, operations, excessive space / stock and rework.

Taiichi Ohno has identified two types of activities, i.e value adding activities and non-value adding activities (NVAA). Activities that do not add value are simply wasteful and should be eliminated. He has also 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). NVAAs are the major cause of schedule delays, cost over runs and other related problems in the construction processes (Emuze and Smallwood 2011). Conversely, the cost of construction is generally too high, and can even be a onetime investment. An alternative way to tackle the problem is to identify activities, which do not add value to the client (Josephson and Saukkoriipi, 2001). According to Salem et al (2006), there is considerable waste in the construction processes which goes unnoticed. The lean concept is one strategy adopted by the construction industry learning from the manufacturing industry to improve its performance (Vilashini and Neitzert (2012). Previous studies show that considerable productivity improvements can be achieved in construction processes by simply targeting the reduction or the elimination of non-value adding activities. All construction activities can be divided into two types i.e. **conversion activities** which produce tangible results and **flow activities** which bind such conversion activities together during the delivery process of the output. Although all activities incur costs and consume time, Lean Principles state that only conversion activities add value and that therefore these should be made more efficient, whereas non- value adding flow activities should be reduced or eliminated (Koskale, 1993). By eliminating wasteful activities, processes can become 'lean' providing 'more with less' resources (Womack and Jones, 2003). The traditional thinking of most of the construction related organizations is on conversion activities and flow activities and value considerations are ignored.

Therefore, there is considerable scope for minimizing non-value adding activities in construction processes especially in terms of cost, health and safety, quality and time. 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 non-value adding activities that create waste and hinder construction performance. In the recent past, researches have placed greater emphasis on developing ways to improve operating systems of construction projects and one such method for improvement is known as Lean Construction (Singleton and Hamzeh, 2011). Lean construction results from the application of this new form of production management to construction, which has a goal to meet the client's needs while using a minimum quantity of everything (Rahman et al, 2012). The goal of lean construction is to implement the project while maximizing value, minimizing waste, and pursuing perfection. Lean construction is a new way to manage construction. Further, Vilashini et al, (2011) have stated that lean is an innovative construction management approach which is linked closely to the overall life of a project ensuring its success. Through an opinion Survey conducted among the construction workforce, Senaratne and Wijesiri (2008) have established that lean construction is suitable to and acceptable in the construction industry in Sri Lanka.

Hence, this study will look deep into lean construction as an approach to solve the productivity issues tied up with non-value adding activities in the construction processes by developing a framework for lean implementation in construction processes.

1.2 Research Problem

The construction sector has a wide range of activities including the provision of professional and technical inputs. Activities that do not add value simply result in waste and therefore need to be eliminated. The background study confirms that the NVAAs have to be recognized as a major weakness, which hinder the performance and the efficiency of the construction industry However, the industry lacks an implementation framework to minimize NVAAs in its construction processes. Therefore, this research aims at developing such a framework for implementing lean techniques to minimize non-value adding activities in the construction processes and achieving long-term sustainable benefits by becoming lean.

1.3 Aim

Aim of this research is to develop a framework for implementing lean techniques in order to minimize non-value adding activities in construction processes of the Construction industry in Sri Lanka.

1.4 Objectives

- To investigate the non -value adding activities in construction processes
- To examine the implementation of lean techniques in construction processes
- To map widely used lean techniques with non-value adding activities in construction processes in order to identify the lean implementation
- To propose a tool for assessing lean maturity of a construction project.

1.5 Methodology

The Quantitative Research Approach was used to develop a framework for implementing lean techniques for minimizing non-value adding activities in the construction processes. The methodology of the research consisted of the following steps:

i. A preliminary literature review of lean construction implementation to explore lean techniques and their applications with benefits and barriers.

ii. A detailed literature review:

  a) to investigate non-value adding activities in construction processes

  b) to examine lean implementation in the construction processes in order to identify the most widely used lean techniques

  c) to derive a conceptual framework for implementing lean techniques in order to minimize non-value adding activities in construction processes.

iii. A pilot Survey to confirm the conceptual framework, the unit of analysis, sample size and the widely used lean techniques in the construction industry in Sri Lanka prior to designing the questionnaires and interview guidelines.

iv. Two separate questionnaire Surveys carried out among professionals working in building construction projects;

  a) to investigate non-value adding activities in construction processes in Sir Lankan construction industry

  b) to examine the current level of implementation of lean techniques in the construction industry in Sri Lanka.

v. A Survey via structured face to face interviews to map non-value adding activities against lean techniques in the construction processes for developing the framework.

vi. A tool to assess the lean maturity in a construction project was developed based on literature and data collected through three Surveys.

vii. The developed tool was applied in five construction projects to validate the tool

viii. Expert opinions were obtained to improve the framework for implementing lean techniques to minimize non-value adding activities in construction processes.

Section 4.3.11 presents the summary the methodology adopted against each objective of the study.

1.7 Scope and Limitations

The scope of the research was to focus on the construction projects to investigate their non–value adding activities and examine the implementation of lean techniques in them in order to develop a framework for the implementation of lean techniques to minimize non-value adding activities in the construction processes in the Construction industry in Sri Lanka. Several professionals working at different levels in construction projects were selected to collect data. The key professionals, viz., engineers, quantity Surveyors and architects working in projects were at one level and project managers in the building projects in Colombo and suburbs of more than hundred million rupees in value were at the second level. At the third level were the senior managers of Grade C1 contracting organizations. The data collection of this study was through professionals working in construction projects in Colombo and suburbs and which had commenced during last three years.

Chapter – 2

Literature Synthesis

2.0 LITERATURE SYNTHESIS

2.1 Introduction

This Chapter mainly discusses the extant literature available on non-value adding activities and lean techniques in the construction sector as an overview to the research. The first half of this Chapter presents the literature findings on non-value adding activities in the construction processes along with examples of such activities. Further, it provides an understanding of non-value adding activities by identifying a definition for waste, categories of waste and sources of waste. A list of examples of non-value adding activities which hinder the performance of construction activities is prepared. The second half of this Chapter presents a detailed literature review to describe lean concepts, lean principles, lean construction and lean implementation in the construction sector using widely used lean techniques. Further this section presents the benefits and challenges of implementing lean techniques in construction with best practices and suggestions for implementing lean techniques to overcome the challenges identified through the literature. A list of most suitable and widely used lean techniques is presented to achieve the aim and objectives of the study.

2.2 Literature Synthesis on Non-Value Adding Activities in the Construction Processes

2.2.1 Understanding Waste

Womack and Jones (2003) describe waste (muda) as any human activity which absorbs resources but creates no value. Thus by eliminating waste, activities can become 'lean' producing more with less resources (Womack and Jones, 2003). Senaratne & Wijesiri, (2008) have revealed that a considerable amount of waste lies in the flow processes of construction. 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 non-value adding activities 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. A link exists between waste in a project and its cost. Waste only exists in relation to value which is different for each end–user / client /owner. One generation's music is another generation's noise. One owner's value can be another owner's waste.

Serpell et al (1999) have defined waste as any construction process / activity that incurs cost but which does not directly or indirectly add value to the construction project. Further they defined waste as something undesirable that consumes time, money and resources that adds no value to the product. In order to eliminate waste it is important to understand exactly what waste is and where it exists.

Waste is a major problem in the construction industry and it amounts to 60% of the construction effort (Vilashini et all, 2011). A study focussing on the construction efficiency made by the National Institute of Standards and Technology in the UK indicates that 25%-50% of waste relates to coordinating labour and managing, moving, and installing material. Many researches (Mosman, 2009; Horman and Kenley, 2005; Vilashini et al, 2011) have revealed that a major portion of time in construction is devoted to wasteful activities. Mosman (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 .

2.2.2 Definitions of waste

The definitions provided for waste by different researches are indicated in Table 2.1

Table 2.1: Definition for waste

Definition for Waste	Sources
Waste is anything other than the minimum amount of equipment materials, parts, space and workers time, which are absolutely essential to add value to a product.	Simonsson (2008)
Waste is an activity that produces cost directly or indirectly, but which does not add value or progress to a product.	Alarcon (1997)
Waste is any human activity which absorbs resources but creates no value	Womack and Jones (1996)
Waste is referred to anything that creates no value for the owner/client/end user.	Mossman (2009)

It is thus clear that waste is a relative term which can be defined in terms of value. When focusing on waste, attention has to be on what is not needed. So, it is easy to lose sight of the value - what the customer wants (Mossman, 2009). Further, Mossman states that when there are more demanding problems or emerging waste, the initial waste that was to be eliminated can re-emerge. The waste emerging cycle demonstrated in Figure 2.1 illustrates that when waste elimination is focused on, it gets into an oscillation in which the amount of waste increases at times and decreases at other times. This pattern can be seen very clearly in construction sites. For example, when one trade falls behind, special pressure is applied to it to catch up. Pressure is then reduced and attention is shifted to another trade which by that time has started lagging. In the first trade things will start to slip again and pressure on it will be increased again. Therefore, Mossman (2009) has stressed that the focus should be on value rather than on waste. Focusing on value is more rewarding and more effective. Value will be delivered and waste eliminated or perhaps not even created altogether in the process.

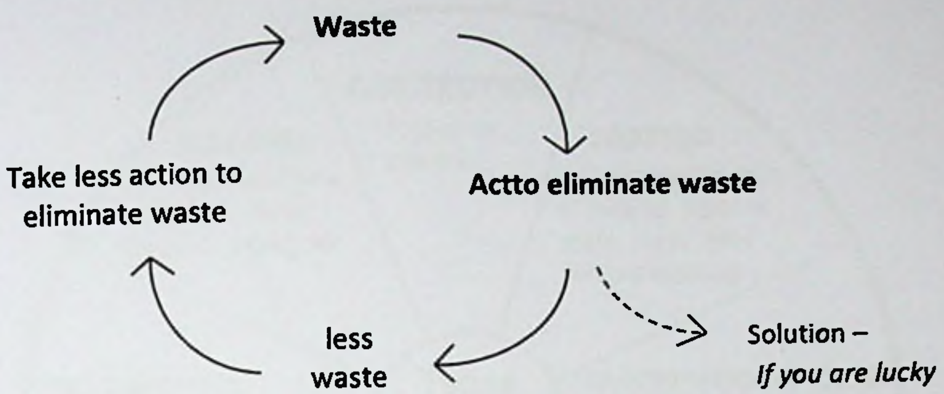


Figure 2.1: Waste elimination Cycle Source: Mossman (2009)

2.2.3 Categories of Wastes

There are many general categories of waste. Wastes that are mentioned here are identified by Taichi Ohno as Seven Wastes 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). Figure 2.2 illustrates the seven categories of waste.

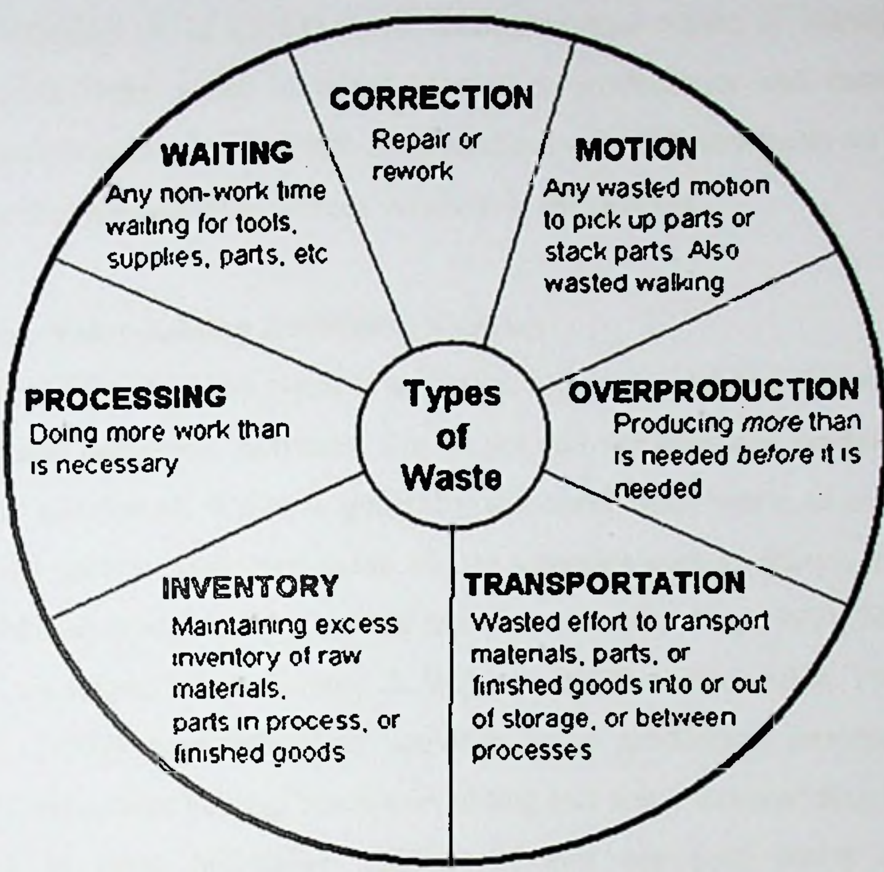


Figure 2.2: Seven category of wastes

Subsequently, researchers have suggested several more types of waste such as 'making do' by Koskela (2004b), 'not taking advantage of people's thoughts' by Macomber and Howell (2004) and 'behavioural change' by Mossman (2009). Thereafter other non-value adding activities also have been identified as indicated in Table 2.2.

Table 2.2: Other Examples of Waste

Behavioural waste – human behaviours that add no value	Bob Emiliani (2008)
Excess information	Robert Hall (2008)
Figuring what to do or how to do	Lararia (1999)
Making do	Koskela (1994)
Not speaking and not listening	Macomber & Howel (2004)
Not taking advantage of people's thoughts (wasting good ideas)	Macomber & Howel (2004)
Not using people's talents, underusing people's skills and capabilities	Suszaki (1987)

Further, Vilashini *et al* (2011) have concluded that waste is identified in lean thinking in a wider scope in terms of worker productivity and customer value. According to Formoso et all (1999, most studies in the industry focus on the waste of material and neglect other resources involved in the process.

2.2.4 Non-Value Adding Activities (NVAAs)

Taiichi Ohno identified two types of activities. i,.e Value Adding Activities and Non Value Adding Activities. Activities that do not add value simply generate waste and have to be eliminated. Waste is generally associated with waste of material in the construction process while non-value adding activities such as delays, transportation of material and others are not recognized as waste (Alarcon, 1997). Most of these activities are intangible (Senaratne & Wijesiri, 2008) and invisible. Further, Hines and Rich (1997) have classified activities in a production process into three categories, viz., value adding, non-value adding and non – value adding but required. According to them non-value adding activities are pure waste and involve unnecessary actions which should be eliminated altogether. Non-value adding activities are operations that may be wasteful but which are necessary under the prevailing operating procedures. In order to eliminate them partial changes will be required. Value adding activities involve the conversion or processing of raw material or semi-finished products in to the final product.

Horman and Kenly (2005) have contended that as much as 49.6% of the construction operative time may be devoted to NVAAs. NVAAs have been identified as one of the problems negatively impacting on issues relating to variations. Emuze and Smallwood (2011) have concluded that NVAAs are the major cause of schedule delays, cost overruns and other related problems in projects that require efforts for minimizing the amount of NVAAs in construction. 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 (rework, errors)

Waste that generates in the flow activities is recognized as a major disadvantage, which hinders performance and efficiency of constriction activities. Several authors including Cornick (1991), Austin et al. (1994), and Koskela *et al* (2001) have indicated poor communication, lack of adequate documentation, deficient or missing allocations, lack of co-operation between disciplines, unbalanced resource allocation and erratic decision making as the main causes for the poor performance of a building design process. According to Rahman (2012) every system contains waste. Whether you are producing a product, processing material, or providing a service, there are elements which are considered as 'waste'. The techniques for analyzing systems, identifying and reducing waste and focusing on the customer are applicable to any system and to any industry.

Performance improvement opportunities can be addressed by adopting waste identification and waste reduction strategies in parallel with value adding strategies (Alarcon, 1997). Keys et al (2000) have mentioned that reasons for waste within the construction industry are widespread and complex. 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 all, 2002). In particular, therefore fewer attempts have been made to minimize waste in construction (Koskela, 1992).

2.2.5 Non-Value Adding Activities in Construction Processes

According to the above findings it can be concluded that there is a considerable amount of Non-Value Adding Activities in the construction processes. These Non-Value Adding Activities are recognized as a major disadvantage, which hinders performance and efficiency of the construction industry. Previous studies have concluded that the workforce of the domestic construction industry is ignorant of these non-value adding activities that create waste and hinder construction performance. Through an opinion Survey done among the construction workforce, Senaratne and Wijesiri (2008) have established that lean construction is suitable for and acceptable to Sri Lanka. Recent findings (Senaratne and Wijesiri, 2008; Nissanka and Senaratne (2009) reveal frequent flow activities that generate waste in the local construction industry and their causes. The traditional thinking in most of the construction related organizations is focused on conversion activities and flow and value considerations are ignored. Waste is generally associated with waste of material in the construction process while activities such as inspection, delays, transportation of material and others are not recognized as non-value- adding flow activities that may lead to waste. Common wastages are the waste due to waiting, defects, design errors, transport/ handling time, activity delays, operations, excessive space / stock and rework. Causes of waste are late information, environmental issues, poor management control, poor planning, poor quality of resources, shortage of resources and defective and unclear information. The majority of flow wastes and their causes are identified as controllable.

Han et al (2008) have contended that errors and changes generally trigger NVAAs in the construction and production systems in the form of interruptions, productivity loss, and rework requiring additional time and efforts (additional resources that were not originally planned for) in order to compensate for the lost time and effort. According to Cooper (2002) the rework in the form of 'the rework cycle' that can occur either at the design stage or at the construction sites seems to pervade the construction process regardless of project activities, types and / or the location.

Huang et al (2009) have discovered that in both owner and contractor reported projects in the database of the Construction Industry Institute (CII) in the USA, design error / omission appeared to be the root cause of rework among other sources that included owner change, design change, vendor error / omission, constructor change, and transportation error. Another study that focused on the construction industry in Australia and Indonesia has discovered that design changes, lack of trade skills, slow decision making, poor coordination among project partners, poor planning and scheduling, delays in material delivery to site, inappropriate construction methods, poor designs, poor quality of site documentation, slow drawing revisions and distributions, unclear site drawings, unclear specifications and weather conditions individually and collectively result in NVAAs at varying degrees.(Alwi et al ,2002)

2.2.6 Sources for NVAAs in construction processes

According to Alwi et al, 2002, sources for NVAAs in the construction processes can be categorized in terms of people, professional management, design and documentation, material, site operations and physical factors. The examples for sources of NVAAs are illustrated in Table 2.3

Table2.3: Sources of NVAAs

Sources	**Examples for Sources of NVAAs**
People	Inadequate trade skills, poor distribution of labour, late supervision of work, shortage of skilled supervisors/ formen, inadequate subcontractor skills and inexperienced inspectors
Professional Management	Poor planning and scheduling, poor information management, poor coordination within the construction supply chain and slow decision making process
Design and documentation	Poor quality site documentation, unclear specifications, unclear site drawings, slow response to Request For Information (RFI), design changes and poor designs
Material	Non-conformance to quality standards, delay of material delivery, poor material handling, inappropriate use of material
Site operation	Poor site layout, outdated equipment, shortage of equipment, inappropriate construction methods, excessive reliance on overtime in order to execute work timely

Further to the above identification of sources of NVAAs, Alwi *et al*, 2002 have stated that NVAAs in various forms have a detrimental effect on construction projects. Therefore it is seen that any form of NVAAs can impact negatively on the cost and productivity.

2.2.7 Examples of NVAAs in Construction processes

The researcher dealt with 200 publications related to construction industry to identify examples of NVAAs. Out of these 200 publications, there were 51 paper publications which were directly related to the research problem of this study and 17 journal papers out of 51numbers have been critically reviewed as broadly defining the issues related to NVAAs. In this literature, 49 examples of NVAAs have been explored as indicated in Figure 2.3. These examples of NVAAs were further categorized into seven types of waste identified by Taichi Ohno with the addition of an eighth category as ' other' for waste which does not fall into any of the above mentioned seven categories.

	Reference	Examples of Non Value Adding Activities	Vilasini N., and Neitzert (2012)	Andersen et al (2012)	Al-Aomar R. (2012)	Rahman et al (2012)	Ballard G. (2011)	Vilasini et al (2011)	and Smallwood (2011)Emuze	Wu and Low (2011)	Mossman, A. (2009)	Senaratne and Wijesiri (2008)	Abdulazizam and Al-Sudairi (2007)	Koskela (2004)	Report by CPN Network (2003)	Josephson and Saukkoriipi (2003)	DTI Report (2001)	Howell and Ballard (1994)	Ballard and Howell (1994)
Defects	D01NA01	Repair Work			x	x		x	x			x		x	x				
	D02NA02	Design errors			x				x										x
	D03NA03	Design changes							x										x
	D04NA04	Installation errors			x				x										
	D05NA05	Vendors errors							x										x
	D06NA06	Damage by other crafts							x										x
	D07NA07	Incomplete Installations							x										x
	D08NA08	Rehandling materials							x										x
	D09NA09	Damaged Materials on site							x								x		
	D10NA10	Poor material allocation						x	x										
	D11NA11	Rework	x	x	x		x	x	x	x		x	x				x	x	
	D12NA12	Site layout is not carefully planned								x									
	D13NA13	Uncomplete work			x			x	x										
Waiting	W01NA14	Delay to schedules												x			x		
	W02NA15	Waiting for Instructions								x							x		
	W03NA16	Waiting for equipment repair															x		
	W04NA17	Waiting for equipments to arrive															x		
	W05NA18	Equipment freequently breakdown										x					x		
	W06NA19	Waiting for Clarifications			x	x						x							
	W07NA20	Waiting (for people, material)						x					x		x				
	W08NA21	Activitiy Delay						x				x							
	W09NA22	Idle Time						x											
Motion	M01NA23	Unnecessary material people movement						x		x				x					
	M02NA24	Unnecessary motion				x									x				
	M03NA25	Excessive labour movement			x														
	M04NA26	Excessive material movement			x														
Inventory	I01NA27	Material stocks										x		x	x				
	I02NA28	Inventory work						x											
	I03NA29	Excess material Inventory								x		x							
	I04NA30	Inventories				x													
Extra Procedures	E01NA31	Unnecessary processing			x			x		x	x	x		x	x				
	E02NA32	Long approval processes			x														
	E03NA33	Retests			x														
	E04NA34	Excessive safety measures			x							x							
	E05NA35	Excessive supervision			x														
	E06NA36	Excess information									x								
	E07NA37	Excessive training time			x														
Transport	T01NA38	Unnecessay material transport movement								x				x	x				
	T02NA39	Travelling time										x	x						
	T03NA40	Unnecessary Transport			x														
	T04NA41	Long transport time			x														
Overproduction	OV1NA42	Unwanted Productions			x	x						x		x	x				
	OV2NA43	Unnecessary work						x		x	x				x		x		
	OV3NA44	Material waste						x											
	OV4NA45	Inefficient work			x			x											
Others	OT1NA46	Material does not meet specification								x							x		
	OT2NA47	Taxes														x			
	OT3NA48	Pilferage			x							x							
	OT4NA49	Making - do						x			x			x					

Figure 2.3: Examples of Non Value Adding Activities in construction processes.

This literature review confirms that NVAAs are the major cause for schedule delays, cost over runs and other related problems (Emuze and Smallwood 2011). An alternative way to tackle the problem is to identify activities, which do not add value to the customer (Josephson and Saukkoriipi, 2001). According to Salem et al (2006), there are so much of waste in construction processes that go unnoticed. Previous studies (Senaratne & Wijesiri, 2008; Vilashini et al, 2011; Rahman et al 2012), disclose that the workforce of the domestic construction industry is ignorant of these NVAAs that create waste and hinder construction performance. NVAAs in various forms have a detrimental effect on construction projects (Alwi et al, 2002). Any form of NVAAs impact negatively on cost and productivity. Vilashini et al (2011) have concluded that there is much opportunity to eliminate waste and add value in construction. Further the methodology for eliminating waste has been suggested by using lean techniques such as continuous improvement, mistake proofing and standardization. Mossman (2009) has identified waste as anything that creates no value for the owner / client / end user and defined it in terms of value. Waste could be identified by knowing the value first. Wu. P and Low S. P (2011) have revealed that the lean production philosophy which originated from the Toyota production system advocates reducing or eliminating non-value adding activities at the same time and improving the efficiency of value adding activities.

2.2.8 Summary

Activities that do not add value is simply waste and should be eliminated. The greatest obstacle to waste removal in general is failure to recognize it. Horman and Kenly (2005) have contended that as much as 49.6% of construction operative time may be devoted to NVAAs. Waste that generates in flow activities is recognized as a major disadvantage, which hinders performance and efficiency in construction activities. 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). Examples of 49 NVAAs were identified through a comprehensive literature Survey and they are categorised into seven types of waste.

2.3 Literature Synthesis on Implementation of Lean Techniques

2.3.1 Lean principles

The manufacturing industry has been a constant reference point and a source of innovation for the construction industry over many decades. The lean concept is one strategy adopted by the construction industry from the manufacturing industry to improve its own performance (Vilashini and neitzert (2012).All construction activities can be divided in to two types, i.e conversion activities which produce tangible results and flow activities which bind such 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). Research into these lean principles in construction has found that considerable waste lies in flow processes of construction. By eliminating waste activities, processes can become 'lean' to provide 'more with less' resources (Womack and Jones, 2010). Lean production was developed by Toyota led by Engineer Ohno who was dedicated to eliminate waste (Howell, 1999). 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 (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. When moving towards zero waste, perfection shifts the focus from improvement of the activity to the delivery system (Howell, 1999). Similarly, Koskela (2004) has defined lean production as 'lean' because it uses a lower amount of everything as compared to mass production. Howell and Ballard (1998) havere defined 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 situation that maximizes value and minimizes waste.

Howell (2011) says, "My favourite definition of lean construction is that it is a new way to see, understand and act in the world". According to Womack and Jones

(2003), the five principles of lean thinking are value, value stream, flow, pull and perfection. Lean construction 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 lean philosophy can be considered as a new way to design and make things that are different from mass and craft forms of production through the objectives and techniques applied on the shop floor, to design and along supply chains (Howell, 1999). Koskela,1992 has concluded that eleven important principles some of which are reducing waste, variability, cycle and increasing transparency, are essential to the lean philosophy. Ballard (2008) and Womack (1996) have refined and expanded the lean concept for construction and have outlined the basic lean thinking principles. Table 2.4 illustrates the five principles of lean thinking.

Table 2.4: Lean Principles

Lean Principle	**Description**
Value	Precisely specify value from the perspective of the ultimate customer
Value stream	Clearly identify the process that delivers what customer values (the value stream) and eliminates all non-value adding steps
Flow	Make the product flow or organize the production in a continuous flow
Customer Pull	Do not make anything until it is needed, then make it quickly
Perfection	Manage towards perfection by continuous improvements and deliver on order a product meeting customer requirements with nothing in inventory

The values normally recognized in the construction industry are quality, time and cost. (Wu. P and Low S. P (2011).The lean concept has proven to be effective in increasing environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value (Huovila and Koskela, 1998; Salem et al (2005): Bae and Kim (2007): Peng and Phene (2010)

EPA (2003) found that 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.

2.3.2 Lean Construction (LC)

In the recent past, researches have placed greater emphasis on developing ways in which the operating system of a construction project can be improved and one such method is known as Lean Construction (Singleton and Hamzeh, 2011). Lean construction is a new way to manage construction work. Further, Shang et al (2012) have revealed that lean is an innovative construction management approach which is linked closely to the overall life of a project ensuring its success. Lean construction is a concept still new to many construction industries in the world (Senaratne and Wijesiri, 2008). Consequently, lean construction is an effort to apply lean production principles to the construction industry to eliminate non-value adding activities in the construction processes and to maximize value to clients. Although all activities incur cost and consume time, Lean Principles state that only conversion activities add value and that therefore these should be made more efficient, whereas non value adding flow activities need to be reduced or eliminated. Research into these lean principles in construction has found that considerable waste lies in the flow processes of construction. By eliminating waste activities, processes can become 'lean' to provide 'more with less' resources. This flow waste is recognized as a major disadvantage, which hinders performance and efficiency of the construction industry. Previous studies have concluded that the workforce of the construction industry is ignorant of these flow activities that create waste and hinder construction performance (Rahman (2012)). Lean construction aims at reducing waste caused by unpredictable work flows. The lean concept has been introduced to different projects of the construction industry at varying levels of success. Terry and Smith (2011) state that as far as a construction company is concerned, lean will involve two significant paths, i.e best people and systems in place to control them. Figure 2.4 illustrates these two paths.

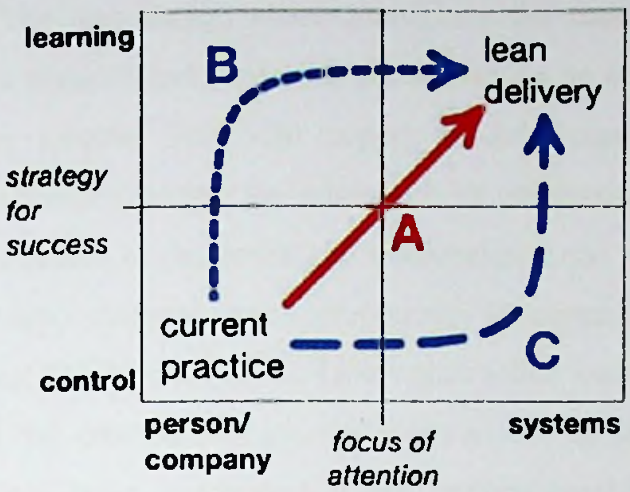


Figure 2.4: Paths to Implementation (Terry and Smith, 2011)

However, Howell (2011) argues saying that "successful transformations in my experience begin with action and study and lean construction focused on improving systems instead of on individual motivation and training rather than control". According to Howell and Ballard (1998), both construction and manufacturing require prototyping, i.e the design of both the product and the process. Thus implementation of lean production does not require making construction to look more like manufacturing by standardizing products; rather it starts by accepting the ideal of perfection offered by lean and understanding the application of each principle and technique to construction. The implementation of lean means the adoption of a 'project-as-production-system' approach to construction.

Ballard (2000a) divides the lean Project Delivery System into four interconnected phases, i.e 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 project definition to its construction phase.

The lean project management is focused on implementing the guidelines of Lean Project Delivery System developed by LCI (Ballard 2008). The Lean Project Delivery System 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. Lean assembly ranges from the delivery of tools, material, and components to commissioning and project delivery to the client (Al-Aomar (2012). Lean construction 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 J. and Pasquire C. (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 client's (as the paying customer) requirements. Bertelsen (2005) have 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. The different phases of the Lean Project Delivery System are further discussed in the next Section.

2.3.3 Lean Project Delivery

2.3.3.1 Introduction

Rahman (2012) has stated that the emerging concept of lean construction 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 lean construction among academics all over the world. These researches seek to investigate the extent to which the Japanese model of lean production can be applied in the construction industry. From the study of its background, lean construction appears to have resulted from the adaptation and implementation of the Japanese manufacturing principles in construction practices. Lean construction, assumes that construction is a kind of production process (Bertelson, 2004). The essential features of lean construction include a clear set of objectives for the delivery process, aiming at maximizing performance for the customer at project level, concurrent design of products and processes and the application of production controls throughout the life of a product from its design to delivery (Rahman 2012). Lean construction is the continuous process of eliminating waste, focusing on the entire value stream, and pursuing perfection in the execution of a construction project. Lean also focuses on the way one activity can affect the next (Pinch, 2005).

According to Rahman (2012), there are three features that distinguish lean construction practice from a conventional construction management viz., (a) Lean construction focuses on reducing waste that may exist in any form in the construction processes such as inspection, transportation, waiting, and motion. (b) Lean construction aims at reducing variability and irregularity so that material and information can flow in the system without interruptions; (c) construction material is expected to be at the site only when it is needed. The lean project delivery system emerged in 2000 from theoretical and practical investigations, and is in the process of undergoing development in many parts of the world through experimentation. In the recent years, studies have focused on the definition and design phase of projects, applying concepts and methods drawn from the Toyota Products (Barrald 2008). Contractors have to align the interests of the project team members in pursuit of the lean ideal to develop the project while generating value. This type of contracts are called 'relational'.

The preliminary starting point for the approach is the claim that project teams are responsible for helping customers to decide what they want, not just doing what they are told. The key steps in the process are:

1. Clients specify how much they are able and willing to spend to get what they want
2. The way a facility is to be used is determined before it is designed
3. Design criteria are developed from values and values from purposes
4. Clients engage key members of the project delivery team to help validate and improve the project business plan
5. Target values and constraints are set as stretch goals to spur innovation.

6. The design is steered toward targets using a set based approach in which alternatives are evaluated from the outset against all design criteria with constraints and decisions being made last.

2.3.3.2 Project definition

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) has revealed that cost, quality, 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 applied as a part of traditional cost management, such as contract and cost management and target cost contract. It includes several phases, i,e client brief, procurement advice and budget, cost planning and control of the design stage.

2.3.3.3 Lean design

Lean Design: The building design process involves thousands of decisions, sometimes taken 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) have 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 material and information; and c) design as a value generating process for the clients. Hence, recent researchers (Bae and Kim, 2007; Formoso et al, 1998; Tzortzopoulos and Formoso, 1999) have discussed the application of some lean principles to design management.

2.3.3.4 Lean supply

Lean Supply: Pasquire and Connolly (2002) have revealed that lean production has made significant improvements in the manufacturing sector and that there is a simple argument that increasing the amount of factory based manufacturing of buildings, 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 material. Moreover, these methods may reduce the various sources of extra inventory. Further, Pasquire and Connolly (2002) have concluded that lean manufacturing has a direct application in construction through the pre-assembly of building components and that considerable benefits are available as a result of off-site manufacturing.

2.3.3.5 Lean assembly

Lean assembly: Lean assembly 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 during the construction implementation stage. Further Salem et al (2006) have expressed that there are approaches to Lean Assembly, i.e Flow Variability, Process Variability, Transparency and Continuous Improvement.

2.4 Lean Implementation in construction settings

2.4.1 Introduction

During the last ten years, an increasing number of companies have implemented lean construction practices in an attempt to improve the performance of their construction projects. Most companies and researches have reported satisfactory results from their implementation (Alarcon et al, 2006). Transferring the lean production practices directly into construction could be risky. It will always be a danger to adopt practices without understanding their underlying principles (Andersen *et al* 2012). The lean concept was developed based on the original Toyota Production system, which aimed to produce what the customer wanted at the time with minimum waste (Womack, 1991). Lean is about designing and operating the right process and having it right at the first time (Rahman,2012) Lean is focused more on value instead of cost, seeking the removal of non-vale adding activities whilst improving those that add value (Rahman., 2012).

2.4.2 Lean implementation

By applying lean production principles to the construction industry, many positive results have been achieved worldwide in many of its areas, such as enhanced value, reduced costs, and increased customer satisfaction. For example, Ballard (1994) has achieved a 30% productivity increase by matching labour with the workflow of backlog and by shielding direct production from upstream variation and uncertainty.

Lean Production (LP) concepts, principles, and tools have been studied by academics for over 20 years (Schonberger, 1982, Womack,1991). Nonetheless for many, the term Lean production is still considered as an ill-defined concept which needs further exploration and agreement in academic as well as in professional settings (Hines et al, 2004, Jorgensen and Emmitt, 2008, Pettersen, 2009). The application of LP in construction is almost as old as the term Lean Construction which first appeared in 1992 (Koskela, 1992). At this point in the construction industry, as in other sectors, a large number of Lean Literature examples abound (International Group for Lean Construction IGLC, 2012 and Lean construction Institute LCI, 2010).

The need for change in construction practices has been discussed time and time again throughout the years and their echoes are still present in people's minds (Luafer and Tucker, 1987; Latham, 1994; Eagan 1998; Koskela and Howell 2002). These calls for change did not merely request the adoption of new technology and tools, or the acquisition of new skills needed to operate them. Rather, they called for a change in the way the industry fundamentally operates and invariably focused on the management of the entire construction process. (Alves et al 2012).

The industry is clearly facing a change of paradigm and whether or not this combination of theory and related practices will still be called 'Lean Construction' ten years from now on is yet to be seen. However, early adopters in the industry are reaping benefits, which cannot be achieved without a change in the current mind set as suggested by the previous studies (Miller, 2002)

It is vital to investigate how lean production has evolved in the construction industry and speculate about its implications. According to Alves et al (2012) there are three challenges in LC implementation;

1. There are many meanings (whether denoted or connoted) for lean when applied to construction
2. Academics need to work closely with the industry (organizations and consultants) in the translations of concepts from the manufacturing industry to construction and to promote the systemic use of concepts/systems without using only the tools
3. Without a sustained effort to engage people in meaningful learning experiences which mix instruction, exchange of ideas and meanings, and guided practice, lean construction may be viewed as a fad in the construction industry.

Lean construction may give a possibility to reduce cost or time of operation by 25% - 50% (Ballard and Howell, 1994).

Novel management concepts have been adopted for performance improvement based on new production methodologies and the lean principle is one such methodology that is being applied in the construction industry (Vilahsini *et al,* 2011)

Lean is a trendy production methodology developed in the manufacturing industry that has been largely ignored by the construction sector (Jorgensen, Matthiesen, Nilesen & Johansen, 2007). Practitioners who have been working towards the implementation of lean concepts in construction have noted that lean construction is not just applying lean manufacturing concepts to construction (Diekman, Krewedl, Balonick, Stewart & Wonis, 2004; Solomon, 2004; Ozgen, 2007). There is a consensus about the need to customize lean manufacturing principles to construction. The realization of benefits of lean requires thorough planning throughout the project life cycle and the integration of project participants (Mawdesley & Long, 2002). According to Mossman (2009), LC is referred to as a philosophy which focuses on continuous improvement through value streams to respond to customer needs. Consequently improvement is accomplished by eliminating waste in a manufacturing process. Stark and Field (as cited in Mossman, 2009) have defined LC as a set of ideas based on the holistic pursuit of continuous improvements. Eagan report (1998) described LC as an influential technique for eliminating waste, delivering improvements in efficiency and quality in construction.

Vilashini et al (2011) have concluded that LC allows meeting customer requirements, focusing on the applicable across design, procurement and production processes. Further, they have concluded that from a relationship management perspective; partnerships seem more to be in tune with lean implementation. Partnerships encourage relationships that cover both external and internal project participants, with a strong focus on collaboration and systems thinking sub-principles.

2.4.3 Case studies on lean implementation

However, there is still a need to provide a 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 the details of those research studies are summarized in Table 2.5.On the whole, there is sufficient evidence on the implementation of lean techniques in construction as discussed above. 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 as discussed next.

Table 2.5: Case studies on Lean Implementation

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 the shortcomings of the mainstream cost and contract management approach that result in regular cost over runs and client dissatisfaction could be cured	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 a significant improvement of the project performance. The final cost of the project was on average 15% less than the 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 rise.
Sustainable value in construction projects and application of lean construction methods ***Bae, J.W., and Kim, Y.W., 2007***	To examine how currently available lean construction tools and methods impact on 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; reduced resource depletion, pollution prevention by eliminating waste, 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 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 charts	There are some gaps in the information available on the application of theory to design. The development and implementation of models for managing the design process in practice is an important step taken and a discussion on it need to 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 support from major construction, consultant and client organizations	Off-site Manufacturing. Kaizen Kaizen Formula One Just-In-Time	Lean manufacturing has direct applications in construction through the pre-assembly of building components which results in considerable benefits: Reduction of on-site labour, welfare cost, and health and safety risks, coordination interface, just in time delivery, reduced opportunities for waste, improved cost certainty, zero defects as a result of off-site manufacturing

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Lean production, value chain and sustainability in a 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 quantified through semi-structured interviews of 17 pre-casters	Lean production philosophy Value Chain	Lean Production philosophy can provide a lean benchmark for construction material. It offers relative measurements of the sustainability factors for construction material based on the best operations that can be achieved. Lean production philosophy makes practical contributions to sustainable development. By eliminating non-value activities, pre-casters can produce more environmental friendly construction material
Lean Assembly				
Site implementation and assessment of lean construction techniques ***Salem.O., Solomon.J, Genaidy,A. and***	To test the effectiveness of a few lean construction tools that can be applied in medium size construction firms	Direct observations, interviews, questionnaires and documentary analysis through lean implementation measurements,	Last planner, increased visualization, daily huddle meetings, first run studies, 5S process,	Last Planner, increased visualization, daily huddle meetings and first run studies achieve a more effective outcome. 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

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Luegring, M. 2005		standards and performance criteria.	Fail safe for Quality.	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 of lean construction ***Alarcon,L.F, Diethelm,S., Rojo, O., and Caldero, R., 2005***	To analyze some of the main impacts and lessons learned from lean implementation.	Data obtained from the authors' own experience and case studies found in 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 in 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 have adopted Last Planner	Last Planner System (LPS)	There is a significant correlation between the implementation of the Last Planner and project performanceand the sum of cost and schedule reduction percentage. If a project implements Last Planner more, it will achieve better project performance than those employing Las Planner

In general, the above findings reveal that lean techniques used in the manufacturing industry can be adopted in the construction industry during different phases of construction. Moreover, many researchers such as Salem et al, 2005, Ballard (2011) and Singleton and Hamzeh (2011) have concluded that in construction projects where more lean techniques are applied, project performance and effectiveness are higher. This study will select lean implementation cases in the lean assembly phase for a detailed review. The lean assembly phase is found more relevant compared to other phases considering the ultimate aim of the research which is to develop a lean implementation framework for the construction processes of construction contractors in Sri Lanka.

2.5 Lean Techniques

Several lean techniques have been developed for the manufacturing industry by many authors. Egan (1998) 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). Lean principles argue that waste could be eliminated by certain techniques which will provide more value with fewer resources. These are discussed in the next Section.

2.5.1 Widely used Lean Techniques

Section 2.2.5.3 presents lean implementation cases in the construction sector along with a critical analysis of their findings. It was revealed that widely used lean techniques in the construction sector reap benefits. Table 2.6 presents these widely used lean techniques.

Table 2.6: Widely used lean techniques in selected case studies

Name of the Study	Lean Techniques applied
Target Value Design: Using collaboration and a lean approach to reduce construction cost ***Zimina,D., Ballard, G., Pasquire, C.,2012***	Target Value Design
Sustainable Value on Construction Project and Application of lean construction Methods ***Bae,J.W., and Kim, Y.W., 2007***	Target Costing Just-in-time Prefabrication Value stream mapping Kaizen
Considerations on Application of Lean Construction Principles to Design Management ***Tzortzopoulos, P. and Formoso, T. (1999)***	Modelling the process using Flow Charts and Input-output chart
Leaner construction through off-site manufacturing ***Christine L Pasquire, C. L., and Connolly, G.E., 2002***	Off-site Manufacturing. Kaizen Kaizen Formula One Just-In-Time
Lean Production, value chain and sustainability in precast concrete factory –a case study in Singapore ***Peng, W. And Pheng, S. 2010***	Lean Production philosophy Value Chain
Site Implementation and Assessment of Lean Construction Techniques ***Salem.O., Solomon.J, Genaidy,A. and. Luegring, M. 2005***	Last Planner, Increased visualization, Daily huddle meetings, First run studies, 5S process, Fail safe for Quality.
Assessing the impact of implementation of lean construction ***Alarcon,L.F, Diethelm,S., Rojo, O., and .Caldero, R., 2005***	Last Planner System (LPS)
Last planner and Integrated Project Delivery ***Cho, S, and Ballard, G., 2011***	Last Planner System (LPS)

The above mentioned lean techniques which are 16 in number were identified through the review of literature on Lean Implementation cases discussed in Section 2.4.3. As the next step of the literature review, the researcher has further identified lean techniques by reviewing more literature on lean construction and these techniques are discussed in the Section that follows.

2.5.2 Literature Review on Lean Techniques

After reviewing the lean implementation cases discussed in Section 2.4.3, some of the lean techniques presented in Table 2.6 were identified and the literature Survey was further continued with a view to explore more lean techniques. More than 50 different publications which had been published during the period from 1998 to 2012 were reviewed to examine the lean techniques. The list of lean techniques shown in Table 2.7 was thereafter established.

Table 2.7: List of lean techniques

Ref	Lean Techniques	Sources
1	Last Planer System	Andersen B., Belay A M, and Seim E A (2012),Hamzeh, F, Ballard G, Tommelein I D (2012), Rahaman H A, Wang C, Lim I Y W (2012) Kalsaas B T (2012) Mossman, A. (2009), Salem, O. and Zimmer E (2005) Ballard, G., and Kim, Y.W., 2005, Bertelsen, S., 2004, Salem O. Genaidy A., Luegring M., Paez., O and Solomon, J.(2004) Salem.O., Solomon.J, Genaidy,A. and. Luegring, M.2005, Alarcon,L.F, Diethelm,S., Rojo, O., and Caldero, R., 2005, Cho, S, and Ballard, G., 2011
2	Just in Time	Andersen B., Belay A M, and Seim E A (2012), Al-Aomar R. (2012), Rahaman H A, Wang C, Lim I Y W (2012 Vilashini, N, Neitzert, T R, and Rotimi, O. J (2011 Senaratne S. and Wijesiri, D., (2008 Salem O., Solomon J., Genaidy A and Minkarah., I (2006 Koskela, L. 2004Bae,J.W., and Kim, Y.W., 2007, Christine L Pasquire, C. L., and Connolly, G.E., 2002
3	3D modelling	Ballard, G., and Kim, Y.W., 2005
4	Visualization	Vilashini N. and Neitzert T R (2012 Al-Aomar R. (2012 Salem, O. and Zimmer E (2005),Ballard, G., and Kim, Y.W., 2005 Salem O. Genaidy A., Luegring M., Paez., O and Solomon, J.(2004)

Ref	Lean Techniques	Sources
5	Value Stream Mapping	Vilashini N. and Neitzert T R (2012 Al-Aomar R. (2012 Salem, O. and Zimmer E (2005) Ballard, G., and Kim, Y.W., 2005 Report by the Construction Productivity Network, 2003, Howel, G. And Ballard G., 98 Bae,J.W., and Kim, Y.W., 2007
6	Reverse Phase Scheduling	Salem O., Solomon J., Genaidy A and Minkarah., I (2006 Salem, O. and Zimmer E (2005), Ballard, G., and Kim, Y.W., 2005 Salem O. Genaidy A., Luegring M., Paez., O and Solomon, J.(2004)
7	Huddle Meeting	Rahaman H A, Wang C, Lim I Y W (2012 Salem.O., Solomon.J, Genaidy,A. and. Luegring, M.2005
8	Prefabrication	Vilashini N. and Neitzert T R (2012 Tam V. W Y., Tam C.M., and William C.Y. N (2007), Luo, Y., Rilley D. R. and Horman M J. 2005 DTI Construction Industry Directorate Project Report: Current practice and potential uses of Prefabrication (2001) Bae,J.W., and Kim, Y.W., 2007
9	Off-site Manufacturing	Vilashini N. and Neitzert T R (2012 Tam V. W Y., Tam C.M., and William C.Y. N (2007 Luo, Y., Rilley D. R. and Horman M J. 2005 Christine L Pasquire, C. L., and Connolly, G.E., 2002
10	Kaizen	Al-Aomar R. (2012 Vilashini, N, Neitzert T R and Gamage J R Mossman, A. (2009 Salem O., Solomon J., Genaidy A and Minkarah., I (2006 Salem, O. and Zimmer E (2005) Bae,J.W., and Kim, Y.W., 2007, Christine L Pasquire, C. L., and Connolly, G.E., 2002, Ballard, G., and Kim, Y.W., 2005 Salem O. Genaidy A., Luegring M., Paez., O and Solomon, J.(2004), Koskela, L. 2004 14. Lean Examples in Construction, Report by the Construction Productivity Network, 2003
11	Five S	Al-Aomar R. (2012), Rahaman H A, Wang C, Lim I Y W (2012), Salem O., Solomon J., Genaidy A and Minkarah., I (2006 Salem, O. and Zimmer E (2005) Salem.O., Solomon.J, Genaidy,A. and. Luegring, M.2005, Ballard, G., and Kim, Y.W., 2005 Salem O. Genaidy A., Luegring M., Paez., O and Solomon, J.(2004)
12	Fail Safe Quality	Al-Aomar R. (2012), Rahaman H A, Wang C, Lim I Y W (2012 Salem O., Solomon J., Genaidy A and Minkarah., I (2006 Salem, O. and Zimmer E (2005) Salem O. Genaidy A., Luegring M., Paez., O and Solomon, J.(2004) Salem.O., Solomon.J, Genaidy,A. and. Luegring, M.2005

Ref	Lean Techniques	Sources
13	Target Value Design	Ballard G. (2011), Salvatierra-Garrido J. and Pasquire C. (2011 Zimina,D., Ballard, G., Pasquire, C.,2012
14	First Run Studies	Andersen B., Belay A M, and Seim E A (2012), Hamzeh, F, Ballard G, Tommelein I D (2012 Rahaman H A, Wang C, Lim I Y W (2012 Salem, O. and Zimmer E (2005) Salem.O., Solomon.J, Genaidy,A. and. Luegring, M.2005, Ballard, G., and Kim, Y.W., 2005
15	Relational Contracting	Ballard G, (2008 Ballard, G., and Kim, Y.W., 2005
16	Target Costing	Ballard G, (2008 Ballard, G., and Kim, Y.W., 2005 Lean Examples in Construction, Report by the Construction Productivity Network, 2003 Bae,J.W., and Kim, Y.W., 2007
17	Set Based Design	Andersen B., Belay A M, and Seim E A (2012 Ballard G, (2008
18	Kanban Material Card	Rahaman H A, Wang C, Lim I Y W (2012 Ballard, G., and Kim, Y.W., 2005
19	BIM	Ballard G, (2008 Ballard, G., and Kim, Y.W., 2005
20	Total Quality Management	Vilashini, N, Neitzert, T R, and Rotimi, O. J (2011 Senaratne S. and Wijesiri, D., (2008) Koskela, L. 2004
21	Work Standardization	Al-Aomar R. (2012) Rahaman H A, Wang C, Lim I Y W (2012 Vilashini, N, Neitzert T R and Gamage J R
22	Work Structuring	Al-Aomar R. (2012) Rahaman H A, Wang C, Lim I Y W (2012)
23	Flow Charts	Tzortzopoulos, P. and Formoso, T. (1999)
24	Lean Production Philosophy	Peng, W. And Pheng, S. 2010
25	Value Chain	Peng, W. And Pheng, S. 2010
26	Increased Visualization	Salem.O., Solomon.J, Genaidy,A. and. Luegring, M.2005

2.5.3 Pilot Survey to select Lean Techniques

After establishing the list of lean techniques, a pilot Survey was done to identify lean techniques appropriate to the construction industry in Sri Lanka. The participants for this pilot Survey were; i) A Senior Manager of a leading manufacturing firm who was a Mechanical Engineer and who had more than 20 years' experience especially in a lean implementing environment, ii) A senior Lecturer who was a PhD holder in construction management, working in a leading foreign university who had a good industry experience in Sri Lanka, iii) A senior Architect who had more than 15 years' experience especially in green building environment and who was an industry practitioner, iv) A senior Quantity Surveyor, who has got more than 20 years' experience in the construction industry in Sri Lanka, v) An entrepreneur who runs a leading construction company and who has worked as a Project Manager for more than 10 years in the local construction industry. Each and every lean technique given in the above list was discussed and there are several techniques with different names but with the same meaning (prefabrication and off-site manufacturing). Visualization, increased visualization and flow charts were referred to as one technique-visualization. 'Huddle meetings' is the technique used within the last planner system. Hence 26 techniques were adjusted to make the total add up to 20. The researcher decided to bring all these 20 techniques to the industry for the purpose of data collection required to develop the framework for lean implementation and minimize non-value adding activities. These lean techniques were coded as shown in able 2.8.

Table 2.8: Lean techniques selected for the study

LT01	Last Planner System
LT02	Just in Time
LT03	3D Modeling
LT04	Visualization
LT05	BIM
LT06	Value Stream Mapping
LT07	Reverse Phase Scheduling
LT08	Prefabrication / Off site manufacturing
LT09	Kaizen / Continuous Improvement
LT10	Five S
LT11	Fail Safe Quality / Poka-yoke
LT12	Target Value Design
LT13	First Run Studies
LT14	Relational Contracting
LT15	Target Costing
LT16	Set Based Design
LT17	Kanban
LT18	Total Quality Management
LT19	Work Standardization
LT20	Work Structuring

Having established the list of lean techniques, the Sections that follow will present a basic introduction to each of the techniques.

Last Planner (LP)

Last Planner is a lean technique that has four main processes, i.e Master Schedule, Phase Schedule, Look Ahead Plan, and Weekly Plan (Hamzeh, 2009). It is a production planning and control system implemented in construction projects to improve their planning and production performance.

Many researchers have proved that reducing plan variability will help to increase productivity. Alarcon et al. (2006) have suggested a regression line between plan reliability and production and Alarcon et al. (1997) have showed a difference in productivity after implementing Last Planner. In construction, the effective point of intervention has proven to be the weekly Work Plan, since it is where work is selected and commitments are made, and the key to the reduction of uncertainty is improving the ability to keep commitments by better selection of the work to be done (Howell, 1994).Production Planning and Control systems are implemented in construction projects to improve planning and production performance (Hamzeh, 2009) 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). LP is based on extensive cooperation among different contractors and subcontractors who commit to coordinating their activities in increasing detail as the practical implementation approaches (Kalsaas, 2012).

Just in Time (JIT)

The concept of Just in Time is utilized in construction work wherein the inventories are kept to the bare minimum and new inventories are ordered based on the current demand (Ballard and Howell, 1998). Stocking of material is always wasteful. JIT is a Japanese management philosophy which has been applied in practice from early 1970s in many Japanese manufacturing organisations. It was first developed and perfected within the Toyota manufacturing plants by Taiichi Ohno as a means of meeting consumer demands with minimum delays (Monden, 1993). JIT manufacturing has the capacity, when properly adapted to the organisation, to strengthen the organisation's competitiveness in the marketplace by substantially reducing waste and improving product quality and efficiency of production. (Cheng and Podolsky, 1993).

3D Modelling

According to Egan (1998), Pacific Contracting of San Francisco, a specialist cladding and roofing contractor, has used the principle of lean thinking to increase its annual turnover by 20% within a period of 18 months. The key to this success was improvement of the design and procurement process to facilitate the construction site. The company used a computerized ***3D design*** system to provide better and faster information through isometric drawings of components and interfaces, fit co-ordination, planning of construction methods and the motivation of the work crews through ***visualization***. Khanzode et al (2005) states that having a constructible design, reduces the amount of contractors' requests for information and change orders related to field changes. Additionally MEP (Mechanical, Electrical and Plumbing) contractors are able to use more prefabrications which can improve productivity at the site with improved safety. Staub-French et al. (2003) have revealed that 3D models can be used for accurate quantity takeoff. When quantities are taken off manually in a construction process there is a lot of waste because the quantity takeoff needs to be performed each time the design is updated. **3D models** can produce quantities automatically based on a means and methods database. 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)

Visualization

The increased visualization lean tool is about communicating key information effectively to the workforce by posting various signs and labels at the construction site. Workers can remember elements such as workflow, performance targets, and specifically required actions if they visualize them (Moser and Santos 2003). This includes signs related to safety, schedule, and quality. This tool is similar to the lean manufacturing tool, Visual Controls, which is a continuous improvement activity that relates to the process control

BIM

BIM, or Building Information Modelling, is a digital representation of physical and functional characteristics of a building creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from its first conception to demolition (Construction Project Information Committee [CPIC], 2011). BIM may also stand for Building Information Model, or Building Information Management. BIM's ability to keep this information up to date and accessible in an integrated digital environment gives architects, engineers, quantity Surveyors, builders, and owners a clear overall vision of their projects, as well as the ability to make decisions better and faster (Jayasena and Wedikkara, 2013).

Value Stream Mapping

Howell and Ballard (1998) have revealed that Value Stream Mapping brings choices to the surface and raises the possibility of maximizing performance at the project level. Normally maps are prepared at the project level and then broken out to better understand the way the design of planning, logistics and operations systems work together to support the value provided to the customer. A value stream map is a comprehensive model. Value stream maps can be identified as Process Flow Charts that determine the action that releases work to the next operation of the project to reveal issues hidden in the current approaches (Howell and Ballard, 1998).

Reverse Phase Scheduling (RPS)

RPS is a pull technique used to develop a schedule that works backwards from the completion date through team planning (Ballard and Howell 2003) Phase scheduling is the link between work structuring and production control, and the purpose of the phase scheduling is to produce a plan for the integration and coordination of various specialised operations.

Prefabrication

According to Koskela (1992), a specialist transforms his/her perception of the client requirements into Design Decisions. Previous researches have confirmed that the adoption of lean principles facilitate manufacturing through increased productivity, reduced manufacturing space, improved quality and safety, reduced lead time, reduced human effort, reduced investments in tools, reduced engineering hours to develop a new product and ultimately resulting in increased sustainability. Vilashini et al, (2011) have argued that many problems persistent with a Prefabrication

Production Process can be solved or reduced by adopting lean principles. Off Site Manufacturing 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)The manufacturing and assembling process, whereby, construction components are made at a location different from the place of final assembly under specialized facilities with different material may lead to a better control of the inherent complexity of a construction process.

Kaizen

'Kaizen' simply means 'good change' .Kaizen refers to the philosophy or practices that focus upon the continuous improvement of processes in manufacturing, engineering, and business management to improve the quality, technology, processes, company culture, productivity, safety and leadership. Kaizen implicates cost reduction and zero defects in the final product. It focuses on eliminating waste, improving productivity, and achieving sustained continual improvement of targeted activities and processes.

Five 'S'

Kobayashi 1998; Hirano (1989) Seiri (Sort) refer to separately needed tools / parts and the removal of unneeded material (trash). Seiton (straighten or set in order) is to neatly arrange tools and material for ease of use (stacks/bundles). Seiso (shine) means to clean up. Seiketsu (standardize) is to maintain the first 3Ss and develop a standard 5S's work process with expectations for system improvement. Shitsuke (sustain) refers to creating the habit of conforming to the rules. Spoore (2003) indicates that 5S is an area-based system of control and improvement. The benefits of implementing 5S include improved safety, productivity, quality, and set-up-times, creation of space, reduced lead times and cycle times, increased machine uptime, improved morale and teamwork, and continuous improvement (kaizen activities). 5S is a set of techniques providing a standard approach to housekeeping within Lean (Kobayashi 1998; Hirano 1989). Visual work place is a place for everything and everything in its place. It has five levels of housekeeping that can help to eliminate wasteful resources

Fail safe for quality

Fail safe for quality relies on the generation of ideas that gives alerts for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected and decisions are taken after defective parts have already been processed. Shingo (1992) introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process.

Target Value Design (TVD)

In the building sector, it has been customary for architects to work with customers to understand what they want, then produce facility designs intended to deliver what is wanted (Ballrad, 2011). The cost of those designs has then been estimated and too often, is found to be greater than what the customer is willing or able to bear requiring the designs to be revised and re- estimated. This cycle of design – estimate – rework is wasteful and reduces the value customers get for their money. Cho and Bollard (2011) have further stressed that cost, time, location and other constraints are conditions that must be met in order to deliver value to customers and the implementation of Target Value Design has also consistently resulted in the delivery of projects faster and under budget in the form of market benchmarks and project targets. TVD is a management practice that seeks to make customer constraints drivers of design for the sake of value delivery (Ballard, 2011). It is a method that assures that customers get what they need (where it is valued by customers) and also a method for continuous improvement and waste reduction (Ballard, 2011)

First Run Studies

First run studies (as lean construction defines) are used to redesign critical assignments as a part of a continuous improvement effort and include productivity studies and reviewing of work methods by redesigning and streamlining the different functions involved. The studies commonly use video files, photos, or graphics to show the process or illustrate the work instruction. The first run of a selected craft operation should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work.

Relational Contracting

A Relational Contract is a contract whose effect is based upon a relationship of trust between the parties. The explicit terms of the contract are just an outline as there are implicit terms and understandings which determine the behaviour of the parties. Vilashini (2012) have stated that the relational contract theory is characterized by viewing contracts as relations rather than as discrete transactions. Thus, even a simple transaction can properly be understood as involving a wider social and economic context.

Target Costing

Target costing has subsequently been replaced by Target Value Design for two reasons; (1) Target costing is a term used in the construction industry with a different meaning, and (2) Target value design indicates better the intent to deliver customer value, as opposed to mere cost cutting (Ballard 2011). Target costing is a pricing method used by firms as a tool for reducing the overall cost of a product over its life cycle.

Set Based Design

A Set Based Design builds on concurrent engineering principles (multifunctional, co-located team design) by establishing a design space for design optimization to meet a challenging set of requirements. A Set Based Design involves exploring many design alternatives up-front to allow for trade-offs particularly important for integrated systems with competing requirements. It improves on 'point design' with its' many shortfalls - fixation on the first design selected, time delay before feedback, and locked in cost too early in the design process. The differences between point design and set based design can be best understood visually.

Kan- ban

One-way to do this is to smooth out and balance material flows by means of controlled inventories. Translated as a signal, this allows an organization to reduce the production lead-time, which in turn will reduce the amount of inventory required. A Kan-ban is a card containing all the information required to be done on a product at each stage along its path to completion indicating the parts that will be needed at subsequent processes. These cards are used to control Work-In-Progress (WIP), production and inventory flow. A Kan-ban System allows a company to use Just-In-Time (JIT) Production and Ordering Systems that allow them to minimize their inventories while still meeting the customer demands.

Total Quality Management

The Total Quality Management is a management approach that originated in the 1950's which has steadily become more popular since the early 1980's. The Total Quality is a description of the culture, attitude and organization of a company that strives to provide customers with products and services that satisfy their needs. The culture requires quality in all aspects of the company's operations, with processes being done right at the first time itself and defects and waste eradicated from operations. Total Quality Management or TQM, is a method by which the management and the employees can become involved in the continuous improvement of the production of goods and services. It is a combination of quality and management tools aimed at increasing business and reducing losses that incur due to wasteful practices. Some of the companies who have implemented TQM include Ford Motor Company, Phillips Semiconductor, SGL Carbon, Motorola and Toyota Motor Company.

Work Standardization

Standardized work is one of the most powerful but least used lean tools. By documenting the current best practices, standardized work forms the baseline for kaizen or continuous improvement. As the standard is improved, the new standard becomes the baseline for further improvements, and so and so forth. Improving standardized work is a never-ending process. Basically standardized work consists of three elements:

- Takt time, which is the rate at which products have to be made in a process to meet the customer demand.
- A precise work sequence in which an operator performs tasks within takt time.
- Standard inventory, including units in machines required to keep the process operating smoothly.

Work Structuring

Work structuring in lean construction is defined as 'the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts with the goal of making 'work flow' more reliable and quick while delivering value to the customer ' (Ballard 2008). Ballard (1999) initially equated the term 'work structuring' to process design and has since broadened the scope of work structuring by equating it to production system design (Ballard 2011). Contracts, history, and traditional practices of designers, suppliers, and building trades affect the way the planners conceive the work required to complete a project. In particular, planners often use a WBS to break out a project into work packages and create a framework for project planning, scheduling, and control.

2.6. Summary

The lean concept is one of the strategies adopted by the construction industry from the manufacturing industry to improve its performance. The lean principle argues that although all activities incur costs and consumes time, only conversion activities add value and that therefore these should be made more efficient with non-value adding flow activities reduced or eliminated altogether. Lean construction is a new way to manage construction and the lean construction concept is still new to many construction industries in the world. Extant literature provides the guidelines for implementing lean principles in construction work while identifying its benefits and further challenges. There is a quite a number of lean techniques that can minimize non-value adding activities in construction processes and 20 such techniques have been selected for this study.

2.7. Guide lines, benefits, challenges and suggestions on lean implementation in construction settings

2.7.1 Guidelines offered by researches for successful Lean Implementation

Ballard and Kim (2006) have offered guidelines for implementing lean as illustrated in Table 2.9.

Table 2.9: Guidelines for lean implementation

Ref	Guidelines for successful Lean Implementation
G1	Select partners or suppliers who are willing and able to adopt lean project delivery
G2	Structure the project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best project – level return
G3	Do target costing: define and align project scope, budget and schedule to deliver customer and stakeholders value
G4	Encourage thoughtful experimentation; explore adaptation and development of methods for perusing the lean ideal
G5	Celebrate breakdowns as opportunities for learning rather than occasions for punishing the guilty
G6	Do set based design: make design decision at the last responsible moment, with explicit generation of alternatives, and document the evaluation of those alternatives against stated criteria
G7	Practice production control in accordance with lean principles such as making the work flow predictable and using pull system to avoid over production
G8	Build quality and safety in to the projects by placing primary reliance and acting to prevent breakdowns
G9	Implement Just In Time and other multi organizational processes
G10	Use 3D modelling to integrate product and process design

2.7.2 Benefits of lean implementation

Significant variations generally occur at every stage of a construction process. Plans change and material arrive late. Howell and Ballard (1994) have stated that in compressed circumstances, variation becomes more apparent and critical as it exposes the interdependence among activities. When lean construction is implemented and the working environment is stabilized by modifying the planning system, it becomes possible to reduce variation in flows thereby improving the downstream operations. Further, Koskela et al.,(2010) have stressed that the application of lean construction principles offer key benefits to prefabrication such as increased productivity, increased quality, increased sustainable values, provision of better value to the customer and reduction of human effort. On the other hand, Koskela et al.,(2010) have concluded that there are issues in implementing lean construction techniques, especially in prefabrication such as waiting times, inventorying, moving, high quality controlling, requirement for efficient testing, stock keeping, lower flexibility to varying designs, standardization and the requirement for well-trained people and resources.

Further, some researchers have attempted to apply lean principles to different construction delivery methods to get higher benefits. For example, Singleton and Hamzeh (2011) and Eagan (2004) have attempted to apply lean principles to play a crucial role in Integrated Project Delivery (IPD) approaches such as in partnering and strategic alliances to maximize value and minimize waste in those projects. Further, Lamming (1996) has related lean principles to construction supply chain and Howell and Ballard (1998) to design process protocol showing the way the benefits such as reduced variation in flows can improve downstream operations and change people's attitudes. Formoso et al.(1999), have identified other general benefits when applying lean principles in construction processes and these are given in Table 2.10

Table 2.10: Benefits in implementing lean techniques

Ref	**Benefits of Lean Implementation**
B1	Reduces sharing of Non-Value Adding Activities
B2	Increases sustainable values
B3	Provides better value to the customer
B4	Increases the output value of customer requirement through systematic construction
B5	Reduces process variability (variations)
B6	Reduces cycle times
B7	Simplifies by minimizing the number of steps, parts and linkages
B8	Increases output flexibility
B9	Increases process transparency
B10	Focuses on the complete process
B11	Builds continuous integration of the processes
B12	Balances flow improvement with conversion improvement
B13	Reduces human effort
B14	Increases the quality of the product / project
B15	Improves the downstream operations
B16	Changes people's attitudes
B17	Benchmarking

2.7.3 Challenges in implementing Lean Techniques in Construction Processes

However, Alarcon et al. (2006) have revealed that there are barriers to the implementation of lean construction. They are, ***Time***: the main difficulty being lack of time for implementing new practices in the projects, ***Training***: Lack of Training, ***Organization:*** Challenges to create organizational elements, ***Self-Criticism***: Lack of self-criticism to learn from errors and responding to deficiencies, ***Low understanding*** of the concepts, low use of different elements, inadequate administration, weak communication and transparency and ***lack of integration*** of the construction chain. However, many researchers have concluded that there is a lack of interest among construction parties to sit for a weekly review meeting to solve the problems causing project plan failures (Salem et al.2005 and Tzortzopoulos and Formoso, 1999). The other major problem is to identify as to how to make people change their mind sets and be open to new ideas on the management of construction projects. Salem et al. (2005) have revealed that changing mindsets and behaviour with lean thinking become a challenge and to eliminate this barrier the contractor has to offer training and recognition.

Howell and Ballard (1998) believed that lean production is a new way to coordinate action that rests on a new mental model and as problems are solved by "lean", the non-value adding flows would be recognized as problems in the construction. Tzortzopoulos and Formoso (1998) have stated that some clients have their needs which are not explicitly represented and some important aspects of the design are abstracted away in conceptualization. Furthermore, persisting problems in conversion may be identified as not all requirements are identified at the beginning of the project with design errors detected in later phases leading to costly rework and time delays. Lean thinking can address these problems. Challenges to implementing lean techniques are summarized in Table 2.11.

Table 2.11: Challenges in lean implementation

Ref	Challenges in Lean Implementation
C1	Lack of time for implementing new practices in the projects
C2	Lack of training
C3	Challenges to create organizational elements
C4	Lack of self-criticism to learn from errors, responding to some deficiencies
C5	Low understanding of the concepts
C6	Low use of different elements
C7	Inadequate administration
C8	Weak communication and transparency
C9	Lack of integration of the construction chain
C10	Negative attitude towards implementing new practices

The next Section discusses suggestions offered by researchers to implement lean principles in different construction contexts.

2.7.4 Suggestions offered to overcome the challenges

Koskela and Siriwardena (2010) have found out that changes are needed in terms of proper implementation of lean principles such as top management commitment to the implementation, sufficient technical expertise in lean production, a quest for a culture of continuous improvement of the company, fullest dedication of workers towards the implementation, awareness of employees about lean principles, changing people's attitudes and sufficient management expertise to induce the changes in the production flow process. Further Salem et al. (2005) have stressed that the commitment of the top management of construction firms to the implementation of these lean tools could be the most important factor for its successful implementation. Some other studies offer guidelines for the effective implementation of lean approaches. Singleton and Hamzeh (2011) have offered the following guidelines for the implementation of Integrated Project Delivery using lean.

a) Avoid a segmented and rigid sequence of design activities
b) Explicit internal client supplier relationships between sub processes
c) Involve designers in joint solutions
d) Work with a set of design alternatives

The suggestions offered in the literature can be summarized as shown in Table 2.12

Table 2.12: Suggestions to overcome the challenges in lean implementation

Ref	Suggestions to overcome the challenges in Lean Implementation
S1	Significant contribution from Senior Management / Decision makers
S2	Leadership of a project must have the lean vision from the beginning
S3	Practicing lessons learned to avoid repeating the same mistakes
S4	Cultural changes with lean thinking / attitudes
S5	Bridging the gap between theory and practice
S6	Introducing a lean benchmark for construction material
S7	Increasing the pre assembling of building components
S8	Structuring the project organization to engage downstream players in upstream processes and vice-versa
S9	Working with alternatives

2.8 Summary for Chapter 2 on literature synthesis

The research problem of the study, the existence of non-value adding activities in construction processes that hinder their performance was widely discussed at the beginning of this Chapter and examples of non-value adding activities were identified with a view to defining, understanding and categorising waste. Next, lean concepts, lean principles and lean construction were described through extant literature. Case studies for Lean implementation were critically evaluated to identify the most widely used lean techniques and to evaluate the outcome of lean implementation. Further, literature review was completed by identifying guide lines for lean implementation, benefits derived in implementing lean, associated challenges to implement lean and the way to overcome the challenges. All findings through literature are conceptually framed in the next Section as a step for data collection and analysis to achieve the aim and objectives of the project.

Chapter – 3

Conceptual Framework

CHAPTER 3

3.0 CONCEPTUAL FRAMEWORK

3.1 Introduction

Chapter 3 explains the conceptual frame work developed for the study based on literature findings and results of a subsequent pilot survey carried out among a few industry professionals. This Chapter begins with the characteristics of a conceptual framework and then goes on to describe the elements of the framework. The framework is divided in to two main areas: i) research problem and ii) the approach to solve the research problem. Concepts and theories established through the literature review are summarized in order to apply them to the framework. Finally, a graphical framework is presented to explain the study on lean implementation in the construction sector.

3.2 Development of the Conceptual Framework

The conceptual framework is a system of concepts, assumptions, expectations, beliefs and theories that supports and indicates the research (Miles and Huberman, 1994; Robson, 2011). It is also revealed that it is a theory that explains either in a graphical or narrative form a visual or written product. It explains as to what is going on or what someone is planning to study. Hence, the function of the conceptual frame work is to explain the rest of the design of the study. The aim of this study is to develop a framework for implementing lean techniques in order to minimize non-value adding activities in the construction processes of the construction industry in Sri Lanka. The two main key areas of this aim are lean implementation and non-value adding activities and therefore the conceptual framework developed for this study has been mainly divided into two areas: i) research problem defined for the study (non-value adding activities) and ii) approach (Lean Implementation) selected to resolve the problem to bridge the gap.

3.2.1 Research problem

3.2.1.1 Introduction

The research problem is a part of the conceptual framework and describes four different areas. The problem of the research exists in the area of construction which is a project centric industry. Projects that exit in the construction industry have a project delivery system commencing from the preparation or project definition to the completion of the project. The background literature of this research indicates that there are issues within this project delivery system and that these issues are mainly due to the inefficiency of resources which create non value adding activities. Activities that do not add value are simply a waste and these should be minimized. Figure 3.1 illustrates the existence of the research problem within the existing environment and this is the first Section of the conceptual framework.

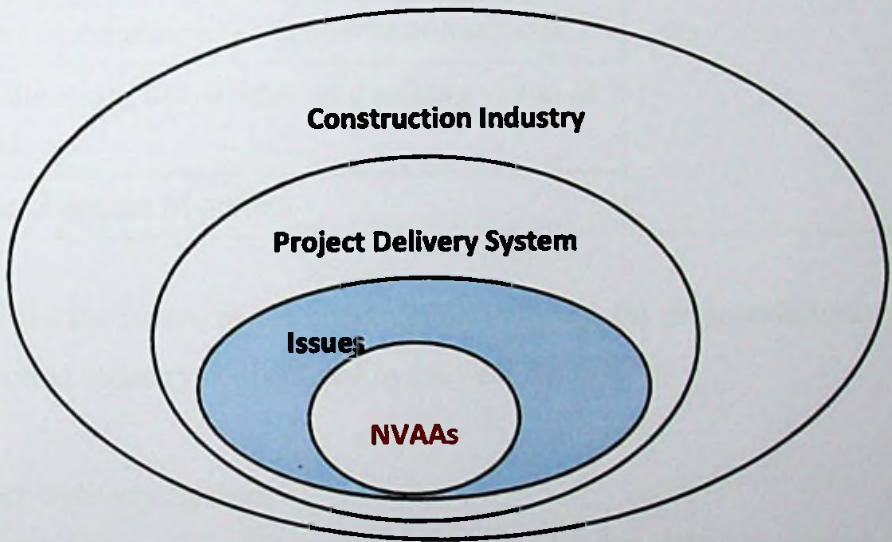


Figure 3.1: Research Problem

The above Figure presents the identified research problem and the extant literature presented in Chapter 2 describes the research problem, i.e the existence of non-value adding activities in construction processes. These literature findings are summarized in the next Section.

3.2.1.2 Construction Industry

The nature of the construction industry can be described as indicated in Table 3.1

Table 3.1: Nature of the construction industry

Ref	Nature of the construction Industry	Sources
1	Project centric industry	Tzortzopoulos and Formoso (1999), Koskela (2000), Barret (2005), Salem *et al* (2006), Thomas *et al* (2010), Picchi (2011), Rahman (2012)
2	Operating within an environment of complexity and uncertainty	
3	Short term, adversarial relationships, supply chain within a temporary organizational structure	
4	Final product has its own nature	
5	Construction projects are unique, static and big in size	
6	Job security is low due to short term assignments	
7	Most of the elements are on-site productions	
8	Challenging, risk adverse and lacking vision & trust	
9	One-of-a-kind of project	

Having identified the nature of the construction industry, the project delivery system in the construction industry is discussed in the next Section.

3.2.1.3 Project Delivery System

According to Thomas *et al* (2010), a construction project delivery system mainly consists of three domains. i.e. i) project organization, or the way parties to a contract is organized, ii) project operating system, or the way a project is managed on an overall and a day-to-day basis and iii) project commercial terms, or the contract. The second domain, the project operating system is considered in this study.

3.2.1.4 Issues in construction project operating systems

Extant literature as indicated in Chapter 1 and Section 2.2 confirm that the construction project delivery system has been largely neglected and that there are several issues as listed in Table 3.2 that need to be addressed.

Table 3.2: Issues in construction project operating system

Ref	Issues in construction project operating system	Sources
1	Low Productivity	Lathem (1994), Howel and Ballard (1997), Eagan (1998), Smith *et al* (1999),Kagioglou *et al* (2000), Salem *et al* (2006), Thomas *et al* (2010), Emuze and Smallwood (2011), Al-Aomar (2012), Vilashini *et al* (2012)
2	Insufficient quality	
3	Time & cost Overruns	
4	Poor safety	
5	Frequent disputes	
6	High rates with project cost being too much and always greater than what the client is willing to pay	
7	Lack of innovation	
8	Project taking too long	
9	Unpredictable in terms of delivery up to the time, cost quality	

Further, this literature indicates that one of the main reasons for these issues is insufficiency and waste with non-value adding activities within the construction processes not adding any value to the final product. The next Section of this report presents the details of these non-value adding activities reviewed through the literature in Chapter 2.2

3.2.1.5 Non-value adding activities

Taichi Ohno identified two types of activities, i.e. value adding activities and non-value adding activities. Activities that do not add value are simply wasteful and should be minimized or eliminated. As explained in Chapter 2.2, previous studies have proven that these non-value adding activities hinder the performance of construction activities. Extant literature (Section 2.2.3) described seven categories of waste, viz., defects, delays, over processing, over production, excess inventories, unnecessary transport and unnecessary motions. Section 2.2.7 identifies examples of non-value adding activities found in construction processes and Figure 3.2 illustrates these non-value adding activities.

Figure 3.2: Categories of waste

3.2.1.6 Summary

The research problem of this study was analysed within a construction framework with the project delivery system focusing on the construction project operating systems. Issues of the construction project operating system were further summarized and inefficiency and waste were identified as two of the main reasons for these issues. Finally, examples of non-value adding activities are presented (see Figure 3.3) in order to achieve the next step of this study.

Category	Reference	Examples of Non Value Adding Activities	Vilasini N., and Neitzert (2012)	Andersen et al (2012)	Al-Aomar R. (2012)	Rahman et al (2012)	Ballard G. (2011)	Vilasini et al (2011)	Emuze and Smallwood (2011)	Wu and Low (2011)	Mossman, A. (2009)	Senaratne and Wijesiri (2008)	Abdelsalam and Al-Sudairi (2007)	Koskela (2004)	Report by CPN Network (2003)	Josephson and Saukkoriipi (2001)	DTI Report (2001)	Howell and Ballard (1998)	Ballard and Howell (1994)
Defects	D01NA01	Repair Work			X	X		X	X			X		X	X				
Defects	D02NA02	Design errors			X				X										X
Defects	D03NA03	Design changes							X										X
Defects	D04NA04	Installation errors			X				X										
Defects	D05NA05	Vendors errors							X										X
Defects	D06NA06	Damage by other crafts							X										X
Defects	D07NA07	Incomplete Installations							X										X
Defects	D08NA08	Rehandling materials							X										X
Defects	D09NA09	Damaged Materials on site							X								X		
Defects	D10NA10	Poor material allocation						X	X										
Defects	D11NA11	Rework	X	X	X		X	X	X	X		X	X				X	X	
Defects	D12NA12	Site layout is not carefully planned								X									
Defects	D13NA13	Uncomplete work			X			X	X										
Waiting	W01NA14	Delay to schedules												X			X		
Waiting	W02NA15	Waiting for instructions								X							X		
Waiting	W03NA16	Waiting for equipment repair															X		
Waiting	W04NA17	Waiting for equipments to arrive															X		
Waiting	W05NA18	Equipment freequently breakdown										X					X		
Waiting	W06NA19	Waiting for Clarifications			X	X						X							
Waiting	W07NA20	Waiting (for people, material)						X					X		X				
Waiting	W08NA21	Activitiy Delay						X				X							
Waiting	W09NA22	Idle Time						X											
Motion	M01NA23	Unnecessary material people movement						X		X				X					
Motion	M02NA24	Unnecessary motion				X									X				
Motion	M03NA25	Excessive labour movement			X														
Motion	M04NA26	Excessive material movement			X														
Inventory	I01NA27	Material stocks										X		X	X				
Inventory	I02NA28	Inventory work						X											
Inventory	I03NA29	Excess material inventory								X		X							
Inventory	I04NA30	Inventories				X													
Extra Procedures	E01NA31	Unnecessary processing			X			X		X	X	X		X	X				
Extra Procedures	E02NA32	Long approval processes			X														
Extra Procedures	E03NA33	Retests			X														
Extra Procedures	E04NA34	Excessive safety measures			X							X							
Extra Procedures	E05NA35	Excessive supervision			X														
Extra Procedures	E06NA36	Excess information									X								
Extra Procedures	E07NA37	Excessive training time			X														
Transport	T01NA38	Unnecessay material transport movement								X				X	X				
Transport	T02NA39	Travelling time										X	X						
Transport	T03NA40	Unnecessary Transport			X														
Transport	T04NA41	Long transport time			X														
Overproduction	OV1NA42	Unwanted Productions			X	X						X		X	X				
Overproduction	OV2NA43	Unnecessary work						X		X	X				X		X		
Overproduction	OV3NA44	Material waste						X											
Overproduction	OV4NA45	Inefficient work			X			X											
Others	OT1NA46	Material does not meet specification								X							X		
Others	OT2NA47	Taxes														X			
Others	OT3NA48	Pilferage			X							X							
Others	OT4NA49	Making - do						X			X			X					

Figure 3.3: Examples of Non-value adding activities

3.2.2 Approach to solve the research problem

3.2.2.1 Introduction

The research problem was discussed in Section 3.2.1 and this Section presents the summary of the literature review on the research approach. The research problem of this study is non-value adding activities which result in inefficiencies and waste in construction processes. Lean principles argue that activities that do not add any value need to be minimized or eliminated and processes can be made lean. Hence the approach of this study is lean implementation in the construction sector to minimize non-value adding activities.

3.2.2.2 Lean concepts and lean principles

All construction activities can be divided in to two types, i.e. conversion **activities** which produce tangible outputs and **flow activities** which bind such conversion activities together during the delivery process of the outputs. Although all activities incur cost and consume time, Lean Principles state that only conversion activities add value and that therefore these should be made more efficient and that non- value adding flow activities should be reduced or eliminated (Koskale, 1993). By eliminating waste activities, processes can become 'lean' to provide 'more with less' resources (Womack and Jones, 2003). Lean principles are discussed in Section 2.3.1 and Figure 3.1 illustrates these lean principles which are further described in Figure 3.4.

Figure 3.4: Five lean principles

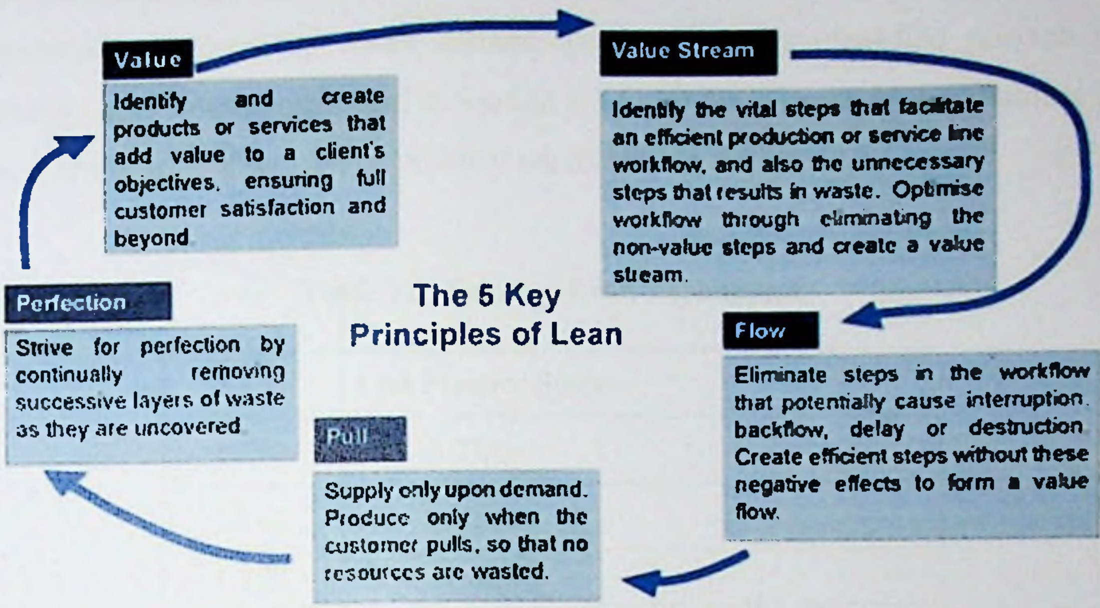


Figure 3.5: Lean Principles

3.2.2.3 Lean Construction

Further to the extant literature presented in Section 2.3.5, lean is found to be more focused on value instead of cost and seeks the removal of non-value adding activities whilst improving value adding activities. The essential features of lean construction include a clear set of objectives for the delivery process aiming at maximizing the performance for the customer at project level, concurrent design of products and processes, and the application of production controls throughout the life of the product from its design to delivery. Ballard (2000a) has divided the lean project delivery system into four interconnected phases, viz., 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. Lean techniques are identified in the next Section.

3.2.2.4 Lean Techniques

Lean principles argue that waste could be eliminated by certain techniques to provide more value with fewer resources. Several lean techniques have been developed for the manufacturing industry and these techniques have been implemented in the construction industry by many authors. Lean techniques identified through the literature review were presented in Section 2.3.6 and the selected lean techniques for this study to solve the research problem are illustrated in Table 3.3.

Table 3.3: Selected Lean Techniques

LT01	Last Planner System
LT02	Just in Time
LT03	3D Modeling
LT04	Visualization
LT05	BIM
LT06	Value Stream Mapping
LT07	Reverse Phase scheduling
LT08	Prefabrication / Off site manufacturing
LT09	Kaizen / continuous improvement
LT10	Five S
LT11	Fail Safe Quality / Poka-yoke
LT12	Target Value Design
LT13	First Run Studies
LT14	Relational Contracting
LT15	Target Costing
LT16	Set based design
LT17	Kanban
LT18	Total Quality Management
LT19	Work standardization
LT20	Work structuring

3.2.2.5 Summary

The purpose of this Section was to summarize lean concepts and their principles together with lean construction and present the lean techniques selected for this study. In developing the conceptual framework lean principles, lean construction and lean techniques were used as elements to demonstrate the approach of the research.

3.3 Concept of the Study

The research problem has been discussed in Section 3.2.1 and the research approach in Section 3.2.2. The research problem for this study is the existence of non-value adding activities in the construction sector and the approach proposed to minimize these non-value adding activities is the implementation of lean techniques within the philosophy of lean. Figure 3.6 explains this relationship.

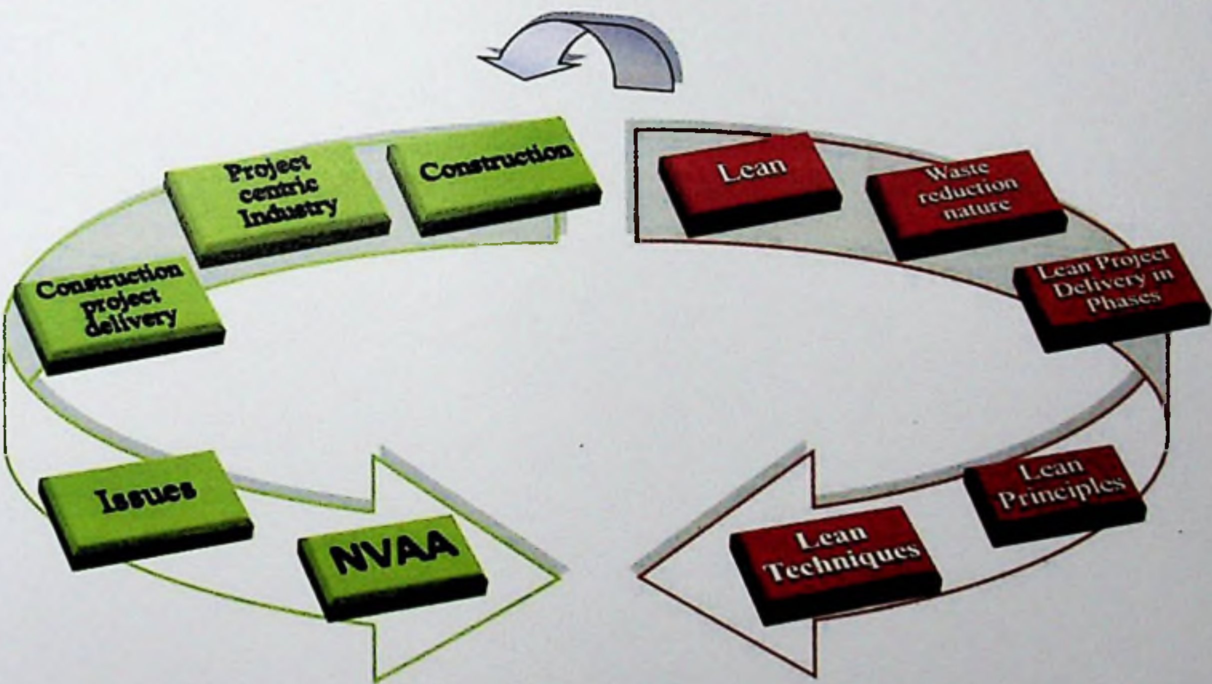


Figure 3.6: Research problem and the approach to bridge the gap

Figure 3.6 shows lean and construction as two different areas and that when lean techniques are applied to minimize non-value adding activities lean and construction bind together as lean construction with construction becoming very lean and making non value adding activities zero or minimal.

3.4 Conceptual Framework

The above Section of this report reveals that non-value adding activities that do not add value can be recognized in construction processes and that they hinder the performance of the construction and that they should be eliminated. Controversial literature findings that were further explored also indicated that these lean techniques can be implemented in the construction processes to minimize waste. The researcher attempts to develop a framework using lean techniques for minimizing non-value adding activities. Figure 3.7 demonstrates the conceptual framework developed for the study after the literature synthesis.

CONCEPTUAL FRAMEWORK

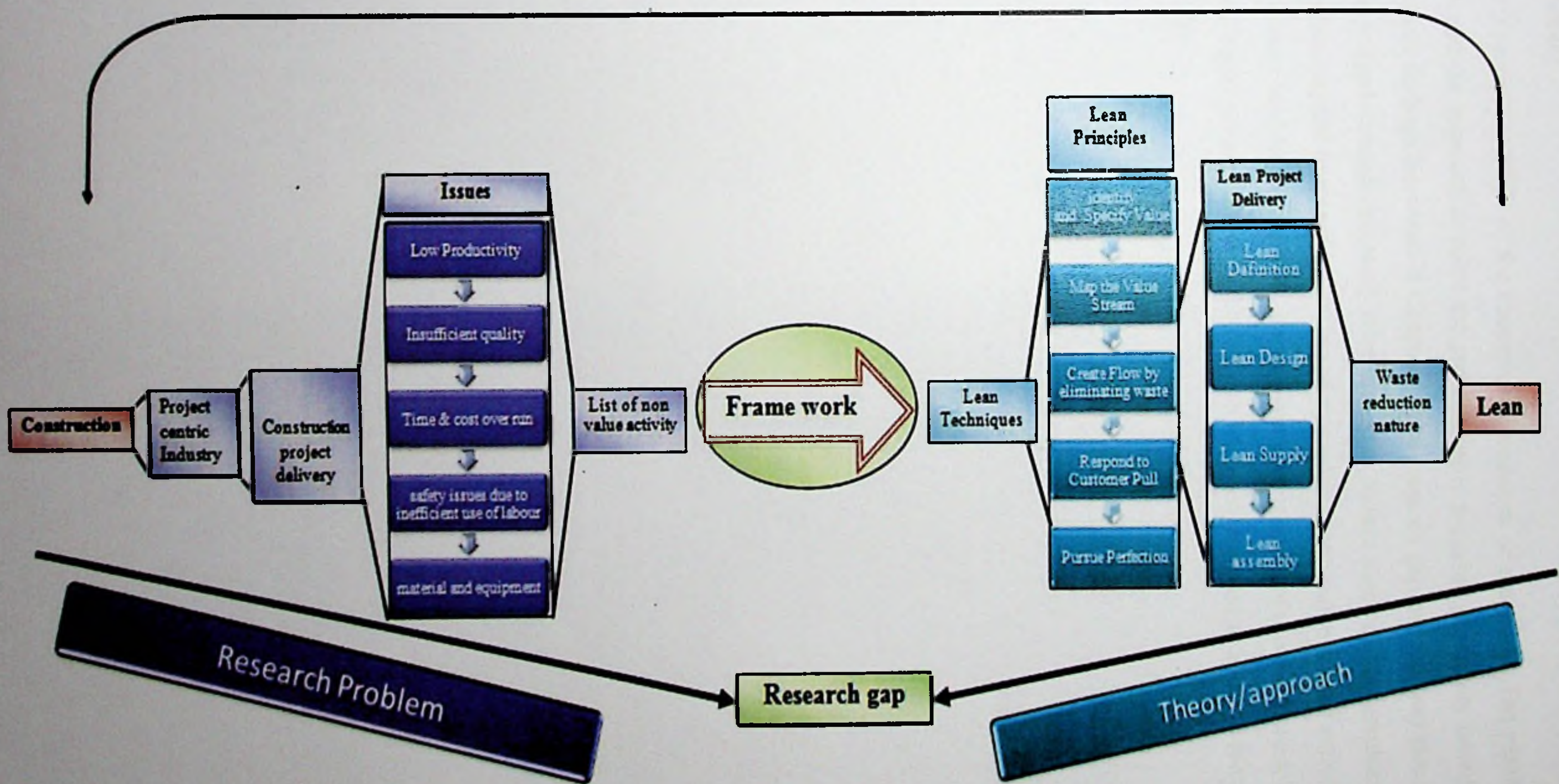


Figure 3.7: Conceptual framework

3.5 Summary

Chapter 3 presented details of the conceptual framework of the study. The research problem and the approach to solve the problem were discussed separately based on the literature findings discussed in Chapter 2. The research gap and the way this gap could be bridged through this study were discussed further based on the graphically presented conceptual framework. The list of examples of non-value adding activities and the widely used lean techniques are the main key elements of this framework and the next Chapter presents the way the research has been designed to achieve the aim of this study.

Chapter – 4

Research Design and Methodology

CHAPTER 4

4.0 RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

Chapter 1 presented the general introduction to the research and Chapter 2 the extant literature on the research problem, i.e the existence of non-value adding activities that lead to inefficiency and waste in construction and the research approach, i.e the implementation of lean techniques to solve the problem. Chapter 3 illustrated the development of a conceptual framework for this study presenting the way the research was designed to collect and analyse data to achieve the aim and objectives of this study. This Chapter is divided in to two areas mainly: (i) research design and, ii) research methodology.

4.2 Research Design

4.2.1 Introduction

Research is a process of enquiry and investigation. It is systematic and methodical and increases knowledge (Amaratunge *et al* 2002). Further it is argued that the clear definition of a research strategy is a fundamental and necessary requirement for a sound empirical study of any field. Conversely Buckley et al (1975) have stated that an operational definition of research requires the satisfaction of the following conditions:

- An orderly investigation of a defined problem
- Use of appropriate scientific methods
- Gathering of adequate and representative evidence
- Employment of logical reasoning, uncoloured by bias in drawing conclusions on the basis of the evidence
- Ability to demonstrate or prove the validity or reasonableness of the conclusions
- Cumulative results of research in a given area yielding general principles or laws that may be applied with confidence under similar conditions in the future.

Amaratunge *et al* (2002) have disclosed that research is conducted in a spirit of inquiry, relying on facts, experience and data, concepts and constructs, hypotheses and conjectures, and principles and laws. Table 3.1 illustrates as to how these concepts of research together form a symbolic and rational system of inquiry (abstracted from Buckley *et al,* 1975 cited in Amaratunge *et al* (2002).

Table 4.1: Basic elements of a scientific research methodology

Elements	**Description**
Laws	A verified hypothesis used to assert a predictable association among variables which can be empirical or theoretical
Principles	A law or general truth which provides a guide to thought or action
Hypothesis	Formal propositions which, though untested, are amendable to testing and usually expressed in causal terms
Conjectures	Informal propositions which are not stated in a testable form, nor is a casual relationship known or even necessarily implied
Concepts and constructs	Concepts are inventions of the human mind to provide a means for organizing and understanding observations. They perform a number of functions, all of which are designed to form logical and systematic relationships among data
Facts	Something that exists, phenomenon that is true or generally considered to be true
Data	Collection of facts, achieved either through direct observations or through garnering from records. Observation is the process by which facts become data

4.2.2 Designing the research

In designing a research three key areas have to be identified. Firstly, identifying a ***research philosophy*** on which the research will be premised, selecting an appropriate ***research approach*** for theory testing / building and finally selecting research ***techniques*** for data collection and data analysis. Figure 4.1 illustrates the nested research methodology identified by Kagiogloe *et al* (2000).

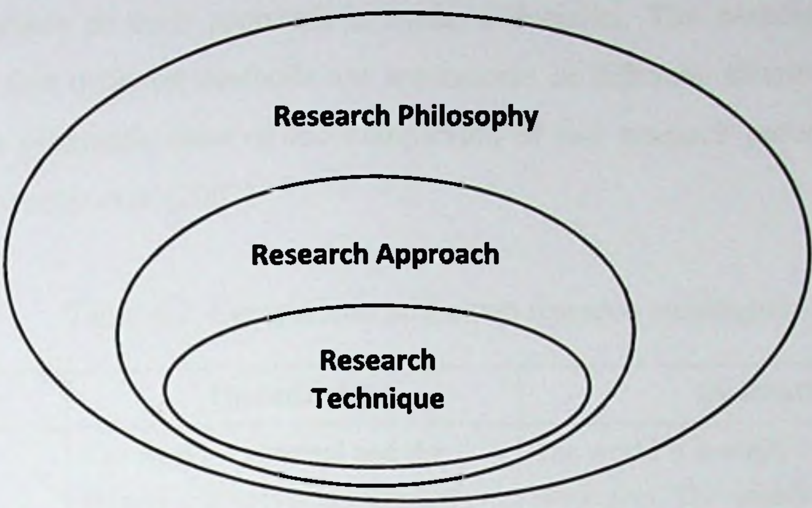


Figure 4.1: Nested Research Methodology

(Kaglogloe *et al* 2000)

4.2.2.1 Research philosophy

A research philosophy or a research paradigm is *'the basic belief system or world view that guides the investigator'*(Guba & Lincoln, 2000, p105).The philosophers of science and methodologists have been engaged in a long standing epistemological debate on as to how best to conduct research (Amaratunge *et al* 2002). This debate has centred on the relative value of two fundamentally different and competing schools of thought. One of these is logical positivism that uses quantitative and experimental methods to test hypothetical-deductive generalizations. According to Easterby- Smith (1991) and Remenyi et al (1998), positivism search for causal explanations and fundamental laws, and it generally reduces the whole to simplest possible elements in order to facilitate analysis. The second is phenomenological (***interpretive science***) inquiry which uses qualitative and naturalistic approaches to inductively and holistically understand human experience in context-specific settings. According to the above schools of thoughts, research may be categorized into two distinct types; ***quantitative and qualitative.*** The quantitative approach grows out of a strong academic tradition that places considerable trust in numbers that represent opinions or concepts. In contrast, the qualitative approach concentrates on words and observations to express reality and attempts at describing people in natural situations. Therefore, it is crucial to know about the key features, strengths and weaknesses of each approach to make a decision. The paradigm of choices recognizes that different methods are appropriate in different situations. Table 4.2 illustrates a pragmatic view of the comparison of two research paradigms adapted from Amaratunge *et al* (2002).

Table 4.2: Comparison of the two research paradigms

Theme	Quantitative	Qualitative
Basic belief	The world is external and the objective observer is independent. Science is value-free.	The world is socially constructed and subjective. The observer is a part of what is observed. Science is driven by human interests
Researcher's obligations	Focus on facts Look for causality and fundamental laws Reduce phenomena to simplest elements	Focus on meanings Try to understand what is happening Look at the totality of each situation Develop ideas through induction from data
Strengths	Provide a wide coverage of a range of situations Fast and economical Statistics are aggregated from large samples and they may be of considerable relevance to policy decisions	Data- gathering methods are seen more as natural than artificial Ability to look at change processes over time Ability to understand people's meaning Ability to adjust to new issues and ideas as they emerge
Weaknesses	The methods used tend to be rather inflexible and artificial Not very effective in understanding processes or the significance that people attach to actions Not very helpful in gathering theories as it is focused on what is, or what has been done recently Make it hard for policy makers to infer what changes and actions should take place in the future	Data collection can be tedious and require more resources Analysis and interpretation of data may be more difficult Harder to control the place, progress and end-points of research process Policy makers may give low credibility to results from qualitative approach

From the above mentioned discussions under the two schools of thought, it is apparent that both quantitative and qualitative methods involve different features, strengths and weaknesses. There are no ideal solutions (Patton, 1990), only a series of compromises. According to Patton (1990) research like diplomacy, is the art of the possible. This is a very emotive guide to any researcher contemplating on the most appropriate avenue of successfully completing a substantial piece of research study.

Therefore, positivism, a quantitative philosophy within deductive reasoning, was selected for this research based on the objectivity principle of scientific inquiry. Variables and relationships were identified and measured using mathematics, statistics and other quantitative techniques.

4.2.2.2 Quantitative research

According to Horns (1994), quantitative research designs are characterised by the assumption that human behaviour can be explained by what may be termed 'social facts' and what can be investigated by methodologies that utilize the deductive logic of the natural sciences. This research process is directed towards the development of testable hypotheses. It is more concerned with theory which can be generalized across settings. Quantitative investigations look for distinguishing characteristics, elemental properties and empirical boundaries and tend to measure 'how much' or 'how often' (Nau, 1995). Figure 4.2 illustrates the quantitative research process.

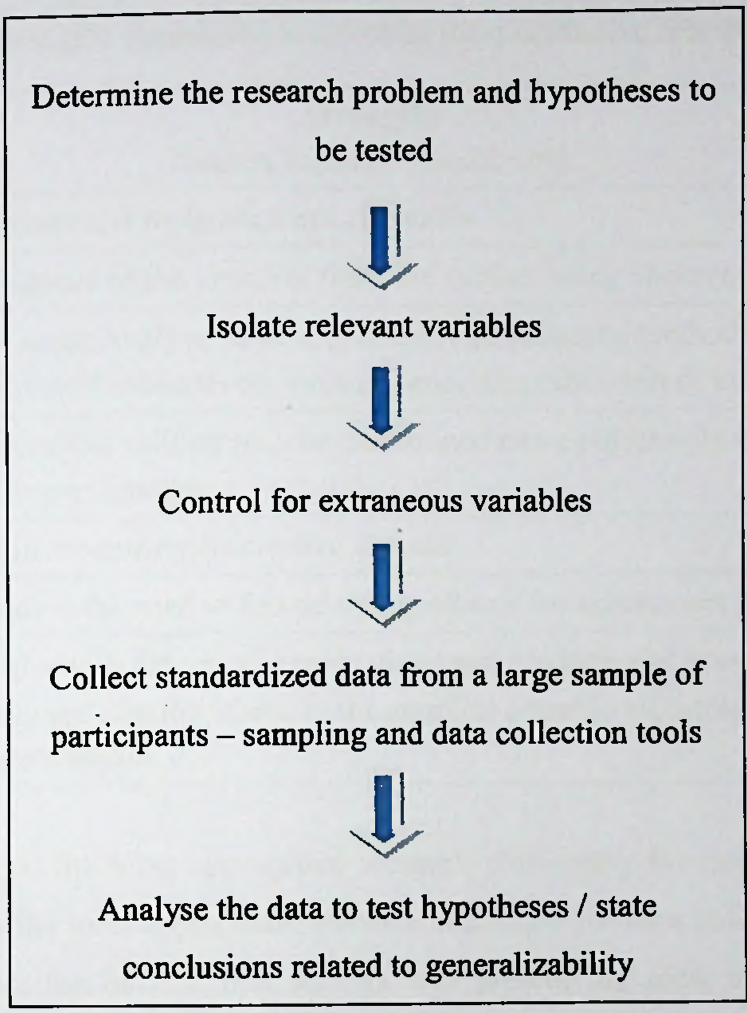


Figure 4.2: Quantitative Research Process

4.2.2.3 Strengths of the Quantitative Research Philosophy

The following strengths are identified (Easterby – Smith, 1991) in a quantitative research approach and the way these strengths are considered in this research in developing a framework to minimize non-value adding activities in construction processes using lean techniques is illustrated in Table 4.3.

Table 4.3: Strengths considered in selecting the quantitative research approach

Strengths (Source: Easterby – Smith, 1991
• Comparison and replication are allowable
• Independence of the observer from the subject being observed
• Subject under analysis is measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition
• Reliability and validity may be determined more objectively than from qualitative techniques
• Strong in measuring descriptive aspects
• Emphasises the need to formulate hypothesis for subsequent verification
• Helps to search for casual explanations and fundamental laws, and generally reduces the whole to the simplest possible elements in order to facilitate analysis

Having discussed the most appropriate research philosophy for this research, it is vital to discuss the most appropriate research technique for data collection and data analysis. Hence, the Section that follows will present the most appropriate data collection technique and the data analysing process.

4.2.3 Research approach

According to Yin (2003), the research technique should be chosen as a function of the research situation. Each research approach has its own specific technique to collect and analyze empirical data, and therefore each technique has its own advantages and disadvantages (Amaratunge *et al* 2002). Although each technique has its own characteristics, there are overlapping areas, which bring complexity to the process of selecting the required strategy. Therefore, Yin (2003) has stressed that the following three conditions would provide the ground for the choice of the strategy:

i) Type of question posed
ii) Control over the actual behavioural elements
iii) Degree of focus on historical or contemporary events

Further, Galliers (1992) has recognized a list of techniques or tactics (experiment, survey, case study, action research and ethnography) and Amaratunge *et al* (2002) have noted that most of the research techniques recognized can be used, at least to some extent, as either quantitative or qualitative devices. Table 4.4 illustrates the key features of each of the research techniques.

Table 4.4: Key features of the research techniques

Research Approach	**Key features**
Experiments	Researcher deliberately controls and manipulates conditions True experiments are done in a laboratory environment Tests relationship between independent and dependable variables. Experimental and control groups Rely on statistical analysis
Surveys	Used mainly in applied research Getting a large amount of data from a representative sample of population Use statistical sampling and analysis Types of analysis are descriptive and analytical
Case Studies	Satisfy three aspects; describing, understanding, explaining within its real life context. Views of the 'actors' in the case study are obtained An empirical study that investigates a contemporary phenomenon A previously developed theory is used as a template Focuses on theoretically significant cases
Action Research	Generation of theory with changing social systems Research in action, rather than research about action Active participation of the researcher in the process under study Research takes place in real-world situations, and aims at solving real problems Learning process is incorporated in to subsequent cycles.

Research Approach	Key features
Grounded theory	Discovery of emerging theory Allows researcher to develop a theoretical account of the general features of a topic Start with field study to find a research problem Develop concepts, categories, and propositions
Ethnography	Applied in sociology, anthropology and psychology to identify behavioural patterns Similar to grounded theory Intensive field study- participation and observation Researcher is a participant in the context that is being studied as well as an observer

From among the above mentioned classes of research approaches, Survey Approach was selected for this research in order to achieve the objectives of the research.

4.2.3.1 Surveys

The survey approach within the paradigm of quantitative philosophy was selected to collect data for the research to fulfil its objectives. The survey approach is a non-experimental, descriptive research method in which a researcher has to collect data on phenomena that cannot be directly observed. In a survey, researcher samples a population which can be any set of persons or objects that possesses at least one common characteristic. There are several types of surveys; ***cross-sectional surveys***: gathering information at a single point in time, ***longitudinal surveys***: gathering data over a period of time.

The cross-sectional survey was selected to collect data for this research and develop a framework for minimizing non-value adding activities in construction processes using lean techniques.

4.2.3.2 Research technique

According to Nahum (2007), the techniques adopted for the conduct of an investigation depends on the nature of the investigation and the type of data and information necessary and available. There are several types of techniques such as questionnaires, interviews, observations and checklists. The aim of this research was to develop a framework for implementing lean techniques to minimize non-value adding activities in construction processes of the construction industry in Sri Lanka. The following are the objectives of the research:

- To investigate the non -value adding activities in construction processes
- To examine the implementation of lean techniques in construction processes
- To map widely used lean techniques with non-value adding activities in construction processes in order to identify the lean implementation
- To propose a tool for assessing lean maturity of a construction project.

A questionnaire using a closed questions approach was selected to collect the data within the paradigm of cross-sectional survey and figure 4.3 summarized the research design for this study.

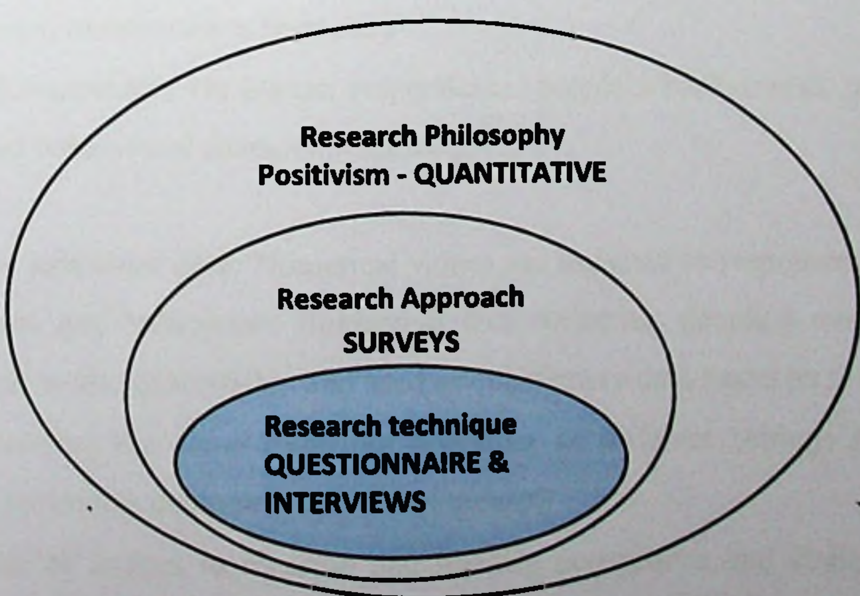


Figure 4.3: Design for the research

4.2.3.3 Hypothesis

Three hypothesis were developed after establishing the research problem and these hypothesis are as follows.

H1: Non-value adding activities are generated in construction processes

H2: Lean techniques are implemented in construction processes

H3: Non-value adding activities can be minimized in implementing lean techniques

4.2.4 Data collection

4.2.4.1 Introduction

Two types of data can be identified within a quantitative paradigm; i) Objective factual data and ii) Subjective perceived data.

Objective factual data: Objective data reflects the reality of a condition or situation. This data covers physical, organizational or cultural attributes of a setting. The physical environment is conceptualized and measured as physical attributes. Data collection is based on the following:

- Direct observation of measurements and records (temperatures, number of users, % of greenery etc.)
- Indirect measurements using secondary sources (population census, site maps, transportation lines etc.)
- Measurements via human respondents (people's background, psychological and behavioural characteristics etc.)

Subjective perceived data: Numerical values are assigned to responses, evaluations, perceptions, and behaviours. Subjective data reflecting people's evaluations and perceptions is also quantifiable and used as quantitative data based on the following:

- Studying the same topic but operating in different settings (same set of questions to measure subjective response)
- Use of indices to measure and identify perceptions and evaluations of an environment. (Several questions are used to tap a single condition)

- User-questionnaires, interviews and ratings by a panel of experts to measure evaluations and perceptions (can be used to compare the views and assessments of an expert panel with those of laymen)

User-questionnaires within the subjective perceived data category were selected for the research to collect the response from a target sample.

4.2.4.2 Data measurements scale

Different scales indicated below are used to collect data.

Interval: The difference between data values is measurable and meaningful (e.g., temperature, time)

Nominal / categorical: Subjects placed in categories (e.g. Male =1 and Female = 0)

Ordinal: Subjects are ranked in order from the greatest to the least or from the best to the worst (e.g. Quality: very bad=1 and very good = 7) and difference between the measures is not meaningful

Ratio: Difference between two points of a scale is precise. The scale starts at 0. (e.g. weight, height etc.)

Scale: Scales can be; (i) Likert scale where the terms usually used are strongly agree, disagree, strongly disagree, and cannot comment. The differences between the scales are meaningless and only hierarchy matters (ii) Semantic differential where people are requested to choose positions between two polar opposites (e.g. love to hate / simple to complex).

The **Likert scale** with a range of answers was selected to collect **ordinal data** for this research.

4.2.4.3 Sampling

The concept of a sample is intrinsic to a survey research. It is impractical and uneconomical to collect data from every single person in a given population and thus a sample of the population has to be selected.The method by which the sample is selected from a sampling frame is integral to the external validity of a survey and the sample selected has to be representative of the larger population to obtain a composite profile of that population. Chapter 5 discusses the ***random samples*** selected for this research to collect data.

4.2.5 Data Analysis

4.2.5.1 Introduction

The analysis and interpretation of research data form the major part of this research. The definition of 'analytical method' is of paramount importance to any analytical strategy. Amaratunge *et al* (2002) have stressed that only when the correct analytical strategy is put together with its correspondent interactions, that it will enable the generation of 'laws' , as the term law is usually employed in science. Different types of methods can be found including examining, categorizing, tabulating, or otherwise recommending the evidence to address the initial propositions of a study. Some of the common data analytical methodologies used can be identified as statistical, content analysis, pattern-matching, and cognitive mapping. The data analysis method adopted for this research is the ***statistical*** strategy within the boundaries of a quantitative research philosophy. The purpose of data analysis is to summarize data so that it is easily understood and provides the answers to the questions. The method used for data analysis will depend on the design of the Survey.

4.2.5.2 Data analysis technique

The Statistical Package for the Social Sciences (SPSS) is comprehensive and is a flexible statistical analysis and data management solution. SPSS is a software package which can take data from almost any type of file and use them to generate tabulated reports, charts, and plots of distributions and trends, descriptive statistics, and conduct complex statistical analysis. Therefore, the SPSS package was selected to analyse the date for this study.

The data was fed to SPSS and labelled based on question types and the format of the display was as shown in Figure 4.4 below.

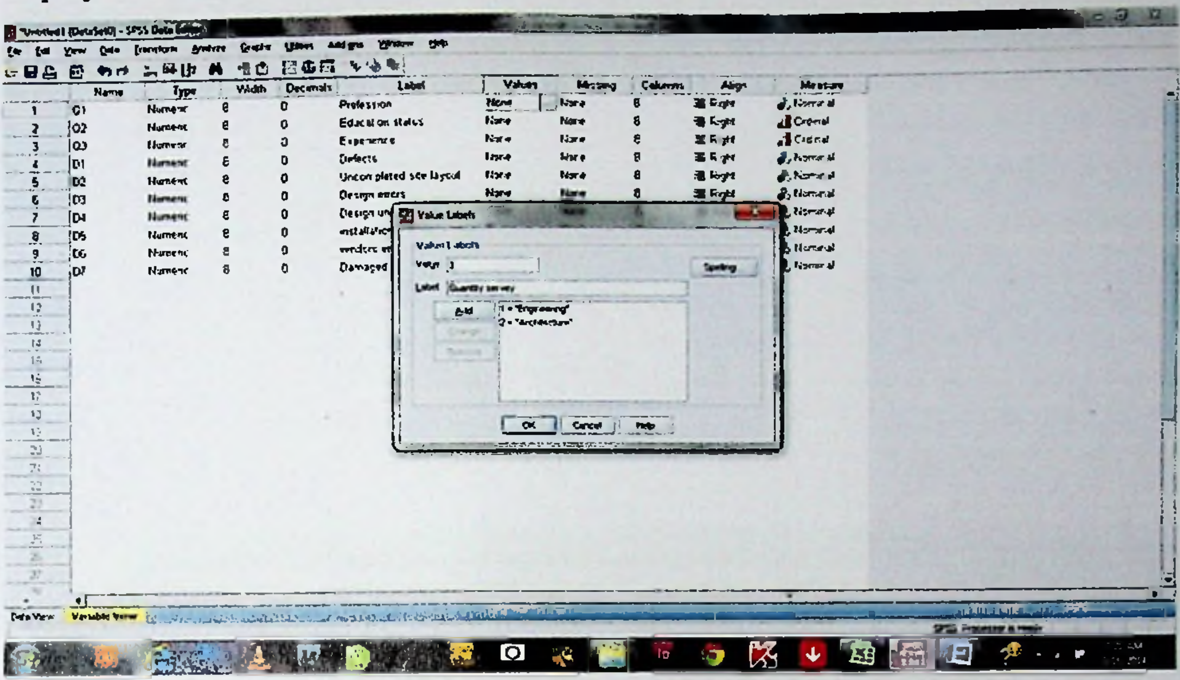


Figure 4.4 Format of the display of data in SPSS

Then, in Likert scale measurements, corresponding pre-defined values were fed and the window displaced was as Figure 4.5.

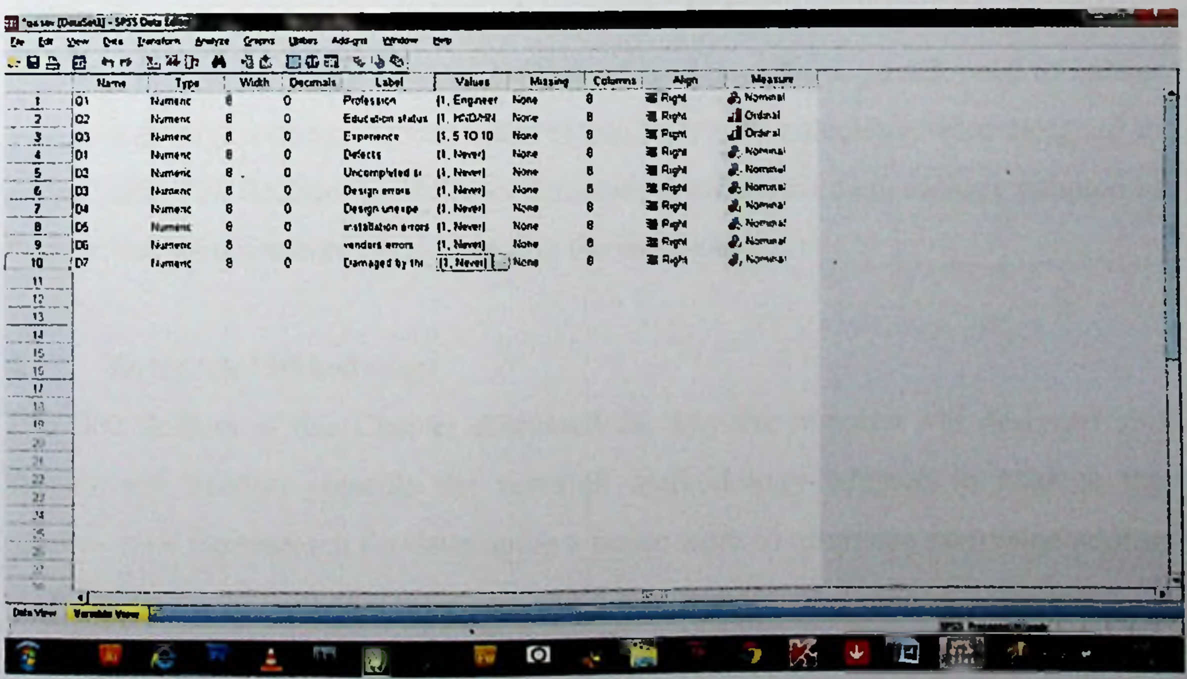


Figure 4.5 Predefine values in the format of SPSS

The sample data design template was completed as shown in figure 4.6

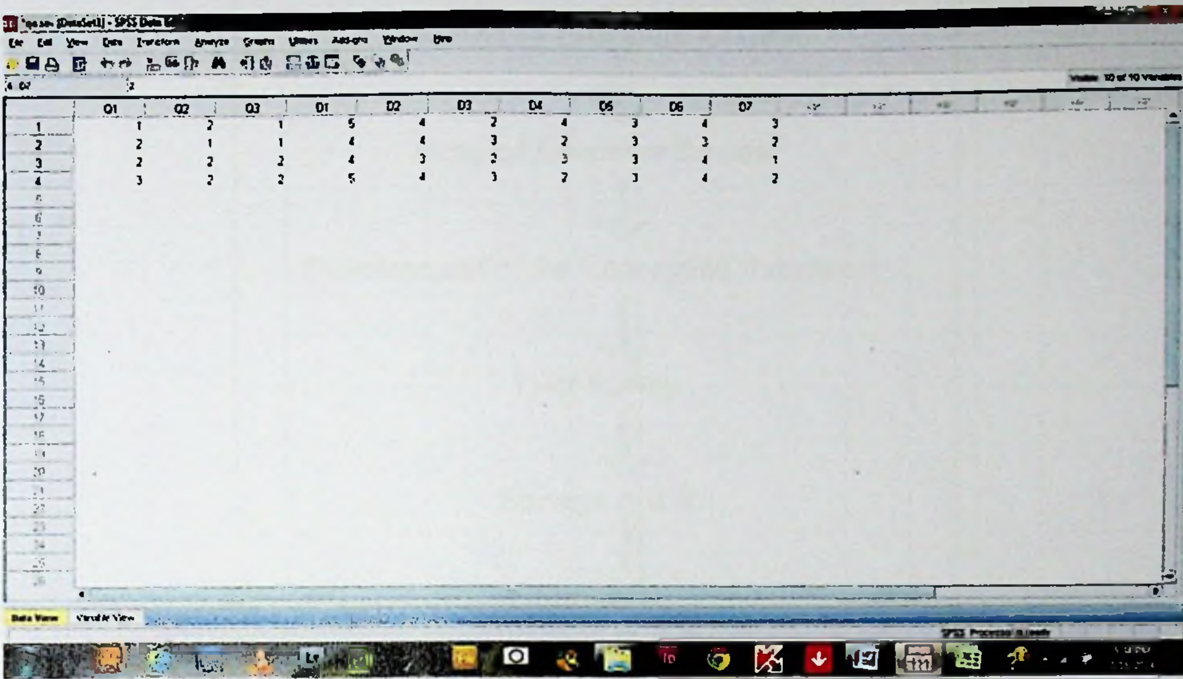


Figure 4.6: Summary of the research design with its elements

4.2.6 Summary of the research design

In a research there are three important areas to be considered. i.e research philosophy, research approach and research techniques. Positivism within a quantitative approach was selected for this research and the approach used to collect data was through surveys. Questionnaires and interview guidelines were designed to collect data. The Section that follows discusses the research methodology adopted to achieve the set objectives after designing the research.

4.3 Research Methodology

The first Section of this Chapter discussed the way the research was designed and this second Section presents the research methodology adopted to achieve the objectives of the research for developing a frame work to minimize non-value adding activities in the construction processes using lean techniques. Figure 4.7 illustrates

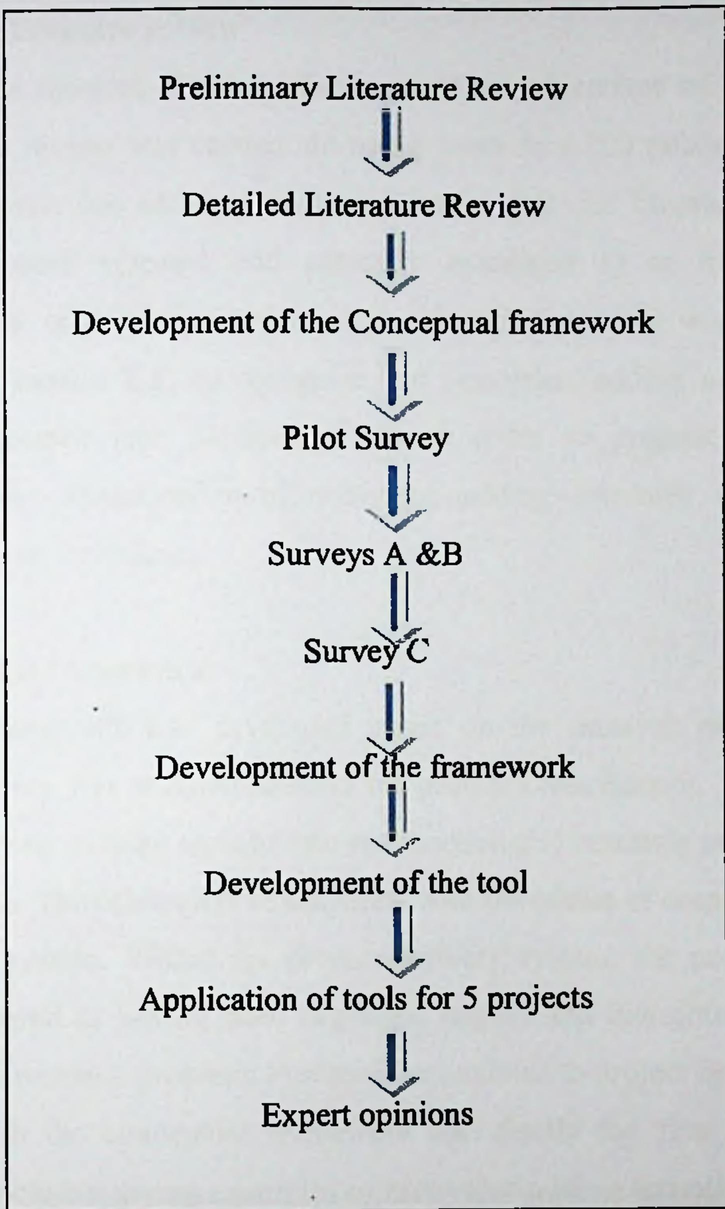


Figure 4.7: Research methodology

4.3.1 Preliminary literature review

The preliminary literature Survey was carried out to explore the research background, to define the research problem and to understand the non-value adding activities in construction processes (See Chapters 1 and 2). Further, this preliminary .literature review has disclosed lean techniques and their applications on the basis of lean principles, lean implementation, benefits and barriers in implementing lean techniques. (See Chapters 1 and 2)

4.3.2 Detailed literature review

After defining the research problem, the aim and the objectives of the research, a detailed literature review was carried out using more than 200 publications on lean techniques and non-value adding activities. From among this literature, 51 specific journal articles were selected and critically examined a) to investigate lean implementation in construction processes to identify the most widely used lean techniques (see Section 2.5) to recognize the non-value adding activities in the construction processes (see Sections 2.2.7) in order to propose a conceptual framework for the minimization of non-value adding activities in construction processes using lean techniques.

4.3.3 Conceptual framework

A conceptual framework was developed based on the research problem and an approach or a theory was selected to solve the problem (see Section 3.4). Hence the framework has been divided mainly into two sections; i) research problem and, ii) research approach. The research problem starts with the nature of construction and its project delivery system. Within the project delivery system, the project operating system is considered as having been neglected largely and therefore this has been considered as the research problem. Further issues related to project operating system were identified in the conceptual framework and finally the first section of the framework is concluded giving examples of non-value adding activities identified to minimize waste through the research approach. The second section of the conceptual framework was developed by appraising the research approach, Lean Implementation. The conceptual framework was developed demonstrating lean concepts, lean project delivery as per the five lean principles, and lastly with commonly used lean techniques. The relationship between non-value adding activities and lean techniques are presented in the main framework developed after data collection and it is discussed in Section 4.3.7.

4.3.4 Pilot survey

Having developed the conceptual framework for this study by describing the research problem and its approach to resolve the problem, a pilot survey was done with the participants illustrated in Table 4.5 to endorse the conceptual framework developed and to get some opinions from the industry related to the data collection, such as the sample size, profile of the samples and questions to be asked from the participants of the Surveys.

Table 4.5: Profile of the participants of the pilot Survey

Ref	Profile of the participants
PS1	Mechanical Engineer working as a senior manager in the manufacturing sector in Sri Lanka who has been exposed to a lean implementation environment and who has got more than 20 years' experience.
PS2	Senior Lecturer with more than 15 years' experience working in a foreign university who is a PhD holder in construction management and engaged in lean researches
PS3	Chartered Civil Engineer working in a local authority as a chief engineer who is more vigilant on non-valued adding activities in construction processes and who has got more than 20 years' experience in the engineering profession
PS4	Senior Lecturer and also a Chartered Quantity Surveyor with more than 15 years' experience mainly in research and following a PhD on Building Information Modelling (BIM)
PS5	Project Manager in a leading construction company managing three building projects in Colombo and suburbs with a wide knowledge in project operating systems

The opinions received from each participant were very useful and the researcher was able to decide on the sample and to design the questions in order to develop the framework for minimizing non-value adding activities using lean techniques. The opinion received from PS2 helped to refine the framework and the opinion received from PS4 and PS5 were really useful to design the questionnaires. The opinion from PS3 contributed immensely to understand the gravity of the research problem in the construction industry in Sri Lanka. PS1 explained the barriers in implementing lean techniques given the Sri Lankan culture and he precisely stated that lean is implemented at a low level in the Sri Lankan industries. The framework developed for this study therefore had substance.

4.3.5 Surveys

Two Surveys were designed to collect data. (i) Survey A to recognize examples of non-value adding activities in the construction industry in Sri Lanka, and (ii) Survey B to examine the current level of implementation of lean techniques in the construction industry in Sri Lanka. The details of these two surveys are presented in this Section.

4.3.5.1 Questionnaire Survey A to recognize non-value adding activities

The examples of non-value adding activities in the construction processes were identified through the literature review as stated in Section 2.4 and the questionnaire A was designed based on this list of non -value adding activities as shown in Figure 4.8 given below:

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

Figure 4.8 Examples of NVVAs

The non-value adding activities identified were categorized under eight waste categories (See Section 2.2) and the main questions of the questionnaire A (Refer Annex - 1) were set out based on these waste categories. An introduction to each question was given to explain the relevant category of waste. The respondents could thereafter easily understand the examples of the non-value adding activities listed. The target sample consisted of 30 construction professionals representing the middle management of construction related organizations. Site Engineers, Project Quantity Surveyors, and Project Architects of construction and consultant firms who had more than 10 years' experience in the construction field were questioned based on a structured questionnaire. The researcher assumed that as per the results of the pilot survey carried out, this sample is well aware of the activities of the construction processes and that the non-value adding activities in the construction processes can be recognized through this questionnaire Survey. Table 4.6 demonstrates the details of the respondents of Survey A.

Table 4.6: Details of the respondents for Survey A

Profession	Highest educational qualification	Number of years of experience	Number of Respondents
Engineering	BSc	≥ 5 years	09
Quantity Surveying	BSc	≥ 5 years	06
Architecture	BSc	≥ 5 years	04
Engineering	NDT	≥ 10 years	05
Quantity Surveying	NCT/HND	≥ 10 years	04
Engineering	HNDE	≥ 10 years	02
Total number of respondents			30

All of the respondents were working in building projects located in Colombo and suburbs with contract values exceeding Rs 100 Million. All respondents were contacted via email and on telephone. Questionnaires were emailed to 22 respondents and 14 fully filled questionnaires were received via email before the due date and the other 8 respondents were contacted and reminded several times after which six of them sent in their responses via email. 2 of them wanted the researcher to take down their response on telephone. 8 respondents were personally met by appointment and they filled the questionnaires in front of the researcher seeking from the researcher any additional clarifications they wanted. Hence the rate of response was 100% for Survey A.

Questionnaire Survey B to examine the current level of Lean Implementation in Sri Lanka

The most widely used lean techniques were identified from the literature review as indicated in Section 3.4 and the lean techniques selected for Survey B are listed in Table 4.7 given below.

Table 4.7: Lean techniques selected for Survey B

LT01	Last Planner System
LT02	Just in Time
LT03	3D Modelling
LT04	Visualization
LT05	BIM
LT06	Value Stream Mapping
LT07	Reverse Phase Scheduling
LT08	Prefabrication / Off site manufacturing
LT09	Kaizen / Continuous Improvement
LT10	Five S
LT11	Fail Safe Quality / Poka-yoke
LT12	Target Value Design
LT13	First Run Studies
LT14	Relational Contracting
LT15	Target Costing
LT16	Set Based Design
LT17	Kanban
LT18	Total Quality Management
LT19	Work Standardization
LT20	Work Structuring

A detailed questionnaire (Refer Annex 2) was designed to collect data to establish the current level of implementation of these lean techniques in construction processes. A sample consisting of 30 members was selected from among Project Managers who worked in recently completed building projects located in the Colombo District in Sri Lanka each of which had an adjusted contract value exceeding Rs 100 million. It was presumed that this sample would have a thorough knowledge of recently developed construction management practices and that they would be aware of the current level of implementation of lean techniques in construction processes in the construction industry in Sri Lanka. Table 4.8 presents the details of the respondents of Survey B.

Table 4.8: Details of the respondents of Survey B

Profession	**Highest educational qualification**	**Number of years of experience**	**Number of Respondents**
Engineering	MSc	≥ 10 years	07
Engineering	PG Dip	≥ 10 years	04
Engineering	BSc	≥ 10 years	05
Engineering	NDT/HNDE	≥ 15 years	06
Engineering	PG Dip	≥ 15 years	05
Engineering	BSc	≥ 20 years	03
Total number of respondents			30

All of the respondents shown in the above Table were working in building projects located in Colombo and suburbs with contract values exceeding Rs 100 million. All respondents were contacted via emails and on telephone. Questionnaires were emailed to 25 respondents and 10 fully filled questionnaires were received via email by the due date. Out of the 15 who did not respond, 7 respondents were contacted and reminded several times and six of them thereafter sent their responses via email. 8 of them wanted the researcher to take down their responses on telephone. 5 respondents were met personally by appointment to get them to fill in the questionnaires in front of the researcher allowing them to seek from the researcher any additional clarifications they wanted. Hence the rate of response was 100% for the Survey B. The researcher had to explain to many respondents what was meant by 'Lean' as though they were well aware of the techniques they were not familiar with the lean culture itself. Except for few lean techniques such as 5S and 3D Modelling, other techniques are used in the industry only as a practice but not as a tool.

4.3.6 Survey based on interviews to develop the framework for lean implementation

An Interview Guideline(Refer Annex 3) was designed with closed questions based on the data already gathered from surveys conducted among 30 members representing the senior management (Project Managers in construction projects) using Questionnaire A (Refer Annex 1) and from 30 members representing the middle management (professionals in contracting and consultants firms) using Questionnaire B (Refer Annex 2). The aim of this Survey was to gather information to establish the relationship between non-value adding activities and lean techniques in order to develop a frame work for minimizing such non-value adding activities to achieve the 3rd objective of this research. At this stage, the researcher had the information on the current level of implementation of lean techniques and on the non-value adding activities of the construction processes in the construction industry in Sri Lanka. Therefore, relationships were established by questioning the top management who were involved in strategic level planning, to enhance the construction management practices towards minimizing non-value adding activities in the processes. A sample consisting of 20 senior Project Managers each of whom had more than 15 years' experience as a Project Manager was selected from 20 C1 contracting firms to collect data via face to face interviews.

The researcher had difficulty in meeting most of the interviewees and the most difficult part of this research was to collect data through interviews as most of the Project Managers had busy schedules and some of them were (INT 1, INT6, INT7, INT13, INT18, INT26) available only for one day in their respective head offices. The appointments with some of the interviewees (INT6, INT18, INT23, and INT27) had to be postponed three times and INT2, INT8, INT9 and INT29 had to be interviewed two times since the permitted time was not sufficient.

4.3.7 Development of the framework

After the completion of data collection of the Surveys A, B and C, the framework for the study was developed. This framework basically contains examples recognized through Survey A and suitable lean techniques identified through Survey B. The two lists (non-value adding activities and lean techniques) were thereafter mapped against each other to identify the relationships between them. Secondly, the framework was expanded by adding guide lines for implementing lean techniques, benefits reaped in implementing lean techniques and the associated challenges with suggestions to overcome the identified challenges based on the data gathered through Survey C. Section 6.2 discusses the framework in detail.

4.3.8 Development of the tool

A tool to assess the lean maturity of a construction project was developed as the next step of the study. The development of this tool is discussed in detail in Section 5.6 of this report. The data collected from Survey B and Survey C was used to develop this tool. The Capability Maturity Model (CMM) was used to assess the lean maturity and this model is further discussed in Section 6.3. The primary objective of this tool is to assess the extent to which a particular building construction project is lean matured, i.e in other words the extent to which lean techniques has been applied in such a project.

4.3.9 Application of the tool

After the data collection, the researcher was able to develop the framework for lean implementation and thereafter the tool for assessing lean maturity of a construction project. Hence, the next step of this study was to apply the tool for five building projects to obtain results to assess the lean maturity of such projects. Table 4.9 illustrates the details of the projects to which the tool was applied.

Table 4.9: Details of the projects selected for the application of the tool

Ref	Name of the project
1	Proposed housing scheme at Athurugiriya
2	Proposed office building complex in Colombo 08
3	Proposed apartment complex at Battaramulla
4	Proposed apartment complex at Rajagiriya
5	Proposed mix development for offices, shops and apartments in Colombo 08

All of the above projects were in the construction stage and were almost nearing completion. Project values ranged from Rs.150 Million to Rs 600 Million. The details of these projects in respect of their lean maturity are presented in Section 6.3.5.

4.3.10 Expert opinions

As the last step of this study, expert opinions were obtained from industry experts to refine the framework discussed in Section 4.3.7 and the tool discussed in Section 4.3.8. The details of the experts from whom the opinions were sought are given in Table 4.10

Table 4.10: Profile of the participants for expert opinions

Ref	Profile of the participants
EO1	Chief Engineer and a Chartered Engineer attached to a local government authority and who has got more than 15 years' experience in building projects as a Project Manager
EO2	Senior Lecturer in construction management and a Chartered Architect who has got more than 20 years' experience in building projects
EO3	Chartered Architect who has got more than 18 years' experience in building projects and who has worked as a member of a project management team
EO4	Senior Lecturer , a PhD holder in the area of construction management and a Chartered Quantity Surveyor who has got more than 10 years' experience
EO5	Computer Engineer, who has expert knowledge in program writing and working in a leading construction company
EO6	Senior Lecturer and an Engineer in Computer Science who has got more than 23 years working experience

The participants EO 05 and EO 06 indicated contributed effectively using their expert knowledge to refine the tool developed adding more value to it to enhance the interface of the tool in the form of a minor computer program. EO1 was an expert in managing many building projects and was good at minimizing waste and his opinions helped significantly to refine the framework. EO2 and EO4 gave their expertise to enhance the framework with a view to mapping non-value adding activities and lean techniques against opinions on the overall output of this research. The summary of the research methodology adopted for this study is presented next.

4.3.11 Summary of the research methodology

A preliminary literature review, a detailed literature review, a pilot survey, three main surveys, expert opinions and five case studies were used as the methodology for this study as summarized in Table 4.11 below.

Table 4.11 Methodologies adopted for the study

Ref	Objectives	Methodologies Adopted							
		Preliminary Literature Review	**Detailed Literature Review**	**Pilot Survey**	**Survey A**	**Survey B**	**Survey C**	**Case Studies**	**Expert Opinion**
1	To investigate the Non Value Adding Activities in construction processes	√	√	√	√				√
2	To examine the implementation of lean techniques in construction processes	√	√	√		√			√
3	To map widely used lean techniques with non-value adding activities in construction processes in order to identify the lean implementation	√	√	√	√	√	√		√
4	To propose a tool for assessing lean maturity in a construction project.	√	√	√	√	√	√	√	√

The above Table shows the different methodologies adopted for this study and the way these methodologies are linked with the objectives of the research. The Chapter that follows presents the research findings made through the three surveys.

Chapter – 5

Data Collection

CHAPTER 5

5.0 DATA COLLECTION

5.1 Introduction

Chapter 4 presented the details of the research design and research methodology of this study. This Chapter presents the research findings that are based on the data collected from three different surveys conducted and the details of statistical and mathematical analysis of such data. The Chapter begins with the Survey A carried out to recognize non-value adding activities in the construction processes in Sri Lanka and goes on to discuss the findings of Survey B carried out to examine the level of lean implementation in the construction industry in Sri Lanka. Finally the Chapter will offer the findings of Survey C carried out to map lean techniques against non-value adding activities to enable the development of a framework for lean implementation.

5.2 Findings of Survey A

5.2.1 Introduction

The objective of this survey was to investigate the non-value adding activities of the construction processes in Sri Lanka. 49 examples of non-value adding activities were identified through the literature review as presented in Figure 2.2 and these examples of non-value adding activities were then categorized in to seven types of waste (See Section 2.2.7). The questionnaire A (See Annex I) was designed to conduct a survey among construction professionals as described in Section 4.3.5.1.The target sample was 30 construction professionals representing the middle management of construction related organizations. Site Engineers, Project Quantity Surveyors, and Project Architects of both construction and consultant organizations each of whom had more than 10 years' experience in the construction field were given a structured questionnaire which had 8 main questions to cover all 48 examples identified thorough the literature Survey. The respondents were asked to rate the significance of each type of waste on a qualitative scale as per their perception. i.e never, very rarely, about 50%, usually, and almost always. The rate of response was 100% as detailed in Section 4.3.5.1.

5.2.2 Non Value adding activities (NVAAs) in construction processes in Sri Lanka

Data obtained through Survey A was statistically analysed using SPSS software and all non-value adding activities identified through the literature review (See Section 2.2) were found to be present in the construction processes in Sri Lanka as well. Figure 5.1 illustrates the non-value adding activities present in the construction processes in Sri Lanka. X axis represents non-value adding activities while Y axis represents the response rate related to each non-value adding activity.

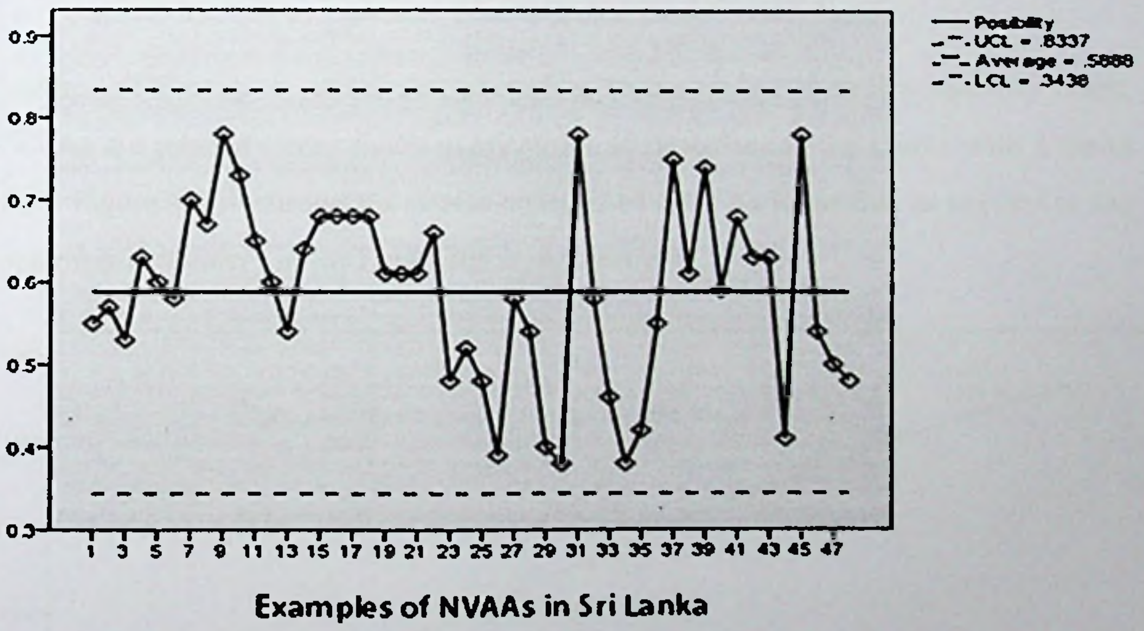


Figure 5.1: Existence of NVAAs in construction processes in Sri Lanka

The above Figure shows that the minimum level of existence of NVAAs is 35% and that its maximum level is 85%. A Histogram was drawn based on the collected data and Figure 6.2 demonstrates the frequency of the 49 identified examples of NVAAs in terms of their rating with the mean at 59%.

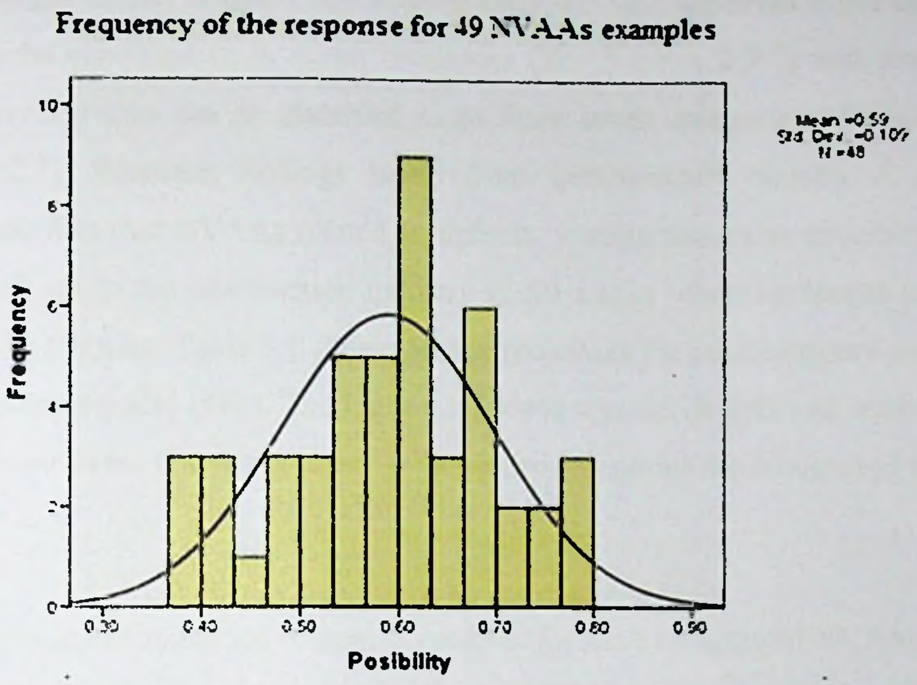


Figure 5.2: Frequency of the response for 49 examples of NVAAs

Findings of Survey A reveal that according to the above control possibility chart, NVVAs are present very much in construction processes in Sri Lanka with a mean of 59. Figure 5.3 illustrates the pareto analysis of NVVAs identified as present in the construction industry in Sri Lanka through Survey A.

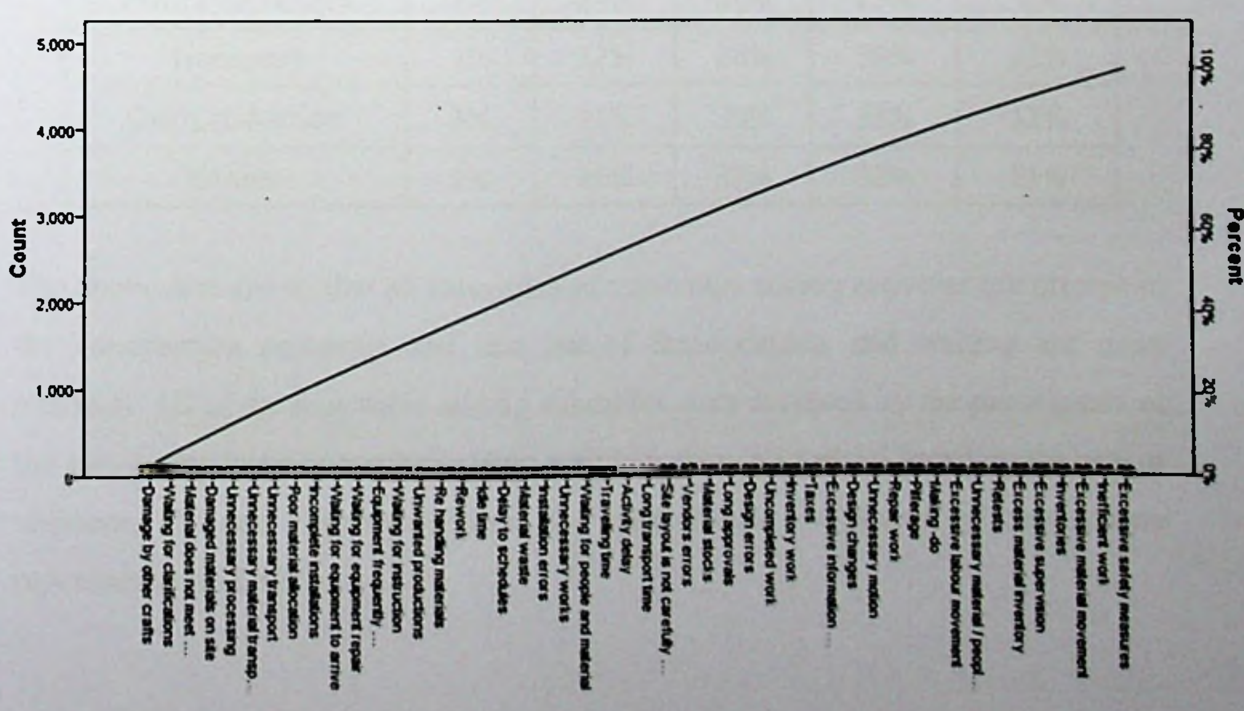


Figure 5.3: Existence of NVAAs in Pareto diagram

5.2.3 Categorization of non-value adding activities into different types of waste

Waste can be classified in to seven categories (See Section 2.2.7) and non-value adding activities also can be classified in to these seven categories of waste (see Section 2.2.7). Research findings made from questionnaire Survey A further highlight the fact that NVAAs related to defects, waiting and extra procedures are more significant in the construction industry in Sri Lanka when compared to other categories of NVAAs. Table 5.1 illustrates the responses for each category based on the five different scales given. The highest response was for defects and waiting and all of these examples that fall into one of these two categories are recognized beyond 50%.

Table 5.1: Percentage of responses received for each category of NVAAs

Types of NVAAs	Never	Very Rarely	About 50%	Usually	Almost always
Defects	0%	14%	33%	41%	12%
Waiting	0%	6%	40%	43%	11%
Motion	10%	33%	28%	19%	10%
Inventory	4%	24%	50%	21%	1%
Extra Procedures	5%	24%	36%	27%	8%
Transport	1%	12%	26%	39%	22%
Overproduction	3%	21%	30%	33%	13%
Others	2%	20%	35%	32%	11%

The above data shows that all categories of non-value adding activities are present in the construction processes and that out of these defects and waiting are more common. All of the non-value adding examples were accepted by the participants of the survey and these non-value adding activities were prioritized based on the rate of response. The next Section discusses the most critical NVAAs in the construction processes in Sri Lanka.

5.2.4 Most critical non-value adding activities in the construction processes in Sri Lanka

Findings from Survey A were further analyzed to identify the most critical NVAAs in the construction processes in Sri Lanka and each category of waste was considered separately with a view to prioritizing the NVAAs in the construction processes.

5.2.4.1 Defects

Findings of Survey A on the waste category 'Defects' are highlighted in Figure 5.4 given below:

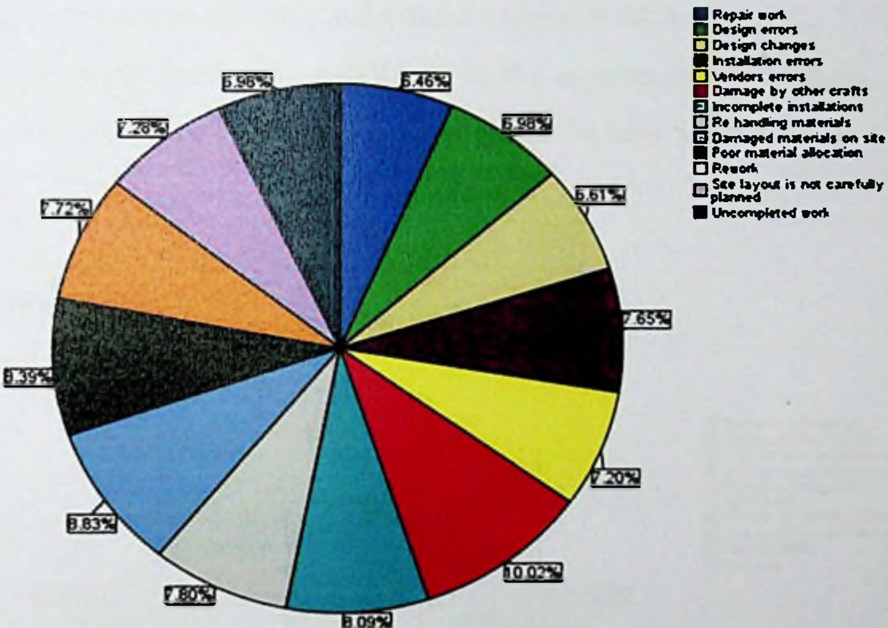


Figure 5.4: Examples of Defects in SLCI

Further, when this data was analyzed through a correlation analysis it was revealed that out of the 13 examples of NVAAs in the category of 'Defects', several NVAAs had correlation coefficient values exceeding 0.5. Corresponding NVAAs were selected considering their higher combination with corresponding NVAAs of other examples of NVAAs. Only combinations of three or more NVAAs were considered. Table 5.2 shows the combinations.

Table 5.2: Data on the correlation analysis of NVAAs in the category 'Defects'

NVAAs	Combinations
1	2,5,7,8,9
2	1,8,9
7	1,4,6,9,10
8	1,2,9,10,11
9	1,2,4,7,8
10	1,7,8

According to the above analysis and considerations NVAA Nos. 1, 2, 7, 8, 9 and 10 are found to be the most critical NVAAs in the construction processes. The waste categories 'Waiting' and 'Motion' are analyzed in the next Section.

5.2.4.2 Waiting

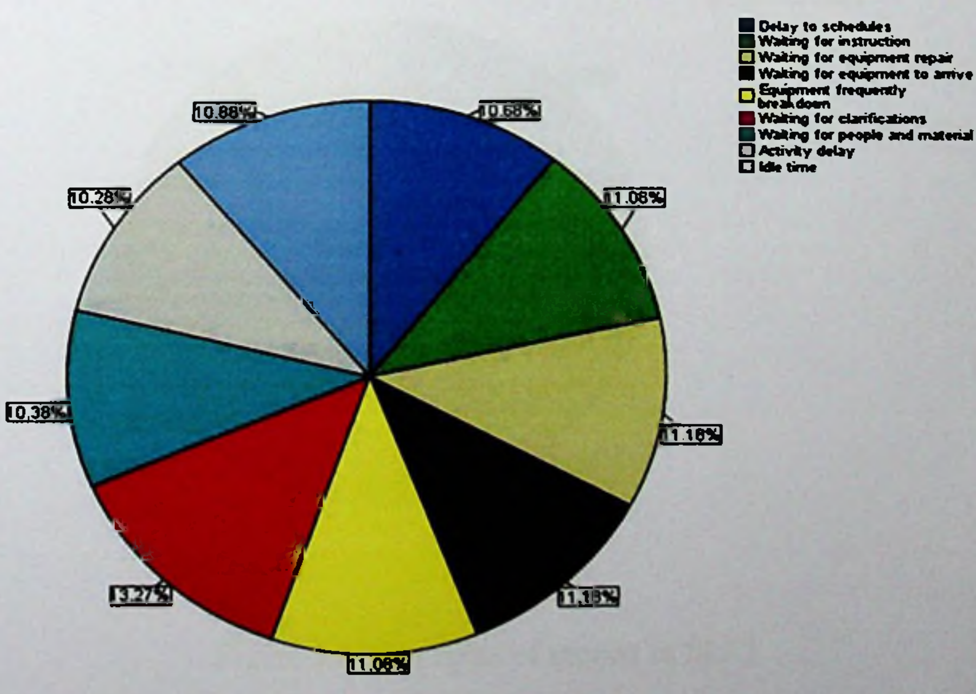


Figure 5.5: Examples of waiting in SLCI

Table 5.3: Combination of NVVAs

NVAAs	Combinations
1	2,3,7,9
2	1,3,7,9
3	1,2,4,8,9
7	1,2,8.9
8	3,7,9
9	1,2,3,7,8

The findings reveal that NVAA Nos. 1, 2, 3, 7, 8 and 9 of the category 'Waiting' are the most critical NVAAs in the construction processes in Sri Lanka and that therefore they need to be further considered.

5.2.4.3 Motion

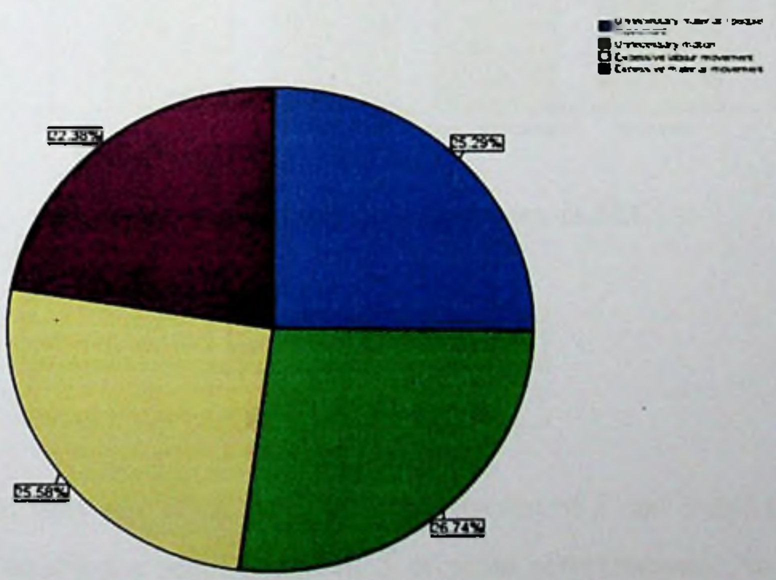


Figure 5.6: Examples of motion in SLCI

Variable	Combinations
3	1,2

This shows that only one NVAA has a combination of 1 and 2 and that it therefore does not satisfy the requirement of 3 or more combinations. No NVVA was therefore selected from this category of waste.

5.2.4.4 Inventory

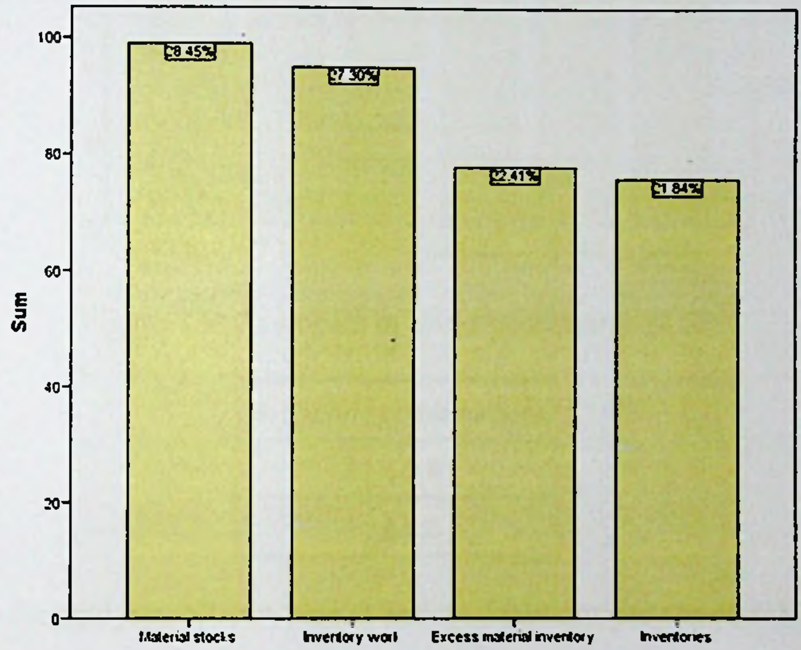


Figure 5.7: Examples of Inventory in SLCI

Variable	Combinations
4	2,3

This shows that only one NVAA has the combination of 2 and 3 and therefore that also does not satisfy the requirement of 3 or more combinations. No NVVA was therefore selected from this category of waste.

5.2.4.5 Extra Processing

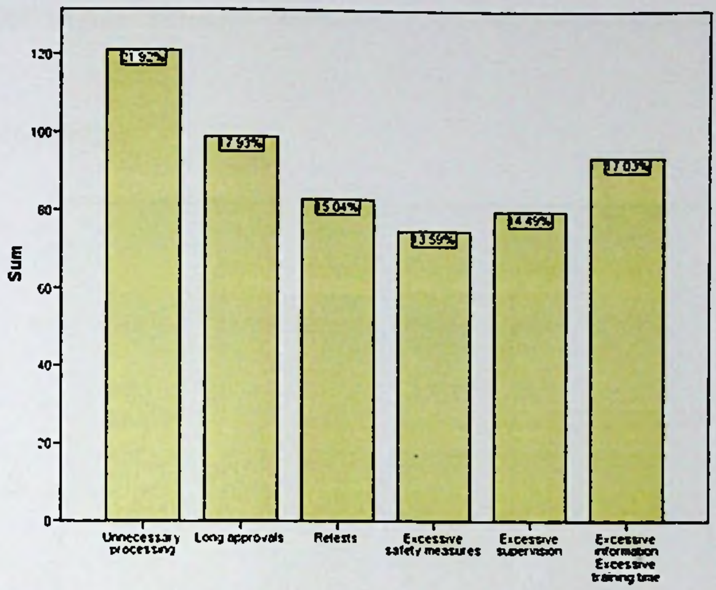


Figure 5.8: Examples of Extra processing SLCI

Variable	combinations
3	4,5,6
4	3,5,6

According to the analysis, NVAA Nos. 3 and 4 of this category have fulfilled the requirement of 3 NVAAs and these were therefore identified as the most critical NVAAs that need further study.

5.2.4.6 Transport

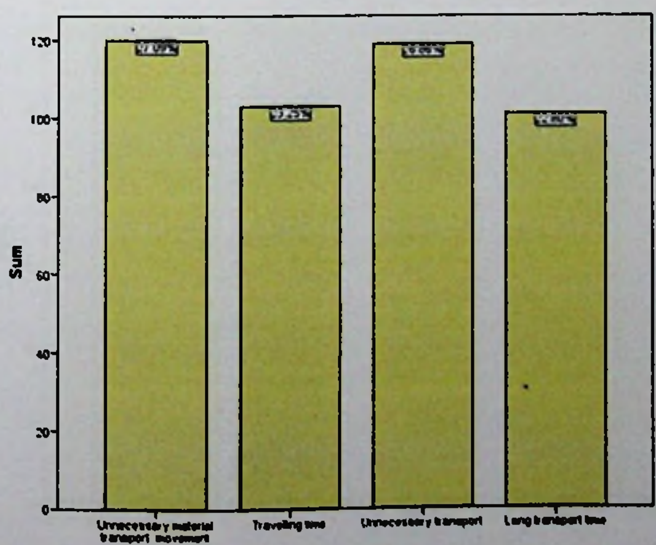


Figure 5.9: Examples of Transport in SLCI

There was no combination with other NVAAs and this category of NVVAs was therefore identified as not critical.

5.2.4.7 Over production

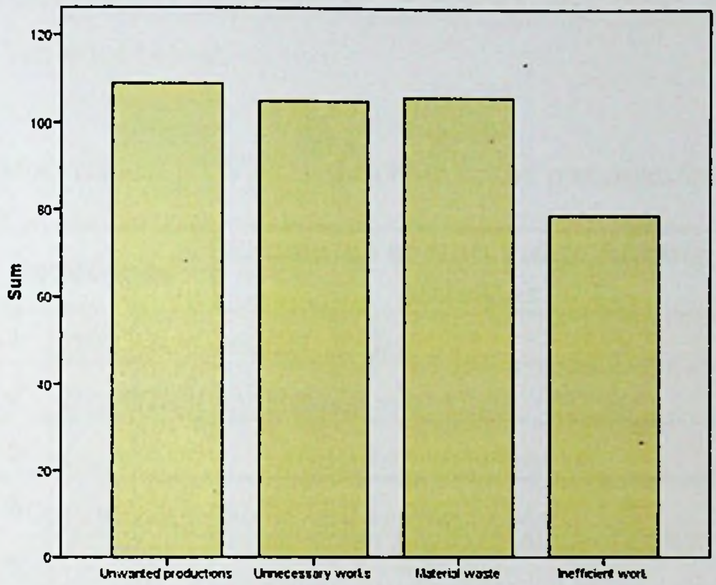


Figure 5.10: Examples of overproduction in SLCI

There was no combination with other NVAAs and this category of NVVAs was therefore identified as not critical

5.2.4.8 Other Categories

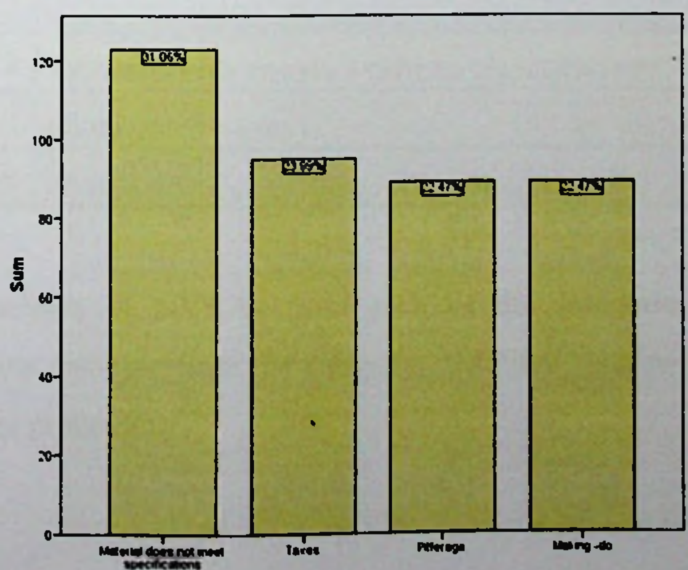


Figure 5.11 Examples of other categories in SLCI

There was no combination with other NVAAs and this category of NVVAs was also therefore identified as not critical.

According to the above analysis, 15 NVAAs can be identified as being most critical NVAAs in the construction processes in Sri Lanka and these 15 NVVAs are demonstrated in Table 5.4 below:

Table 5.4: Most critical NVVAs in the construction processes in Sri Lanka

Reference		Examples of Non Value Adding Activities
1	D01NA01	Repair Work
2	D02NA02	Design errors
3	D07NA07	Incomplete Installations
4	D08NA08	Rehandling materials
5	D09NA09	Damaged Materials on site
6	D10NA10	Poor material allocation
7	W01NA14	Delay to schedules
8	W02NA15	Waiting for Instructions
9	W03NA16	Waiting for equipment repair
10	W07NA20	Waiting (for people, material)
11	W08NA21	Activitiy Delay
12	W09NA22	Idle Time
13	M03NA25	Excessive labour movement
14	E03NA33	Retests
15	E04NA34	Excessive safety measures

There are 6 examples of NVAAs from each of the categories, 'Defects' and 'Waiting' with one example from the category 'Motion' and two examples from the category 'Extra processing'.

5.2.5 Summary of Survey A

Data collected from the survey reveals that almost all 49 examples of NVAAs identified through the literature review have been considered by the respondents to the survey as prevaling in the construction industry in Sri Lanka. The findings of the survey show that NVAAs are generated at a significant level in the construction processes in Sri Lanka. Hence hypothesis A (See section 4.2.3.3) is acceptable to SLCI. Further it is revealed through the survey that the most significant categories of NVAAs are the 'Defects' and 'Waiting'. It can also be identified that NVAAs occur to an extent of 57% when performing the activities of the construction processes. Hence, it can be concluded that there is a requirement for developing a framework for minimizing these NVAAs in the construction industry in Sri Lanka.

5.3 Data collection and analysis of Survey B

5.3.1 Introduction

A sample of 30 Project Managers was selected from among Project Managers of building projects which were completed recently and which had an adjusted contract values exceeding Rs. 100 Million and which were located in Colombo in Sri Lanka. It was presumed that this sample will have a thorough knowledge of the recently developed construction management practices and that they will be aware of the current level of implementation of lean techniques in the construction processes in the construction industry in Sri Lanka. A questionnaire was designed with 20 questions to represent each lean technique on a five scale rating, i.e never, very rarely, about 50%, usually, almost always.

5.3.2 Current level of implementing lean techniques in the construction industry in Sri Lanka

Data collected from Survey B revealed that the level of implementation of lean techniques differs from one to the other and that the average level of their implementation is 40%. 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. Figure 5.4 illustrates the level of implementing the 20 lean techniques in the construction processes of the construction industry in Sri Lanka.

5.3.3 Implementation of lean techniques in the construction industry in Sri Lanka

Research findings of Survey B further highlight the fact that the level of implementation of lean techniques in the construction industry in Sri Lanka is at different levels. Figure 5.12 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.

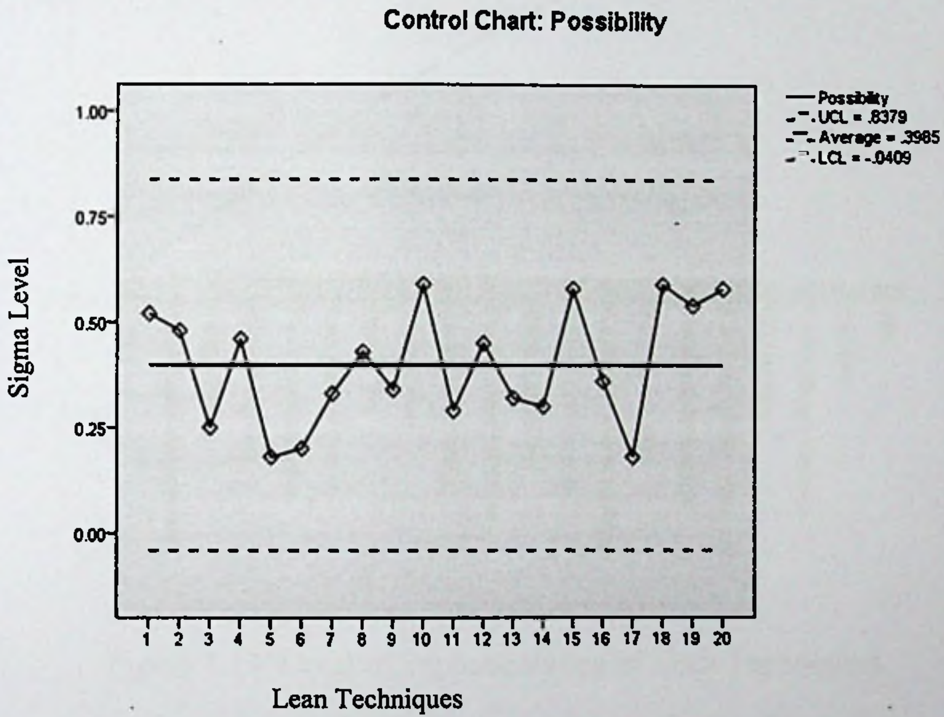


Figure 5.12: Current level of implementing lean techniques in the construction industry in Sri Lanka

The Y axis of the graph shows the cumulative count of the responses received for each of the lean techniques selected for the study. It is obvious that all 20 lean techniques are significant as per the data analysis indicated in Figure 5.12. 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.

5.3.4 Current level of implementing lean techniques in the construction industry in Sri Lanka

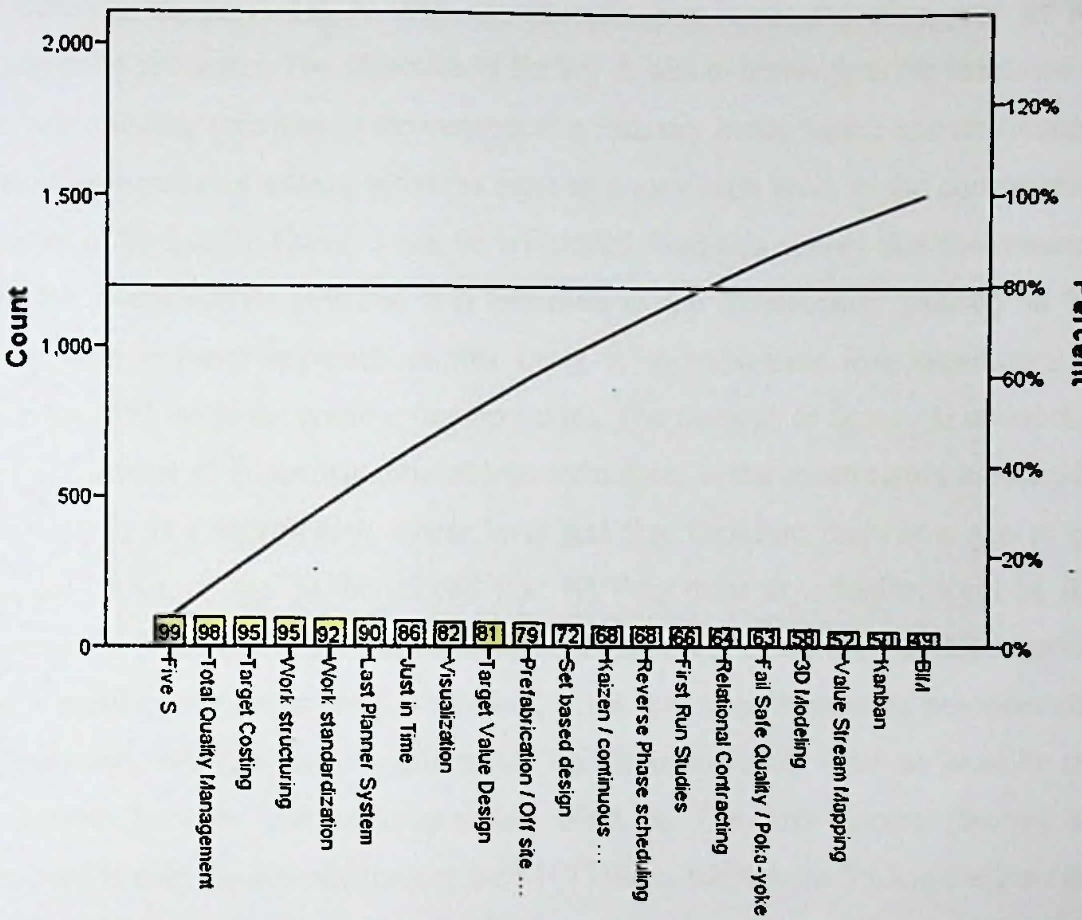


Figure 5.13: Level of implementation of Lean Techniques

5.3.5 Summary of Survey B

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. Hence hypothesis B (See section 4.2.3.3) is acceptable to SLCI. Literature findings have revealed that lean techniques have been widely implemented in other countries with their benefits valued. However the construction industry in Sri Lanka is significantly lagging behind in implementing lean techniques in their construction processes and therefore there is substantial scope to improve the implementation of lean techniques in Sri Lanka.

5.4 Summary of Surveys A and B

The research problem of this study is the existence of non-value adding activities in the construction processes as they are wasteful and lower the efficiency of the construction processes. The objective of Survey A was to investigate the existence of non-value adding activities in the construction industry in Sri Lanka and its findings reveal that non-value adding activities exist at a very high level in the construction industry in Sri Lanka. Hence it can be concluded from this survey that the research problem is appropriate and that it is common in the construction industry in Sri Lanka. The research approach of this study is to implement lean techniques to minimize NVVAs in the construction processes. The findings of Survey B reveal that the current level of implementation of lean techniques in the construction industry in Sri Lanka is at a significantly lower level and that therefore there is a gap to be bridged. Hence, it can be concluded that NVVAs exist at a higher level in the construction processes in Sri Lanka and that on the other hand, lean implementation is at a significantly lower level. Therefore, if the lean implementation practices can be improved, NVVAs can be minimized and it is therefore vital to identify the relationship between lean techniques and NVAAs. The next Survey (Survey C) attempted to map the lean techniques with NVVAs in addition to finding the benefits and associated challenges of lean implementation together with suggestions to overcome the identified challenges.

5.5 Data Collection and Analysis of Survey C

5.5.1 Introduction

Survey A (See Section 5.2.5) concluded that there is a considerable number of NVAAs in the construction processes in the construction industry in Sri Lanka and that almost all 49 examples of NVVAs identified through the literature Survey were also identified by the participants of Survey A. Conversely, Survey B (See Section 5.3.5) proved that the implementation of lean techniques in the construction industry in Sri Lanka is at a substantially lower level and that therefore there is a gap to be bridged. Survey C identifies that there is a positive relationship between NVAAs and lean techniques and it is proved that these identified NVAAs can be minimized using lean techniques identified through this study. An interview guideline was designed as discussed in Section 4.3.6 to conduct the survey by interviewing 20 members of the senior management (Project Managers in construction projects). The aim of this survey is to gather information to establish a relationship between non-value adding activities and lean techniques for developing a frame work for minimizing these non-value adding activities to achieve the 3rd objective of the research. The profiles of the interviewees are discussed in Section 4.3.6 and the rate of response was 100% , although obtaining these responses was quite difficult. The objectives of this survey which were based on the interview guide line (See Annex 3) were to i) map the lean techniques (LTs) against NVAAs to establish the relationship between the two variables (LTs and NVVAs) ii) categorize the application of lean techniques in to different stages of construction, iii) identify the benefits of implementing lean techniques, iv) identify the associated challenges in implementing lean techniques, v) identify suggestions to overcome the challenges. The Sections that follow discuss how these objectives could be achieved through Survey C.

5.5.2 Mapping non-value adding activities against lean techniques

Section 2 of the interview guideline (See Annex 3) was designed to map NVAAs against lean techniques and Table 5.1 was given to the interviewees to mark their responses. Rows of the Table represent the most critical NVAAs identified through Survey A (See Section 5.2.4) whereas columns of the Table represent the lean techniques confirmed through Survey B (See Section 5.3.5)

The mapping diagram was explained to each interviewee who was thereafter requested to map each NVVA against each lean technique. A separate description for each lean technique was provided as a part of the interview guideline (see Annex 3 of Section 1). Table 5.2 presents the summary of the data obtained through Survey C and describes the relationship between the participants who selected the most appropriate lean techniques that will minimize the NVAAs.

Table 5.5: Mapping sheet provided to map lean techniques against NVVAs

Mapping examples of NVAAs with Lean Techniques																					
Ref	Examples of NVAAs	Lean Techniques																			
		LPS	JIT	3D	Vis	BIM	VSM	RPS	OSM	KAIZ	5S	FSQ	TVD	FRS	RC	TC	SBD	KAN	TQM	WS	WST
		LT01	LT02	LT03	LT04	LT05	LT06	LT07	LT08	LT09	LT10	LT11	LT12	LT13	LT14	LT15	LT16	LT17	LT18	LT19	LT20
D01NA01	Repair Work																				
D02NA02	Design errors																				
D07NA07	Incomplete installations																				
D08NA08	Re-handling materials																				
D09NA09	Damaged Materials on site																				
D10NA10	Poor material allocation																				
W01NA14	Delay to schedules																				
W02NA15	Waiting for instructions																				
W03NA16	Waiting for equipment repair																				
W07NA20	Waiting for People and materials																				
W08NA21	Activity Delay																				
W09NA22	Idle Time																				
M01NA25	Excessive labour movement																				
W03NA33	Retests																				
W04NA34	Excessive safety measurers																				

Table 5.6: Data obtained through Survey C

Survey C	LT01	LT02	LT03	LT04	LT05	LT06	LT07	LT08	LT09	LT10	LT11	LT12	LT13	LT14	LT15	LT16	LT17	LT18	LT19	LT20
Interviewee 1	15	9	3	10	0	0	4	9	5	8	4	0	4	0	7	0	0	10	8	10
Interviewee 2	12	12	4	9	15	12	5	5	2	9	4	2	4	6	2	9	3	8	14	5
Interviewee 3	15	9	3	10	0	0	4	9	5	8	4	0	4	0	7	0	0	10	8	10
Interviewee 4	15	9	3	10	0	0	4	9	5	8	4	0	4	0	7	0	0	10	8	10
Interviewee 5	13	8	3	10	3	4	4	8	5	8	3	0	4	0	7	0	0	9	8	9
Interviewee 6	12	12	4	9	15	12	5	5	2	6	4	2	4	6	2	5	3	8	6	5
Interviewee 7	15	9	3	10	0	0	4	9	5	8	4	0	4	0	7	0	0	10	8	10
Interviewee 8	13	7	10	11	13	11	9	11	12	10	7	1	10	11	10	10	4	14	13	9
Interviewee 9	13	7	10	11	13	10	9	11	12	5	7	2	10	10	10	10	4	14	13	8
Interviewee 10	13	7	10	11	13	10	9	10	12	9	7	3	10	11	10	10	4	14	11	9
Interviewee 11	15	9	3	10	0	0	4	9	5	8	4	0	4	0	7	0	0	10	8	10
Interviewee 12	13	7	10	11	13	11	9	11	12	13	7	1	10	10	9	10	3	14	13	9
Interviewee 13	13	7	10	11	13	11	9	11	12	10	7	1	10	11	10	10	4	14	13	9
Interviewee 14	13	7	10	11	13	11	9	11	12	14	7	2	10	11	10	10	4	14	13	9
Interviewee 15	15	9	3	10	0	0	4	9	5	8	4	0	4	0	7	0	0	10	8	10
Interviewee 16	14	7	10	11	13	11	9	11	12	14	7	1	10	11	10	10	4	14	13	9
Interviewee 17	12	7	10	11	13	11	9	11	12	14	7	1	10	11	10	10	4	14	12	9
Interviewee 18	14	12	4	9	15	12	5	9	2	13	4	2	4	6	2	5	3	8	12	5
Interviewee 19	12	12	4	9	15	12	5	5	2	12	4	2	4	6	2	5	3	8	15	5
Interviewee 20	12	12	4	9	15	12	5	5	2	6	4	2	4	6	2	5	3	8	6	5

The above findings show that interviewee 1 has said that all given 15 NVAAS can be minimized using LT01 and similarly interviewee 2 has said that 12 NVAAs out of the given 15 NVAAs can be minimized using LT01. The data shows that all NVVA has a relationship with one or more LTs and similarly that all LTs have a relationship with one or more NVVAs. Hence, these findings reveal that there is a strong relationship among LTs and NVAAs and hypothesis C is therefore acceptable to the construction industry in Sri Lanka. Further it is revealed through this survey that NVAAs in the construction processes can be minimized using LTs. Table 5.7 further explains the relationship between each LT and each NVAA based on the findings of Survey C. Interviewees were asked to map the NVAAs against LTs and they as presented in Table 5.7 have suggested the most suitable LT that will in their opinion would minimize each NVAA

Table 5.7: Relationships between NVAAs and LTs

	Reference	LT01	LT02	LT03	LT04	LT05	LT06	LT07	LT08	LT09	LT10	LT11	LT12	LT13	LT14	LT15	LT16	LT17	LT18	LT19	LT20
1	D01NA01	14	4	12	14	3	14	13	13	13	13	11	5	9	14	13	2	3	11	14	12
2	D02NA02	0	1	13	10	11	14	12	4	12	6	12	12	12	13	4	13	12	14	12	6
3	D07NA07	13	13	4	13	13	12	13	3	3	13	12	6	9	3	13	14	5	13	2	3
4	D08NA08	3	13	3	14	14	12	4	11	11	11	3	3	5	4	6	5	12	12	14	3
5	D09NA09	12	12	14	13	12	4	4	12	11	11	13	3	4	4	13	3	12	13	13	3
6	D10NA10	13	12	7	2	13	13	3	13	13	13	13	4	13	14	4	13	3	14	13	12
7	W01NA14	12	13	13	2	13	13	9	12	10	2	2	3	12	12	12	10	6	13	13	12
8	W02NA15	14	3	13	11	14	14	10	10	10	5	4	3	12	12	10	11	2	11	13	12
9	W03NA16	13	3	13	12	14	11	11	13	13	5	4	0	13	13	13	10	5	8	9	11
10	W07NA20	13	4	11	11	11	11	12	13	12	11	4	2	11	11	11	11	1	9	8	14
11	W08NA21	14	5	12	12	11	14	12	12	11	10	5	1	12	13	12	14	2	13	12	14
12	W09NA22	12	12	11	14	11	5	12	11	14	10	9	0	13	13	5	12	3	13	12	11
13	M03NA25	12	14	11	12	12	4	4	11	11	10	4	2	2	12	4	3	2	11	12	5
14	E03NA33	11	6	2	6	14	5	4	2	3	12	12	2	2	11	12	14	11	11	12	4
15	E04NA34	11	6	2	5	4	2	5	5	6	6	3	2	3	3	12	3	2	1	1	14

For example, in order to minimize the first NVAA in the list, i.e D01NA01, all of the LTs indicated except LT02, LT05, LT14, LT15, LT21 and LT22 can be implemented. Similarly LT01, LT18 and LT42 can be utilized to minimize EO4NA34.The minimum number of LTs for a given NVAA is three and the maximum number of LTs for a given NVAA is 16 and for all other NVAAs the number of LTs ranges from 10 to 15. Figure 5.14 demonstrates the mapping of NVAAs against LTs based on the research findings revealed through Survey C.

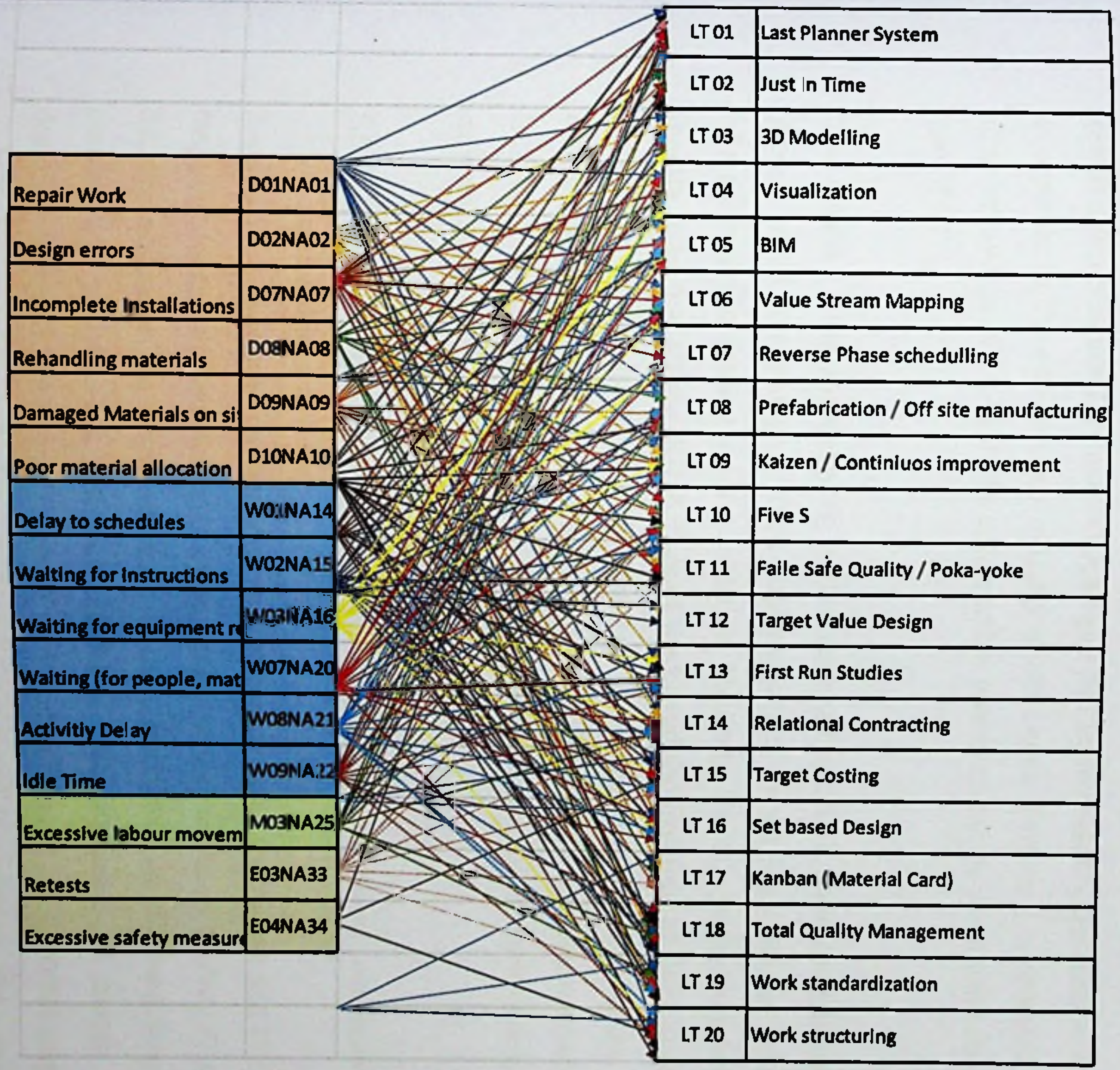


Figure 5.14: Mapping NVAAs with Lean techniques

The above Figure shows 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 and that hypothesis C (See section 4.2.3.3) is acceptable to the construction industry in Sri Lanka. Further it is revealed through this survey that NVAAs in the construction processes can be minimized through the use of LT.

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. The entire life of a 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 5.8 illustrates the implementation of the LTs selected for this study in the four different stages of a construction project delivery system.

5.5.3 Implementing lean techniques in different stages of construction in Sri Lanka

Section 5.3.3 discussed the relationships between the lean techniques and NVAAs by mapping these two against each other based on the results of Survey C and this Section discusses the implementation of lean techniques in different stages of a construction project. The interview guideline (See Section 3 in Annex 3) was designed to identify the application of each lean technique in different stages of a construction process and respondents were requested to identify the techniques used in each stage of the construction process (i) inception stage, (ii) design stage, (iii) planning stage, and (iv) construction stage. Table 5.8 illustrates the findings from Survey C on lean technique implementation in different stages of a construction process.

Table 5.8: Implementing LTs in different stages of a construction project delivery system

Ref	Lean Techniques	Summary of Data				
		Project Delivery Stages				
		1	2	3	4	N /A
LT01	Last Planner System	7	10	11	20	0
LT02	Just in Time	0	0	16	20	0
LT03	3D Modelling	6	20	16	14	0
LT04	Visualization	0	14	14	19	0
LT05	BIM	11	13	15	15	4
LT06	Value Stream Mapping	6	6	16	16	4
LT07	Reverse Phase schedulling	4	15	20	20	0
LT08	Prefabrication / Off site manufact	0	20	16	20	0
LT09	Kaizen / Continiuos improvement	11	19	20	20	0
LT10	Five S	14	18	20	20	0
LT11	Faile Safe Quality / Poka-yoke	4	14	15	20	0
LT12	Target Value Design	18	20	4	4	1
LT13	First Run Studies	4	4	0	16	0
LT14	Relational Contracting	5	16	14	14	4
LT15	Target Costing	14	20	20	20	0
LT16	Set based Design	0	9	10	9	4
LT17	Kanban (Material Card)	0	0	5	17	5
LT18	Total Quality Management	6	13	15	20	0
LT19	Work standardization	12	19	20	20	0
LT20	Work structuring	1	20	20	20	0

The above Table shows the responses of the interviewees on implementation of different LTs in different stages of a construction project delivery system. LT12 and LT22 can be implemented in Stages 3 and 4 and all interviewees have said that LT 18 (Target costing) can be implemented in Stages 2, 3 and 4. Four interviewees (IW 04, 07 and 20) have said that LT05, LT07, LT17 and LT21 cannot be implemented in the construction industry in Sri Lanka due to the specific nature of projects implemented in Sri Lanka. However, the above Table shows that all LTs can be implemented as least in one stage. Data obtained from Survey C was further analysed and sorted out to identify a rate of response of the interviewees as a percentage. 12 out of 20 respondents, i.e 60% of the total respondents, have selected as the cut-off point. Table 5.9 demonstrates the rate of responses at or exceeding 60% in implementing LTs in different stages.

Table 5.9: Rate of Response at or above 60% (on or above 12 out of 20)

Ref	Lean Techniques	Summary of Data Project Deliery Stages					Implementation of LT in different			
		1	2	3	4	N /A	1	2	3	4
LT01	Last Planner System	7	10	11	20	0				LT01
LT02	Just in Time	0	0	16	20	0			LT02	LT02
LT03	3D Modelling	6	20	16	14	0		LT03	LT03	LT03
LT04	Visualization	0	14	14	19	0		LT04	LT04	LT04
LT05	BIM	11	13	15	15	4		LT05	LT05	LT05
LT06	Value Stream Mapping	6	6	16	16	4			LT07	LT07
LT07	Reverse Phase schedulling	4	15	20	20	0		LT09	LT09	LT09
LT08	Prefabrication / Off site manufact	0	20	16	20	0		LT10	LT10	LT10
LT09	Kaizen / Continiuos improvement	11	19	20	20	0		LT11	LT11	LT11
LT10	Five S	14	18	20	20	0	LT12	LT12	LT12	LT12
LT11	Faile Safe Quality / Poka-yoke	4	14	15	20	0		LT13	LT13	LT13
LT12	Target Value Design	18.	20	4	4	1	LT14	LT14		
LT13	First Run Studies	4	4	0	16	0			LT15	LT15
LT14	Relational Contracting	5	16	14	14	4		LT17	LT18	LT19
LT15	Target Costing	14	20	20	20	0	LT18	LT18	LT18	LT18
LT16	Set based Design	0	9	10	9	4				
LT17	Kanban (Material Card)	0	0	5	17	5				LT22
LT18	Total Quality Management	6	13	15	20	0		LT24	LT24	LT24
LT19	Work standardization	12	19	20	20	0		LT28	LT28	LT28
LT20	Work structuring	1	20	20	20	0		LT42	LT42	LT42
							3	14	16	18

The above Table highlights the responses received from 12 or more of 20 of the interviewees and identifies the applicable LTs for each stage. For example, LT01 is most suitable for implementing in Stage 4 whereas LT12 and LT18 are most suitable for implementing in all of the four stages. Conversely, most of the LTs can be implemented in Stages 2, 3 and 4 whereas LT02, LT07 and LT15 can be implemented only in Stages 3 and 4. Three of the LTs can be implemented in Stage 1, fourteen in Stage 2, sixteen in Stage 3 and eighteen in Stage 4. Moreover, it was revealed that LT21 (Set based design - working with alternatives) has to be eliminated from the selected list as the rate of response for it was less than 60% in each of the stages. All of the nineteen remaining LTs were considered in the next stage of the study.

5.5.4 Guidelines for lean implementation

Guidelines stated in Table 5.10 shows the priority order has been changed after the survey results.

Table 5.10: Findings of the Guidelines to implement lean techniques

Ref	**Guidelines based on literature review**	**Priority of guidelines based on Survey C**
G1	Select partners or suppliers who are willing and able to adopt lean project delivery	Select partners or suppliers who are willing and able to adopt lean project delivery
G2	Structure the project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best project – level return	Do target costing: define and align project scope, budget and schedule to deliver value to customers and stakeholders
G3	Do target costing: define and align project scope, budget and schedule to deliver value to customers and stakeholders	Use 3D modelling to integrate product and process design
G4	Encourage thoughtful experimentation; explore adaptation and development of methods for perusing the lean ideal	Implement Just In Time and other multi organizational processes
G5	Recognise breakdowns as opportunities for learning rather than occasions for punishing the guilty	Structure the project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best return at project – level
G6	Do set based design: make design decisions at the last responsible moment, with explicit generation of alternatives, and document evaluation of those alternatives against stated criteria	Recognise breakdowns as opportunities for learning rather than occasions for punishing the guilty
G7	Practice production control in accordance with lean principles such as making work flow to be predictable and using pull system to avoid over production	Build quality and safety in to the projects by placing primary reliance on preventing breakdowns

Ref	Guidelines based on literature review	Priority of guidelines based on Survey C
G8	Build quality and safety in to the projects by placing primary reliance on preventing breakdowns	Practice production control in accordance with lean principles such as making work flow to be predictable and using pull system to avoid over production
G9	Implement Just In Time and other multi organizational processes	Encourage thoughtful experimentation; explore adaptation and development of methods for perusing the lean ideal
G10	Use 3D modelling to integrate product and process design	Do set based design: make design decisions at the last responsible moment, with explicit generation of alternatives, and document the evaluation of those alternatives against stated criteria

5.5.5 Benefits and challenges of lean implementation

5.5.5.1 Introduction

Having identified the relationships between lean techniques and non-value adding activities (see Section 5.5.2), the implementation of lean techniques was discussed in Section 5.5.3. As the next step of this study, it is necessary to identify the benefits which can be obtained in implementing lean techniques and the associated challenges of implementing lean techniques in construction processes. Therefore the next Section discusses the benefits and challenges of implementing lean techniques based on the findings of Survey C.

5.5.5.2 Benefits of implementing lean techniques

The general benefits of applying lean principles in construction processes are stated in Table 3.4 of the Section on literature review. These benefits were mentioned to the interviewees and the subsequent responses obtained from them are indicated in Figure 5.15. All benefits identified through literature review were accepted and no additional benefits could be identified through this survey.

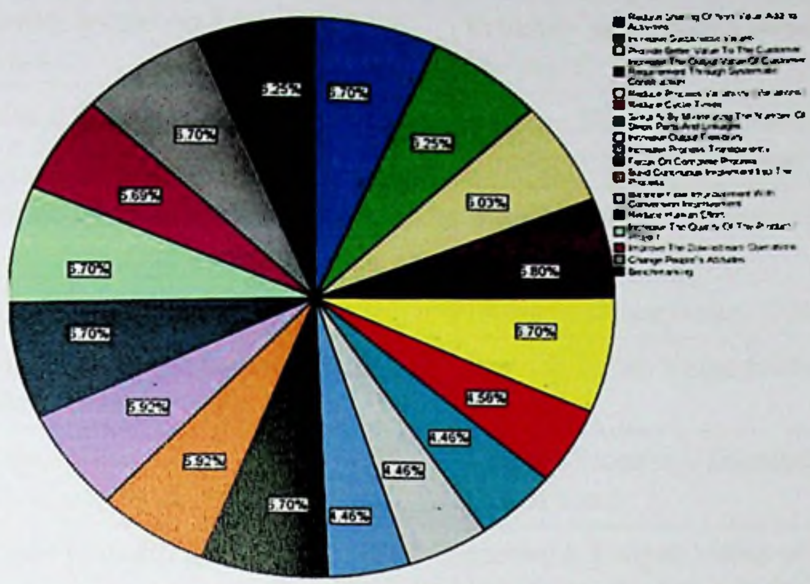


Figure 5.15: Benefits of implementing lean techniques

According to the graph given above, all of the benefits were identified by the interviewees with almost same weightage and it is therefore difficult to establish a priority order. All of the interviewees agreed with the indicated list of benefits and Table 5.10 shows the results.

Table 5.11: Findings of Benefits in implementing lean techniques

Ref	Benefits based on Literature Review	Priority of Benefits based on Survey C
B1	Reduce sharing of Non-Value Adding Activities	Reduce sharing of Non-Value Adding Activities
B2	Increase Sustainable Values	Reduce Human Effort
B3	Provide better Value to the Customer	Increase Quality of the Product / Project
B4	Increase the Output Value of Customer Requirements through Systematic Construction	Change people's Attitudes
B5	Reduce Process Variability (Variations)	Focus on the Complete Process
B6	Reduce Cycle Times	Benchmarking
B7	Simplify by minimizing the number of Steps, Parts and Linkages	Increase Sustainable Values

Ref	Benefits based on Literature Review	Priority of Benefits based on Survey C
B8	Increase Output Flexibility	Balance Flow Improvement with Conversion Improvement
B9	Increase Process Transparency	Build Continuous Improvement in to the Process
B10	Focus on the Complete Process	Improve Downstream Operations
B11	Build Continuous Improvement in to the Process	Provide better Value to the Customer
B12	Balance Flow Improvement with Conversion Improvement	Reduce Process Variability (Variations)
B13	Reduce Human Effort	Increase Output Value of Customer Requirements through Systematic Construction
B14	Increase Quality of the Product / Project	Increase Process Transparency
B15	Improve Downstream Operations	Increase Output Flexibility
B16	Change people's Attitudes	Simplify by minimizing the number of Steps, Parts and Linkages
B17	Benchmarking	Reduce Cycle Times

5.5.5.3 Challenges of implementing lean techniques in Sri Lanka

Extant literature indicates the challenges (see Section 2.7.3) of implementing lean techniques and a separate section of the interview guide line (see Section 3.5 in Annex 3) is about the challenges of implementing lean techniques in the construction industry in Sri Lanka. The respondents identified associated challenges of implementing lean techniques and Figure 5.16 shows the findings about the challenges.

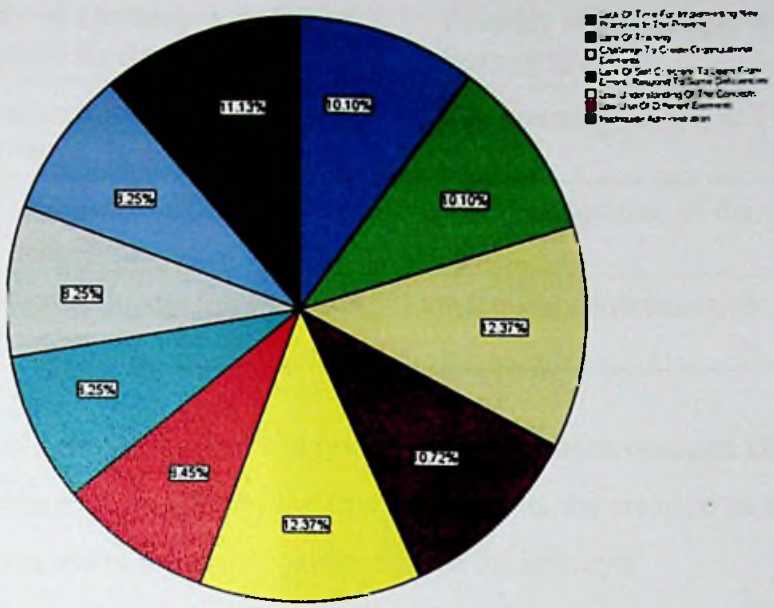


Figure 5.16: Challenges for lean implementation

Though the interviewees were questioned on any other challenges which were outside what was indicated in the given list, no new challenges were recognized through this survey. According to the above graph, challenges can be prioritized (see Table 5.11) based on the responses of the interviewees.

Table 5.12: Findings on challenges

Ref	**Priority of challenges based on Literature Review**	**Priority of challenges based on Survey C**
C1	Lack of time for implementing new practices in the projects	Creation of organizational elements
C2	Lack of training	Low understanding of the concepts
C3	Creation of organizational elements	Negative Attitude on implementing new practices
C4	Lack of self-criticism to learn from errors, and respond to deficiencies	Lack of self-criticism to learn from errors and respond to deficiencies
C5	Low understanding of the concepts	Lack of training
C6	Low use of different elements	Lack of time for implementing new practices in the projects
C7	Inadequate administration	Low use of different elements

Ref	Priority of challenges based on Literature Review	Priority of challenges based on Survey C
C8	Weak communication and transparency	Weak communication and transparency
C9	Lack of integration of the construction chain	Lack of integration of the construction chain
C10	Negative attitude on implementing new practices	Inadequate administration

The above Table shows the way the priority order has been changed after the survey results. According to the survey, the first challenge is the creation of organizational elements and second is the low understanding of the concepts

5.5.6 Suggestions to overcome the challenges of implementing lean techniques in Sri Lanka

Having identified the challenges of implementing lean techniques, it was necessary to identify suggestions to overcome those challenges of implementing lean techniques. Section 6 of the interview guideline (see Annex 3) discusses the suggestions offered by various authors in the literature (see Section 2.7.4). Figure 5.17 illustrates the responses of the interviewees.

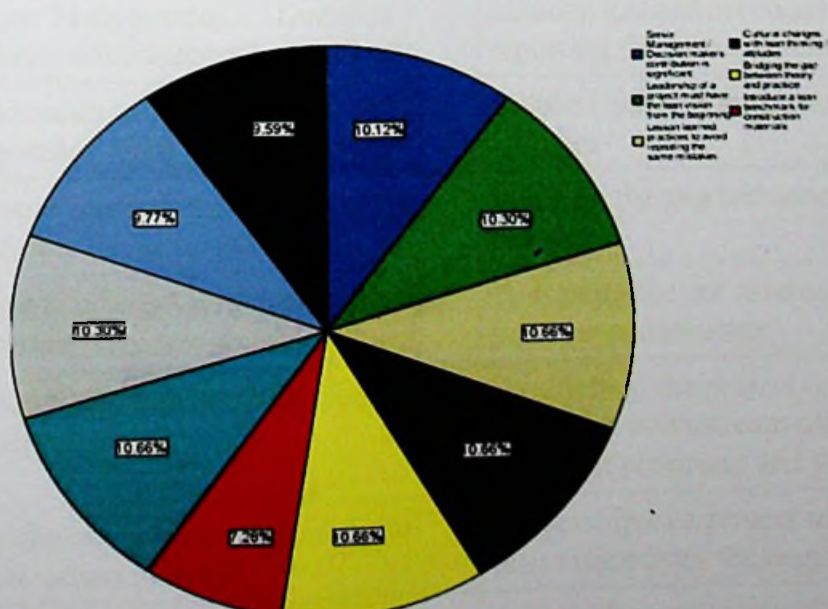


Figure 5.17: Suggestions to overcome challenges

The above Figure shows that almost same weightage is given for each suggestion offered in the interview guideline except S7 which is about increasing the preassembly of building components. All respondents agreed with the list of suggestions and INT1 and INT 12 have suggested that lean implementation be introduced as a prequalification criteria to encourage the implementation of lean to minimize NVAAs to save money and INT7, INT8 and INT 23 have suggested that it is worth to publish a manual for lean implementation as a guideline to the contractors for solving the identified challenges. Further INT 17, INT 26, INT 30 have suggested that professional institutions can organizing awareness programs for the professionals and that an evaluation should be carried out at the end of each project to assess its lean maturity so that there could be better implementation of lean techniques in future projects overcoming the challenges. Table 5.13 shows the suggestions offered in the literature review (see Section 2.7.4) against the suggestions recognized from Survey C.

Table 5.13: Findings of suggestion to overcome the challenges

Ref	Priority of suggestions made to overcome the challenges identified from Literature Review	Priority of suggestions made to overcome the challenges identified through Survey C
S1	Senior Management's / Decision makers' contribution is significant	Lessons learned practices to avoid repeating the same mistakes
S2	Leadership of a project must have the lean vision from the beginning	Cultural changes with lean thinking / attitudes
S3	Lessons learned practices to avoid repeating the same mistakes	Bridging the gap between theory and practice
S4	Cultural changes with lean thinking / attitudes	Increasing the pre assembling of building components
S5	Bridging the gap between theory and practice	Structuring the project organization to engage downstream players in upstream processes and vice-versa
S6	Introducing a lean benchmark for construction material	Leadership of a project must have the lean vision from the beginning
S7	Increasing the pre assembling of building components	Senior Management's / Decision makers' contribution is significant

Ref	Priority of suggestions made to overcome the challenges identified from Literature Review	Priority of suggestions made to overcome the challenges identified through Survey C
S8	Structuring the project organization to engage downstream players in upstream processes and vice-versa	Working with alternatives
S9	Working with alternatives	Introducing a lean benchmark for construction material
S10		Lean implementation can be introduced as a pre-qualification criteria
S11		publish a manual for lean implementation as a guide line to the contractor
S12		Professional institution can take a part of organizing awareness program for the professionals
S13		The project should be reviewed at the end of the project to assess the maturity in lean in order to improve the implementation of lean techniques in future projects

The suggestions S10 to S13 were identified from Survey C

5.5.7 Summary for Survey C

The main objective of the Survey C was to map lean techniques against NVAAs and it was found that there is a many-to-many relationship among them. There is a strong relationship between lean techniques and NVAAs and it was revealed through the survey that lean techniques can be applied to minimize non-value adding activities in construction processes. This survey also revealed the benefits of implementing lean techniques and identified the challenges of implementing lean techniques. Furthermore, suggestions were also made to overcome the challenges identified.

5.6 Summary

This Chapter presented the findings from Surveys A, B and C carried out to achieve the objectives of this study. Survey A revealed that all NVAA examples identified through literature review are acceptable to the construction industry in Sri Lanka and that these non-value adding activities exist considerably in the construction processes. The most critical NVAAs in the construction industry in Sri Lanka were also identified. The current level of implementing lean techniques was investigated through Survey B and it was revealed that lean techniques are implemented at a significantly low level in the construction industry in Sri Lanka. The primary objective of Survey C was to find out the relationships between lean techniques and NVAAs along with the applicability of implementing these techniques in different stages of the construction processes and the secondary objective was to recognize the benefits and challenges of and suggestions to implementing lean techniques in the construction processes. 'Many-to-many' relationships among lean techniques and NVAAs were identified and it was revealed that NVVAs can be minimized by implementing lean techniques. Benefits and challenges identified through the literature review were accepted though this survey and four new suggestions were obtained as an outcome of the survey. The next Chapter discusses the development of a tool for assessing lean maturity of a project based on the findings of the three surveys towards achieving the 4th objective of this study.

Chapter – 6

Tool for Assessing Lean Maturity

CHAPTER 6

6.0 TOOL FOR ASSESSING LEAN MATURITY OF CONSTRUCTION PROJECTS

6.1 Introduction

The 4th objective of achieving the aim of this study was to propose a tool for assessing the lean maturity of a construction project by developing a framework for minimizing non value adding activities using lean techniques. Research findings show that there is a strong relationship between non value adding activities and lean techniques. Further this research presents a framework for minimizing non value adding activities using lean techniques as given in Section 9. Hence it is important to discuss the implementation of lean techniques in construction processes since processes can become lean when non value adding activities are minimized. Therefore, a tool was designed to assess the lean maturity of a construction project covering all of its stages from the initial stage to its completion. The purpose of this tool is to measure the extent of application of lean techniques in different stages of construction processes and then assess the lean maturity of that particular project.

6.2 Development of the tool for assessing the lean maturity of a construction project

6.2.1 Step 1: Identifying suitable lean techniques

Lean techniques were identified through literature review and they were combined into 20 techniques as described in Section 3.4. Survey B was carried out among members of the construction industry in Sri Lanka as explained in Section 5.4 and it was revealed that these lean techniques are being implemented at a low level. Survey C conducted via interviews revealed that one of the techniques listed among the 20 techniques finally identified is not suitable to minimize non value adding activities and that the balance 19 techniques can be implemented to minimize the non-value adding activities in construction processes. Therefore, the proposed tool was designed using only these 19 lean techniques.

6.2.2 Step 2: Identifying the different stages of a construction project

According to the RIBA plan of work, all construction processes can be categorized in to several stages and the stages selected for this study are (i) Preparation stage, (ii) Design stage, (iii) Pre-construction stage, and (iv) Construction stage

6.2.3 Step 3: Assessing the Weighted Average of Lean Techniques

The weighted average of each lean technique was calculated using the data obtained through Survey C and through interviews and these weighted averages are presented in Table 6.1. It was revealed from the survey that certain lean techniques can be applied in several stages and Table 6.2 illustrates the application of lean techniques in different stages. The weighted average calculated for each lean technique was then distributed among the stages and Table 10.3 shows the weighted average allocated for each lean technique in each stage of a construction project.

As the next step of the data analysis, weighted averages of all 19 lean techniques were calculated based on the data collected and these averages are presented in Table 6.1.

Table 6.1: Weighted averages of LTs

Survey C	LT01	LT02	LT03	LT04	LT05	LT06	LT07	LT08	LT09	LT10	LT11	LT12	LT13	LT14	LT15	LT16	LT17	LT18	LT19	LT20
Interviewee 1	15	9	3	10			4	9	5	8	4		4		7			10	8	10
Interviewee 2	12	12	4	9	15	12	5	5	2	9	4	2	4	6	2	9	3	8	14	5
Interviewee 3	15	9	3	10			4	9	5	8	4		4		7			10	8	10
Interviewee 4	15	9	3	10			4	9	5	8	4		4		7			10	8	10
Interviewee 5	13	8	3	10	3	4	4	8	5	8	3		4		7			9	8	9
Interviewee 6	12	12	4	9	15	12	5	5·	2	6	4	2	4	6	2	5	3	8	6	5
Interviewee 7	15	9	3	10			4	9	5	8	4		4		7			10	8	10
Interviewee 8	13	7	10	11	13	11	9	11	12	10	7	1	10	11	10	10	4	14	13	9
Interviewee 9	13	7	10	11	13	10	9	11	12	5	7	2	10	10	10	10	4	14	13	8
Interviewee 10	13	7	10	11	13	10	9	10	12	9	7	3	10	11	10	10	4	14	11	9
Interviewee 11	15	9	3	10			4	9	5	8	4		4		7			10	8	10
Interviewee 12	13	7	10	11	13	11	9	11	12	13	7	1	10	10	9	10	3	14	13	9
Interviewee 13	13	7	10	11	13	11	9	11	12	10	7	1	10	11	10	10	4	14	13	9
Interviewee 14	13	7	10	11	13	11	9	11	12	14	7	2	10	11	10	10	4	14	13	9
Interviewee 15	15	9	3	10			4	9	5	8	4		4		7			10	8	10
Interviewee 16	14	7	10	11	13	11	9	11	12	14	7	1	10	11	10	10	4	14	13	9
Interviewee 17	12	7	10	11	13	11	9	11	12	14	7	1	10	11	10	10	4	14	12	9
Interviewee 18	14	12	4	9	15	12	5	9	2	13	4	2	4	6	2	5	3	8	12	5
Interviewee 19	12	12	4	9	15	12	5	5	2	12	4	2	4	6	2	5	3	8	15	5
Interviewee 20	12	12	4	9	15	12	5	5	2	6	4	2	4	6	2	5	3	8	6	5
Mean	13.45	8.9	6.05	10.15	9.1	7.5	6.25	8.9	7.05	9.55	5.15	1.1	6.4	5.8	6.9	5.45	2.3	11.05	10.5	8.25
Total	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4	144.4
Weighted Average	0.093	0.062	0.042	0.07	0.063	0.052	0.043	0.062	0.049	0.066	0.036	0.008	0.044	0.04	0.048	0.038	0.016	0.077	0.073	0.057

The above results reveal that there is a relationship between lean techniques and NVAAs. LT01, LT 02, LT04, LT12, LT24 and LT28 show a strong relationship with a strong weightage when implementing them to minimize NVAAs whereas LT14 with a weighted average of 0.008 and LT22 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.

Table 6.2: Weighted averages for lean techniques in each stage based on findings

Implementation of Lean Techniques in different stages			Weighted Average	Implementation of LT in different stages				No of stages	Weighted Average for each stage
				1	2	3	4		
1	LT01	Last Planner System	0.093				LT01	1	0.093
2	LT18	Total Quality Management	0.077			LT02	LT02	2	0.038
3	LT19	Work standardization	0.073		LT03	LT03	LT03	3	0.024
4	LT04	Visualization	0.070		LT04	LT04	LT04	3	0.023
5	LT10	Five S	0.066		LT05	LT05	LT05	3	0.022
6	LT05	BIM	0.063			LT07	LT07	2	0.032
7	LT02	Just in Time	0.062		LT09	LT09	LT09	3	0.021
8	LT08	Prefabrication / Off site manufacturing	0.062		LT10	LT10	LT10	3	0.021
9	LT20	Work structuring	0.057		LT11	LT11	LT11	3	0.019
10	LT06	Value Stream Mapping	0.052	LT12	LT12	LT12	LT12	4	0.013
11	LT09	Kaizen / Continiuos improvement	0.049		LT13	LT13	LT13	3	0.016
12	LT15	Target Costing	0.048	LT14	LT14			2	0.024
13	LT13	First Run Studies	0.044			LT15	LT15	2	0.022
14	LT07	Reverse Phase schedulling	0.043		LT17	LT18	LT19	3	0.014
15	LT03	3D Modelling	0.042	LT18	LT18	LT18	LT18	4	0.010
16	LT14	Relational Contracting	0.040				LT22	1	0.040
17	LT11	Faile Safe Quality / Poka-yoke	0.036		LT24	LT24	LT24	3	0.012
18	LT17	Kanban (Material Card)	0.016		LT28	LT28	LT28	3	0.005
19	LT12	Target Value Design	0.008		LT42	LT42	LT42	3	0.003

6.2.4 Step 4: Using the Capability Maturity Model (CMM)

The Capability Maturity Model (CMM) conceived by Watts Humphrey, is a process capability maturity model which 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. CMM provides specific steps and activities to move from one level to the next level. Maturity gained by a construction project through lean implementations could be assessed using CMM. Table 6.3 describes the five steps of the CMM.

Table 6.3 Capability Maturity Model

Stage	Name of the Stage	Description
1	Initial	Processes are ad-hoc and chaotic or only a few processes are actually defined
2	Repeatable	Basic processes have been established and there is a level of discipline to stick to these processes
3	Defined	All processes are defined, documented, standardized and integrated into each other
4	Managed	Processes are measured by collecting detailed data on the processes and their quality
5	Optimizing	Continuous process improvement is adopted through quantitative feedback and piloting new ideas and technologies

The model described above was used to prepare a tool for assessing the lean maturity of a construction project and a scoring system was defined as 1, 2, 3, 4 and 5 for each stage.

6.3. Tool developed to assess the lean maturity of a construction project

			Level of Implementation of Lean Techniques				
			Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
Lean Techniques implemented in Construction Project Delivery System			Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
Stage 1: Preparation	1	**Five S** : Standard approach to housekeeping	82.50	66.000	49.500	33.000	16.500
	2	**Target Value Design** : Assures customers get what they need	20.00	16.000	12.000	8.000	4.000
	3	**Target Costing** : Assures the target within the established cost	60.00	48.000	36.000	24.000	12.000
Stage 2 : Design	1	**3D Modeling** : computerized 3D design system or physical model to provide better, faster information of components and interfaces	70.00	56.000	42.000	28.000	14.000
	2	**Visualization** :communicating key information effectively to the workforce through posting various signs and labels around the construction site	116.67	93.333	70.000	46.667	23.333
	3	**BIM** :Building Information Modeling, digital representation of physical and functional characteristics of a building	105.00	84.000	63.000	42.000	21.000
	4	**Reverse Phase scheduling** : a schedule that works backwards from the completion date	71.67	57.333	43.000	28.667	14.333
	5	**Prefabrication** / Off site manufacturing : 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	103.33	82.667	62.000	41.333	20.667
	6	**Kaizen** / Continuous improvement : "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes	81.67	65.333	49.000	32.667	16.333
	7	**Five S** : standard approach to housekeeping	82.50	66.000	49.500	33.000	16.500
	8	**Fail Safe Quality** / Poka-yoke : generation of ideas that alert for potential defects	60.00	48.000	36.000	24.000	12.000
	9	**Target Value Design** : method that assures customers get what they need	20.00	16.000	12.000	8.000	4.000
	10	**Relational Contracting**: is characterized by a view of contracts as relations based on trust between parties rather than as discrete transactions	66.67	53.333	40.000	26.667	13.333
	11	**Target Costing** : Assures the target within the established cost	60.00	48.000	36.000	24.000	12.000
	12	**Total Quality Management** : combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices	128.33	102.667	77.000	51.333	25.667
	13	**Work standardization** : documenting the current best practice	121.67	97.333	73.000	48.667	24.333
	14	**Work structuring** : the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources	95.00	76.000	57.000	38.000	19.000
Stage 3 : Pre-construction	1	**Just In Time** : inventories are kept to the bare minimum and new inventories are ordered based on the current demand	155.00	124.000	93.000	62.000	31.000
	2	**3D Modeling** : computerized 3D design system or physical model to provide better, faster information of components and interfaces	70.00	56.000	42.000	28.000	14.000

Lean Techniques implemented in Construction Project Delivery System			Level of Implementation of Lean Techniques				
			Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
			Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
	3	**Visualization** :communicating key information effectively to the workforce through posting various signs and labels around the construction site	116.67	93.333	70.000	46.667	23.333
	4	**BIM** :Building Information Modeling, digital representation of physical and functional characteristics of a building	105.00	84.000	63.000	42.000	21.000
	5	**Value Stream Mapping** : Process Flow Charts that identify what action releases work to the next operation.	130.00	104.000	78.000	52.000	26.000
	6	**Reverse Phase scheduling** : a schedule that works backwards from the completion date	71.67	57.333	43.000	28.667	14.333
	7	**Prefabrication** / Off site manufacturing : 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	103.33	82.667	62.000	41.333	20.667
	8	**Kaizen** / Continuous improvement : "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes	81.67	65.333	49.000	32.667	16.333
	9	**Five S** : Standard approach to housekeeping	82.50	66.000	49.500	33.000	16.500
	10	**Fail Safe Quality** / Poka-yoke : generation of ideas that alert for potential defects	60.00	48.000	36.000	24.000	12.000
	11	**First Run Studies:** video files, photos, or graphics to show the process or illustrate the work instruction	110.00	88.000	66.000	44.000	22.000
	12	**Relational Contracting:** is characterized by a view of contracts as relations based on trust between parties rather than as discrete transactions	66.67	53.333	40.000	26.667	13.333
	13	**Target Costing** : Assures the target within the established cost	60.00	48.000	36.000	24.000	12.000
	14	**Total Quality Management** : combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices	128.33	102.667	77.000	51.333	25.667
	15	**Work standardization** : documenting the current best practice	121.67	97.333	73.000	48.667	24.333
	16	**Work structuring** : the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources	95.00	76.000	57.000	38.000	19.000
Stage 4 - Construction	1	Last Planner System : Master Schedule, Phase Schedule, Look ahead plan, and Weekly plan	465.00	372.000	279.000	186.000	93.000
	2	Just in Time	155.00	124.000	93.000	62.000	31.000
	3	**3D Modeling** : computerized 3D design system or physical model to provide better, faster information of components and interfaces	70.00	56.000	42.000	28.000	14.000
	4	**Visualization** :communicating key information effectively to the workforce through posting various signs and labels around the construction site	116.67	93.333	70.000	46.667	23.333
	5	**BIM** :Building Information Modeling, digital representation of physical and functional characteristics of a building	105.00	84.000	63.000	42.000	21.000

		Level of Implementation of Lean Techniques				
		Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
Lean Techniques implemented in Construction Project Delivery System		Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
6	**Value Stream Mapping** : Process Flow Charts that identify what action releases work to the next operation.	130.00	104.000	78.000	52.000	26.000
7	**Reverse Phase scheduling** : a schedule that works backwards from the completion date	71.67	57.333	43.000	28.667	14.333
8	**Prefabrication** / Off site manufacturing : 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	103.33	82.667	62.000	41.333	20.667
9	**Kaizen** / Continuous improvement : "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes	81.67	65.333	49.000	32.667	16.333
10	**Five S** : Standard approach to housekeeping	82.50	66.000	49.500	33.000	16.500
11	**Fail Safe Quality** / Poka-yoke : generation of ideas that alert for potential defects	60.00	48.000	36.000	24.000	12.000
12	**First Run Studies:** video files, photos, or graphics to show the process or illustrate the work instruction	110.00	88.000	66.000	44.000	22.000
13	**Relational Contracting:** is characterized by a view of contracts as relations based on trust between parties rather than as discrete transactions	66.67	53.333	40.000	26.667	13.333
14	**Target Costing** : Assures the target within the established cost	60.00	48.000	36.000	24.000	12.000
15	**Kanban** : a card containing all the information required to be done on a product at each stage along its path to completion and which parts are needed at subsequent processes	80.00	64.000	48.000	32.000	16.000
16	**Total Quality Management** : combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices	128.33	102.667	77.000	51.333	25.667
17	**Work standardization** : documenting the current best practice	121.67	97.333	73.000	48.667	24.333
18	**Work structuring** : the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources	95.00	76.000	57.000	38.000	19.000
Total Score		5.00	4.00	3.00	2.00	1.00

6.4 Use of the Tool for Assessing the Lean Maturity of a Construction Project

The tool can be used to assess the lean maturity of a construction project by identifying the extent to which that particular project is lean. The tool contains a list of 19 lean techniques used in four different stages of a construction project delivery system. The Capability Maturity Model (CMM) was used to assess the lean maturity of a selected project. 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. Table 6.4 illustrates the steps of using the tool for assessing the lean maturity of a construction project.

Table 6.4 Steps of using the tool proposed

1	The user of the tool should select a construction project to assess its lean maturity
Step 2	Open the interface of the tool
Step 3	Go through each lean technique starting from the preparation stage (Stage 1) of the construction project
Step 4	Select the most suitable stage of the CMM model against the lean technique selected in a particular stage of the construction project
Step 5	Complete selecting each lean technique against the appropriate CMM stage
Step 6	Obtain the final score received for the selected project

6.5 Application of the Tool for Assessing the Lean Maturity of a Construction Project

The tool illustrated in section 6.3 was further developed to become a user friendly software application / web program as indicated below in Figure 6.1

Figure 6.1 Application of the tool for assessing lean maturity in a construction project

Tool for Assessing Lean Maturity in a Construction Project

			Level of Implementation of Lean Techniques				
			Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
Lean Techniques implemented in Construction Project Delivery System			Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
Stage 1: Preparation	1	**Five S** : Standard approach to housekeeping					
	2	Target Value Design : Assures customers get what they need					
	3	**Target Costing** : Assures the target within the established cost					
Stage 2 : Design	1	**3D Modeling** : computerized 3D design system or physical model to provide better, faster information of components and interfaces					
	2	**Visualization** :communicating key information effectively to the workforce through posting various signs and labels around the construction site					
	3	**BIM** :Building Information Modeling, digital representation of physical and functional characteristics of a building					
	4	**Reverse Phase scheduling** : a schedule that works backwards from the completion date					
	5	**Prefabrication** / Off site manufacturing : 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					
	6	**Kaizen** / Continuous improvement : "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes					
	7	**Five S** : standard approach to housekeeping					
	8	**Fail Safe Quality** / Poka-yoke : generation of ideas that alert for potential defects					
	9	**Target Value Design** : method that assures customers get what they need					
	10	**Relational Contracting:** is characterized by a view of contracts as relations based on trust between parties rather than as discrete transactions					
	11	**Target Costing** : Assures the target within the established cost					
	12	**Total Quality Management** : combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices					
	13	**Work standardization** : documenting the current best practice					
	14	**Work structuring** : the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources					

			Level of Implementation of Lean Techniques				
			Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
Lean Techniques Implemented in Construction Project Delivery System			Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
Stage 3 : Pre- construction	1	**Just in Time** : inventories are kept to the bare minimum and new inventories are ordered based on the current demand					
	2	**3D Modeling** : computerized 3D design system or physical model to provide better, faster information of components and interfaces					
	3	**Visualization** :communicating key information effectively to the workforce through posting various signs and labels around the construction site					
	4	**BIM** :Building Information Modeling, digital representation of physical and functional characteristics of a building					
	5	**Value Stream Mapping :** Process Flow Charts that identify what action releases work to the next operation.					
	6	**Reverse Phase scheduling** : a schedule that works backwards from the completion date					
	7	**Prefabrication** / Off site manufacturing : 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					
	8	**Kaizen** / Continuous improvement: "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes					
	9	**Five S** : Standard approach to housekeeping					
	10	**Fail Safe Quality** / Poka-yoke : generation of ideas that alert for potential defects					
	11	**First Run Studies:** video files, photos, or graphics to show the process or illustrate the work instruction					
	12	**Relational Contracting:** is characterized by a view of contracts as relations based on trust between parties rather than as discrete transactions					
	13	**Target Costing :** Assures the target within the established cost					
	14	**Total Quality Management** : combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices					
	15	**Work standardization :** documenting the current best practice					
	16	**Work structuring** : the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources					

Total

Score

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. Table 6.5 presents the data obtained using the tool in five construction projects which are all in the stage of being completed.

Table 6.5: Data on application of the tool to five different projects

Ref	Name of the Project	Score
1	Proposed housing scheme at Athurugiriya	2.55
2	Proposed office building complex in Colombo 08	2.76
3	Proposed apartment complex at Battaramulla	1.78
4	Proposed apartment complex at Rajagiriya	2.95
5	Proposed mix development for offices, shops and apartments in Colombo 08	3.05

The above data 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 compared the scores of the projects, project 5 is the most matured project in lean where project 3 is the least matured project in lean. Annex 4 illustrates the data collected from five projects.

6.6 Summary for Chapter 6

How the 4th objective of this study was achieved was discussed in this Chapter by presenting the details pertaining to the development of the tool. Firstly, the most suitable and widely used lean techniques were identified and then the implementation of these techniques in different stages was identified though Survey C. Further weighted averages were calculated based on the data collected through Survey C and a score was assigned to each of the techniques by combining with the Capability Maturity Model (CMM). An excel work sheet was developed as a tool and thereafter this tool was modified as a computer program that can assess the lean maturity of a construction project. Finally, the proposed tool was applied to five projects and data gathered was presented.

Chapter – 7

Framework for Lean Implementation

7.0 FRAMEWORK FOR LEAN IMPLEMENTATION

7.1 Introduction

The preceding Chapter presented the findings of Surveys A, B and C which respectively recognized the non-value adding activities in the construction processes in Sri Lanka, examined the current level of implementation of lean techniques in the construction industry in Sri Lanka, and explored the application of lean techniques in different stages of a construction project with their benefits, challenges and suggestions for improvement. This Chapter offers the details of development of the framework for implementing lean techniques which is based on the findings of these three surveys. The 1st objective of recognizing the non-value adding activities in construction processes, and the 2nd objective of examining lean implementation in construction processes have been already achieved as set out in the previous Chapters. The 3rd objective of this study is to map lean techniques with non-value adding activities in the construction processes in order to identify the lean implementation. 4th objective is to propose a tool for assessing lean maturity in a construction project. After achieving all four objectives, the next step of this study is to present this framework based on findings of the three surveys carried out (See Chapter 5). The framework is developed for use by professionals who manage construction processes so that the efficiency of construction activities from their inception to completion could be improved by implementing lean techniques to minimize wasteful non-value adding activities.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. Finally, the tool will assist to assess the lean maturity of a construction project.

7.2 Fundamentals of the framework

This Section of the report presents the fundamentals of the framework selected based on the main findings of the study as detailed in Chapter 5. These fundamentals are illustrated in Figure 7.1.

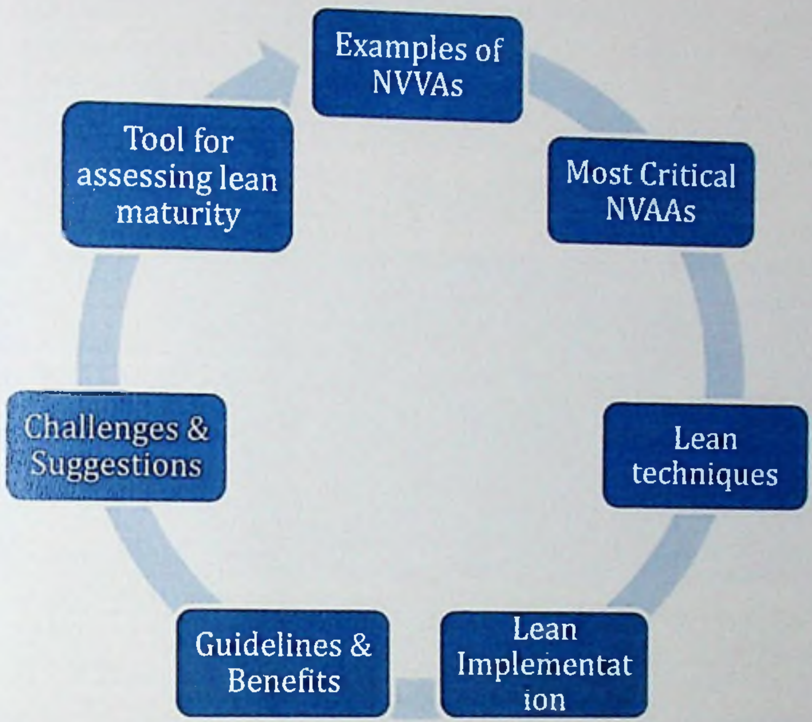


Figure 7.1: Fundamentals of the framework

7.2.1 Examples of NVAAs

Examples of NVAAs were identified from literature review (See Section 2.7) and from Survey A (See Section 5.2) and these examples are illustrated in Table 7.1.

Table 7.1: Examples of NVAAS

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

7.2.2 Most critical NVAAs

Findings of Survey A reveal (See Section 5.2.4) that the most critical NVAAs in the construction industry in Sri Lanka are among the examples of NVAAS identified through this study (See Figure 6.2). Table 7.2 presents the most critical NVAAs in the construction process in the construction industry in Sri Lanka.

Table 7.2: Most critical NVVAs in construction processes in Sri Lanka

Reference		Examples of Non Value Adding Activities
1	D01NA01	Repair Work
2	D02NA02	Design errors
3	D07NA07	Incomplete Installations
4	D08NA08	Rehandling materials
5	D09NA09	Damaged Materials on site
6	D10NA10	Poor material allocation
7	W01NA14	Delay to schedules
8	W02NA15	Waiting for Instructions
9	W03NA16	Waiting for equipment repair
10	W07NA20	Waiting (for people, material)
11	W08NA21	Activitiy Delay
12	W09NA22	Idle Time
13	M03NA25	Excessive labour movement
14	E03NA33	Retests
15	E04NA34	Excessive safety measures

Having identified the most critical NVAAs in construction processes, the next step of the study is to identify the approach to solve the problem, the existence of NVAAs in construction processes and Lean Implementation (See Section 2.3).

7.2.3 Lean Techniques

The widely used and most suitable lean techniques were identified (See Section 2.5.2) and these techniques were further examined though Survey B (See Section 5.3). Table 7.3 illustrates the list of lean techniques identified for lean implementation

Table 7.3: Lean techniques implemented in construction processes

LT01	Last Planner System
LT02	Just in Time
LT03	3D Modeling
LT04	Visualization
LT05	BIM
LT06	Value Stream Mapping
LT07	Reverse Phase scheduling
LT08	Prefabrication / Off site manufacturing
LT09	Kaizen / continuous improvement
LT10	Five S
LT11	Fail Safe Quality / Poka-yoke
LT12	Target Value Design
LT13	First Run Studies
LT14	Relational Contracting
LT15	Target Costing
LT16	Set based design
LT17	Kanban
LT18	Total Quality Management
LT19	Work standardization
LT20	Work structuring

7.2.4 Implementing Lean Techniques

The next fundamental of the framework is the implementation of lean techniques. Section 5.5.3 discussed the implementation of lean techniques in different stages of a construction project and Table 7.4 illustrates the implementation of lean techniques in different stages of a construction project.

Table 7.4: Implementation of lean techniques in different stages of a construction project

Ref		Lean Techniques	Implementation of LT in different			
			1	2	3	4
1	LT01	Last Planner System				LT01
2	LT02	Just in Time			LT02	LT02
3	LT03	3D Modelling		LT03	LT03	LT03
4	LT04	Visualization		LT04	LT04	LT04
5	LT05	BIM		LT05	LT05	LT05
6	LT07	Value Stream Mapping			LT07	LT07
7	LT09	Reverse Phase schedulling		LT09	LT09	LT09
8	LT10	Prefabrication / Off site manufacturing		LT10	LT10	LT10
9	LT11	Kaizen / Continiuos improvement		LT11	LT11	LT11
10	LT12	Five S	LT12	LT12	LT12	LT12
11	LT13	Faile Safe Quality / Poka-yoke		LT13	LT13	LT13
12	LT14	Target Value Design	LT14	LT14		
13	LT15	First Run Studies			LT15	LT15
14	LT17	Relational Contracting		LT17	LT18	LT19
15	LT18	Target Costing	LT18	LT18	LT18	LT18
16	LT21	Set based Design				
17	LT22	Kanban (Material Card)				LT22
18	LT24	Total Quality Management		LT24	LT24	LT24
19	LT28	Work standardization		LT28	LT28	LT28
20	LT42	Work structuring		LT42	LT42	LT42
Number of Techniques in each stage			3	14	16	18

7.2.5 Guidelines for lean implementation

Guidelines for lean implementation were identified through Survey C (See Section 5.4) and these guidelines are presented in Table 7.5

Table 7.5: Guidelines for lean implementation

Ref	Guidelines for Lean Implementation
G1	Select partners or suppliers who are willing and able to adopt lean project delivery
G2	Do target costing: define and align project scope, budget and schedule to deliver value to customers and stakeholders
G3	Use 3D modelling to integrate product and process design
G4	Implement Just In Time and other multi organizational processes
G5	Structure project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best returns at project – level
G6	Recognise breakdowns as opportunities for learning rather than occasions for punishing the guilty
G7	Build quality and safety in to projects by placing primary reliance on preventing breakdowns
G8	Practice production control in accordance with lean principles such as making work flow to be predictable and using pull system to avoid over production
G9	Encourage thoughtful experimentation, explore adaptation and development of methods for perusing the lean ideal
G10	Do set based design, make design decisions at the last responsible moment, with explicit generation of alternatives, and document evaluation of those alternatives against stated criteria

7.2.6 Benefits reaped from lean implementation

Survey C further revealed (See Section 5.4) that there are benefits in implementing lean techniques and these benefits are presented in Table 7.6.

Table 7.6: Benefits of lean implementation

Ref	Benefits in Lean Implementation
B1	Reduced sharing of Non-Value Adding Activities
B2	Reduced Human Effort
B3	Increased Quality of the Product / Project
B4	Change in people's Attitudes
B5	Focus on Complete Process
B6	Benchmarking
B7	Increased Sustainable Values
B8	Balance Flow Improvement with Conversion Improvement
B9	Continuous Improvement of the Process
B10	Improved Downstream Operations
B11	Better Value to the Customer
B12	Reduced Process Variability (Variations)
B13	Increased Output Value of Customer Requirements through Systematic Construction
B14	Increased Process Transparency
B15	Increased Output Flexibility
B16	Minimized number of Steps, Parts and Linkages
B17	Reduced Cycle Times

7.2.7 Challenges of lean implementation

The challenges shown in Table 7.7 were identified through Survey C (See Section 5.4) and these challenges form one of the fundamentals of the framework for lean implementation.

Table 7.7: Challenges of lean implementation

Ref	Priority of challenges based on Survey C
C1	Creation of organizational elements
C2	Low understanding of the concepts
C3	Negative Attitude to implement new practices
C4	Lack of self-criticism to learn from errors, respond to deficiencies
C5	Lack of training
C6	Lack of time for implementing new practices in the projects
C7	Low use of different elements
C8	Weak communication and transparency
C9	Lack of integration of the construction chain
C10	Inadequate administration

7.2.8 Suggestions to overcome the challenges of lean implementation

Having identified the guidelines, benefits and challenges of lean implementation, the suggestions to overcome the challenges were also identified finally through Survey C (Section 5.4) and these suggestions are presented in Table 7.8 below.

Table 7.8: Suggestions to overcome challenges of lean implementation

Ref	Suggestions to overcome the challenges
S1	Implementing lessons learned practices to avoid repeating the same mistakes
S2	Making cultural changes with lean thinking / attitudes
S3	Bridging the gap between theory and practice
S4	Increasing the pre assembling of building components
S5	Structuring the project organization to engage downstream players in upstream processes and vice-versa
S6	Leadership of a project to have the lean vision from the beginning
S7	Senior Management's / Decision makers' contribution to be significant
S8	Working with alternatives
S9	Introducing a lean benchmark for construction material

Ref	Suggestions to overcome the challenges
S10	Lean implementation can be introduced as a pre-qualification criteria
S11	publish a manual for lean implementation as a guide line to the contractor
S12	Professional institution can take a part of organizing awareness program for the professionals
S13	The project should be reviewed at the end of the project to assess the maturity in lean in order to improve the implementation of lean techniques in future projects

7.3 Framework for lean implementation

Fundamentals of the framework were identified in Section 5.2 and this Section presents the framework for lean implementation. Figure 7.2 illustrates the outline of the framework for implementing lean techniques to minimize NVVAs in construction processes.

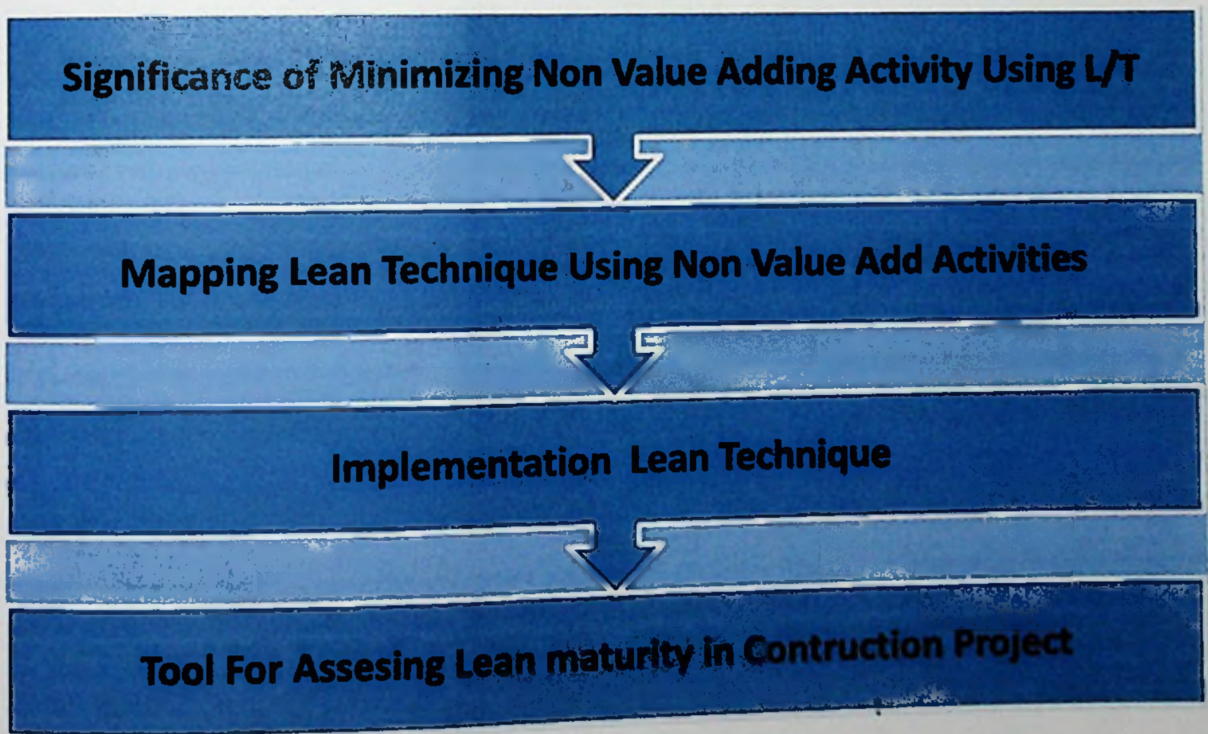
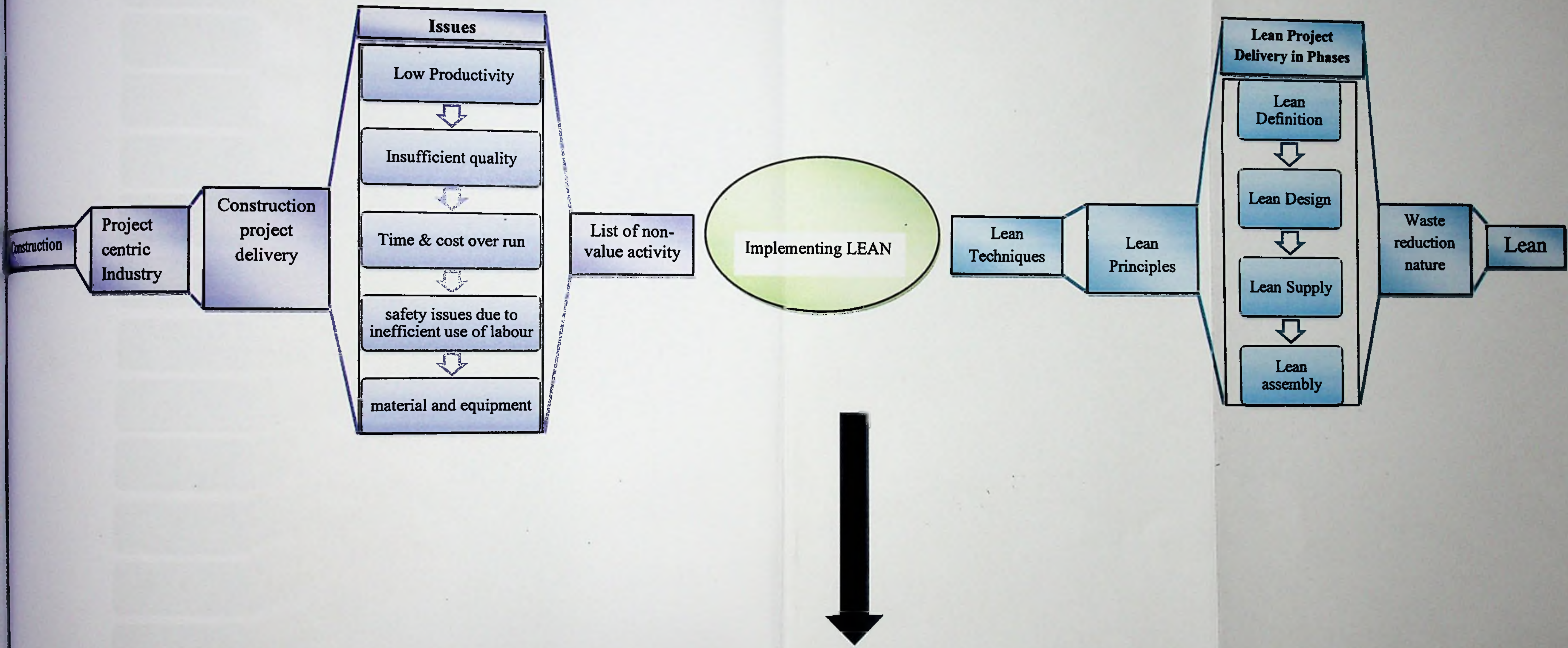


Figure 7.2: Outline of the Framework

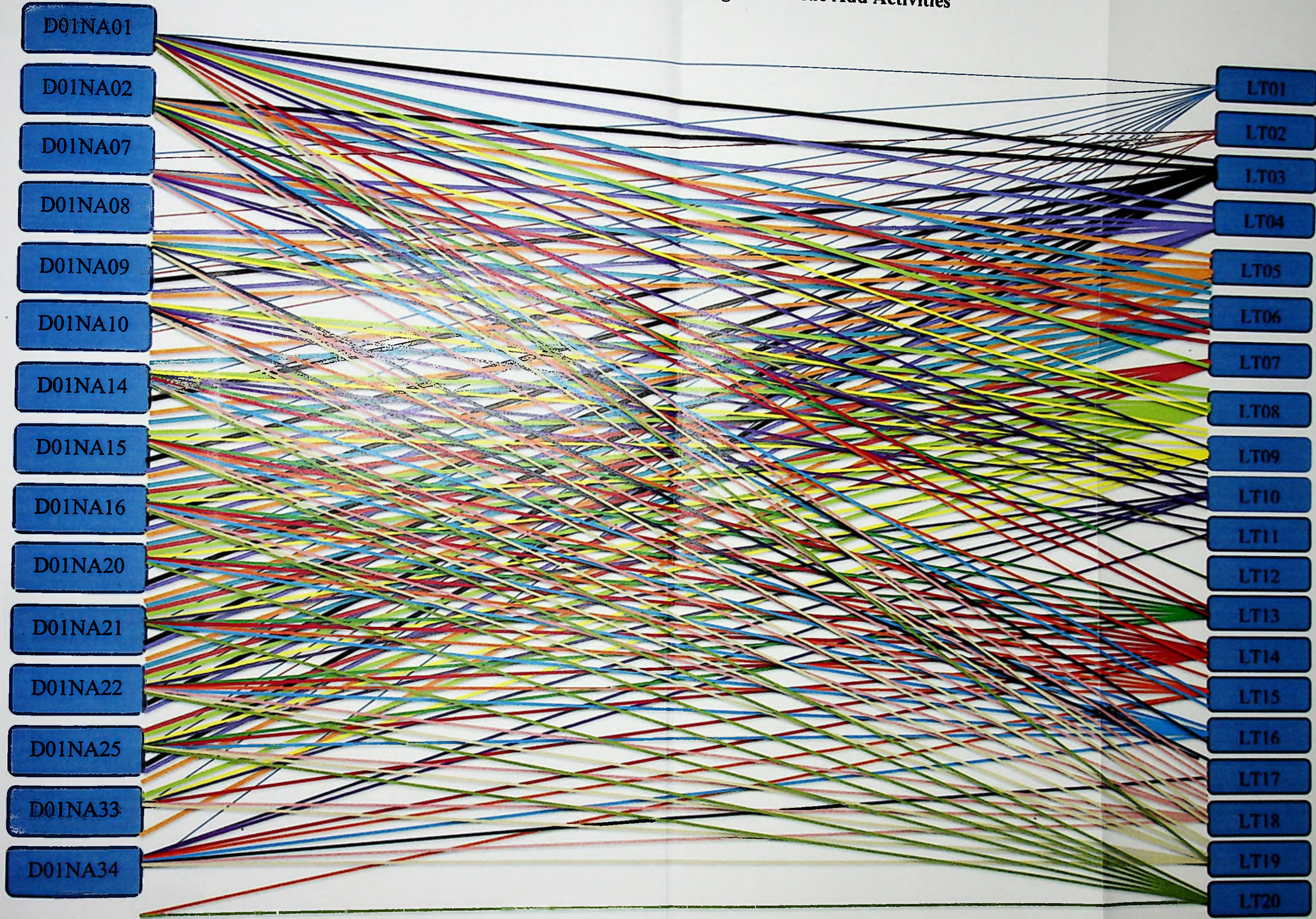
Significance of Minimizing Non Value Adding Activity Using L/T



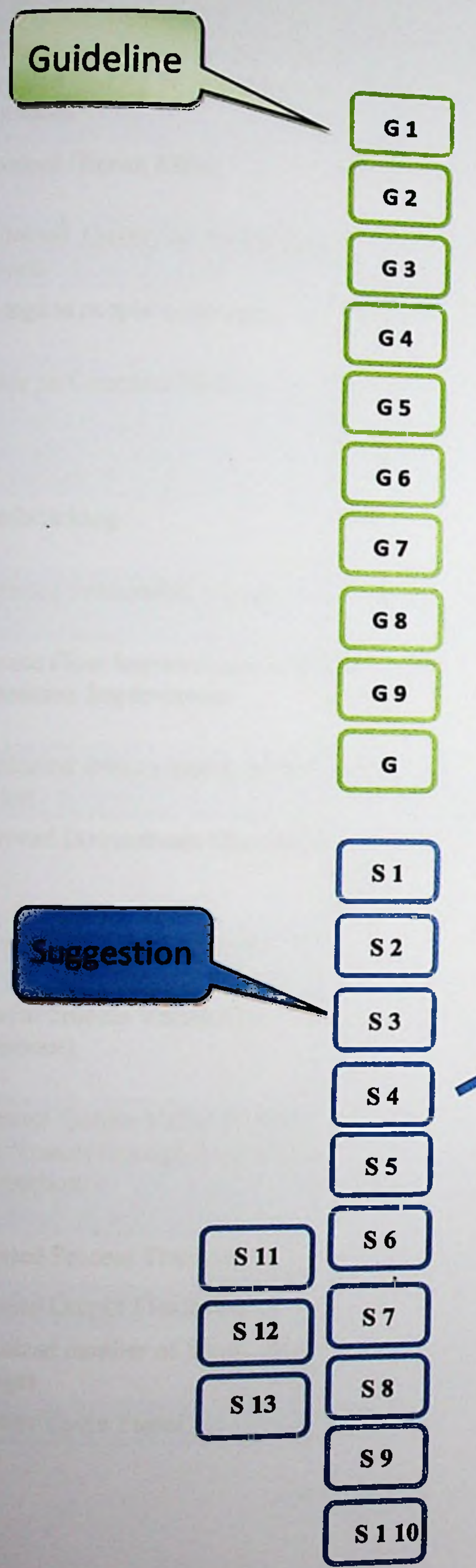
Mapping Lean Technique Using Non Value Add Activities

Figure 7.3: Framework for lean implementation

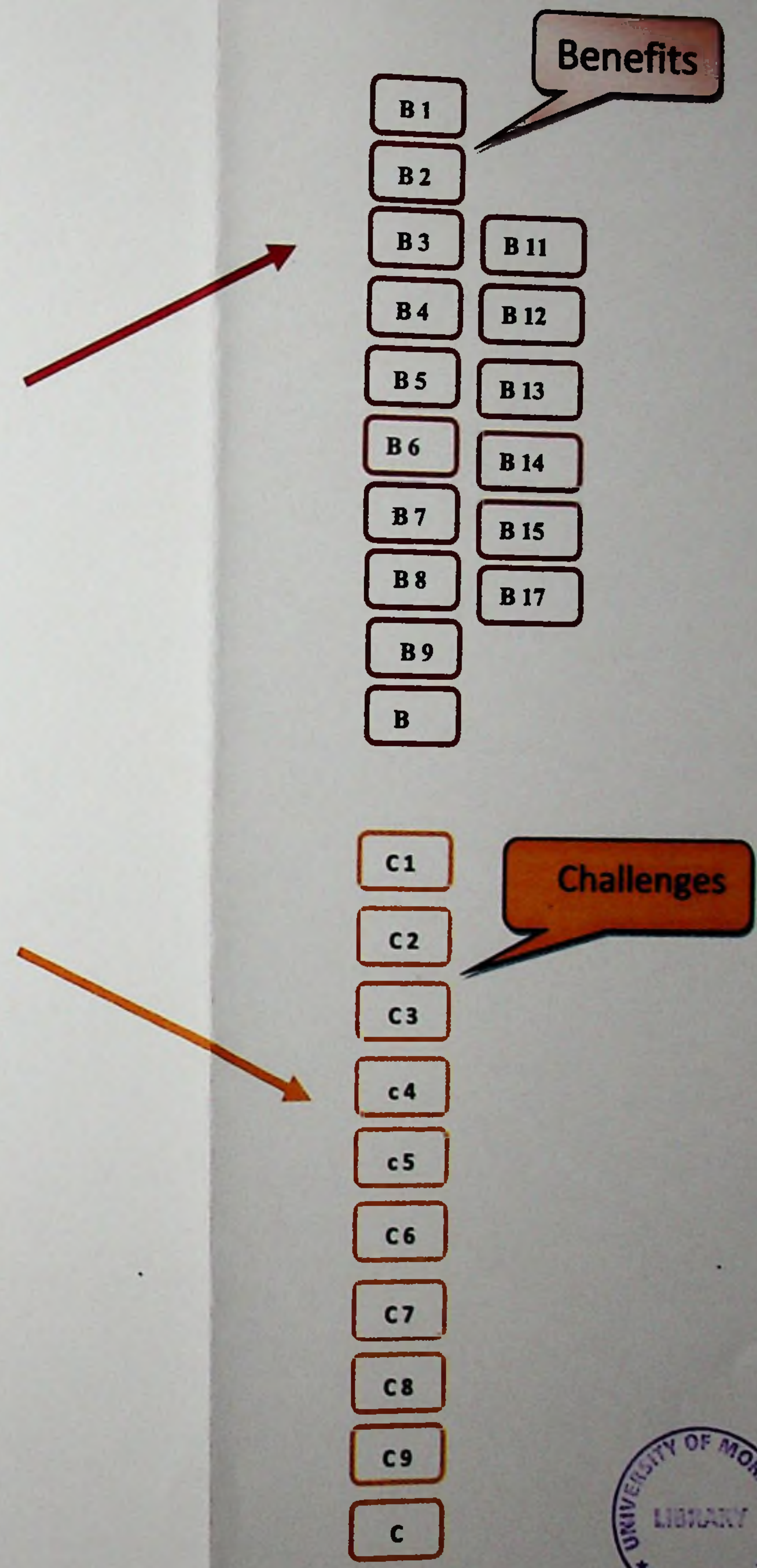
Mapping Lean Technique Using Non Value Add Activities



Implementing Lean Technique



Ref		Implementation of LT in different			
		1	2	3	4
1	LT01				LT01
2	LT02			LT02	LT02
3	LT03		LT03	LT03	LT03
4	LT04		LT04	LT04	LT04
5	LT05		LT05	LT05	LT05
6	LT07			LT07	LT07
7	LT09		LT09	LT09	LT09
8	LT10		LT10	LT10	LT10
9	LT11		LT11	LT11	LT11
10	LT12	LT12	LT12	LT12	LT12
11	LT13		LT13	LT13	LT13
12	LT14	LT14	LT14		
13	LT15			LT15	LT15
14	LT17		LT17	LT18	LT19
15	LT18	LT18	LT18	LT18	LT18
16	LT21				
17	LT22				LT22
18	LT24		LT24	LT24	LT24
19	LT28		LT28	LT28	LT28
20	LT42		LT42	LT42	LT42



Ref	Benefits in Lean Implementation	Ref	Suggestions to overcome the challenges	Ref	Guidelines for Lean Implementation	Ref	Priority of challenges based on Survey C
B1	Reduced sharing of Non-Value Adding Activities	S1	Implementing lessons learned practices to avoid repeating the same mistakes	G1	Select partners or suppliers who are willing and able to adopt lean project delivery	C1	Creation of organizational elements
B2	Reduced Human Effort	S2	Making cultural changes with lean thinking / attitudes	G2	Do target costing: define and align project scope, budget and schedule to deliver value to customers and stakeholders	C2	Low understanding of the concepts
B3	Increased Quality of the Product / Project	S3	Bridging the gap between theory and practice	G3	Use 3D modelling to integrate product and process design	C3	Negative Attitude to implement new practices
B4	Change in people's Attitudes	S4	Increasing the pre assembling of building components	G4	Implement Just In Time and other multi organizational processes	C4	Lack of self-criticism to learn from errors, respond to deficiencies
B5	Focus on Complete Process	S5	Structuring the project organization to engage downstream players in upstream processes and vice-versa	G5	Structure project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best returns at project – level	C5	Lack of training
B6	Benchmarking	S6	Leadership of a project to have the lean vision from the beginning	G6	Recognise breakdowns as opportunities for learning rather than occasions for punishing the guilty	C6	Lack of time for implementing new practices in the projects
B7	Increased Sustainable Values	S7	Senior Management's / Decision makers' contribution to be significant	G7	Build quality and safety in to projects by placing primary reliance on preventing breakdowns	C7	Low use of different elements
B8	Balance Flow Improvement with Conversion Improvement	S8	Working with alternatives	G8	Practice production control in accordance with lean principles such as making work flow to be predictable and using pull system to avoid over production	C8	Weak communication and transparency
B9	Continuous Improvement of the Process	S9	Introducing a lean benchmark for construction material	G9	Encourage thoughtful experimentation, explore adaptation and development of methods for perusing the lean ideal	C9	Lack of integration of the construction chain
B10	Improved Downstream Operations	S10	Lean implementation can be introduced as a pre-qualification criteria	G10	Do set based design, make design decisions at the last responsible moment, with explicit generation of alternatives, and document evaluation of those alternatives against stated criteria	C10	Inadequate administration
B11	Better Value to the Customer	S11	publish a manual for lean implementation as a guide line to the contractor				
B12	Reduced Process Variability (Variations)	S12	Professional institution can take a part of organizing awareness program for the professionals				
B13	Increased Output Value of Customer Requirements through Systematic Construction	S13	The project should be reviewed at the end of the project to assess the maturity in lean in order to improve the implementation of lean techniques in future projects				
B14	Increased Process Transparency						
B15	Increased Output Flexibility						
B16	Minimized number of Steps, Parts and Linkages						
B17	Reduced Cycle Times						

Tool for Assessing Lean Maturity in a Construction Project

			Level of Implementation of Lean Techniques				
			Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
Lean Techniques implemented in Construction Project Delivery System			Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
Stage 1: Preparation	1	Five S					
	2	Target Value Design					
	3	Target Costing					
Stage 2 : Design	1	3D Modeling					
	2	Visualization					
	3	BIM					
	4	Reverse Phase scheduling					
	5	Prefabrication					
	6	Kaizen					
	7	Five S					
	8	Faile Safe Quality					
	9	Target Value Design					
	10	Relational Contracting					
	11	Target Costing					
	12	Total Quality Management					
	13	Work standardization					
	14	Work structuring					
Stage 3 : Pre-construction	1	Just in Time					
	2	3D modeling					
	3	Visualization					
	4	BIM					
	5	Value Stream Mapping					
	6	Reverse Phase scheduling					
	7	Prefabrication					
	8	Kaizen					
	9	Five S					
	10	Faile Safe Quality					
	11	First Run Studies					
	12	Relational Contracting					
	13	Target Costing					
	14	Total Quality Management					
	15	Work standardization					
	16	Work structuring					

			Level of Implementation of Lean Techniques				
			Focus on process improvements	Processes measured and controlled	Processes characterized & proactive	Processes characterized & often reactive	Processes unpredictable poorly controlled
Lean Techniques implemented in Construction Project Delivery System			Optimization Level	Quantitatively Managed Level	Defined Level	Repeatable Level	Initial Level
Stage 4 - Construction	1	Last Planner System					
	2	Just in Time					
	3	3D Modeling					
	4	Visualization					
	5	BIM					
	6	Value Stream Mapping					
	7	Reverse Phase scheduling					
	8	Prefabrication					
	9	Kaizen / Continuous improvement					
	10	Five S					
	11	Fail Safe Quality / Poka-yoke :					
	12	First Run Studies					
	13	Relational Contracting					
	14	Target Costing					
	15	Kanban					
	16	Total Quality Management					
	17	Work standardization					
	18	Work structuring					
Total Score			5.00	4.00	3.00	2.00	1.00

7.4 Summary of Chapter 7

Chapter 7 focussed mainly on the development of a framework for implementing lean techniques to minimize NVAAs and on the tool proposed for assessing lean maturity of a construction project. Details were presented on each of the fundamentals of the framework developed through three surveys and the framework so developed was graphically presented as a guideline to the professionals working in the construction industry.This framework guides the industry professionals on how to implement lean techniques to minimize NVVAs in construction processes and achieve long term benefits by becoming lean. It is therefore hoped that the framework developed in this study would overcome any hindrance to performance and efficiency in construction activities.

Chapter – 8

Conclusion and Recommendations

8.0 CONCLUSIONS, RECOMMENDATIONS, LIMITATIONS AND FURTHER RESEARCH

8.1 Conclusion

Inefficiency and waste in construction processes are the main factors that adversely affect the performance of the construction activities and non-value adding activities have been identified as the main cause for this inefficiency and waste. Hence the research problem of this study was the existence of non-value adding activities in construction processes which have to be minimized to if their 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 non-value adding activities in the construction processes. Lean is an innovative construction management approach which is linked closely to the overall life of a project ensuring its success.

There are two types of activities in construction, i.e conversion activities which produce tangible outputs and flow activities which bind such conversion activities during the delivery process of those outputs. Lean principles state that only conversion activities add value and that therefore they need to be made more efficient whereas the non-value adding flow activities need to be reduced or eliminated altogether. By eliminating waste, processes can become 'lean' to provide 'more with less' resources. Research into lean principles has found that there is considerable waste in the flow processes of construction projects. This flow waste is recognized as a major weakness, which adversely affects the performance and the efficiency of the construction industry.

The background to this study indicates that the construction industry in Sri Lanka does not have a lean implementation framework that can minimize its non-value adding activities. Hence, the aim of this research was to develop a framework for the implementation of lean techniques so that non-value adding activities in construction processes could be minimized. Four main objectives were identified towards this end.

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 develop a conceptual framework by identifying the research problem which was the existence of non-value adding activities in construction processes. The research approach was the implementation of lean techniques that will solve the problem. A pilot survey was conducted to confirm the conceptual framework. The research methodology adopted for data collection for this study was the quantitative approach with three different surveys carried out through questionnaires given to industry professionals. The tool that was developed through the study was applied to five construction projects to make an assessment of their lean maturity. Finally, expert opinions were used to improve the framework developed based on the main findings of the research.

The first objective of this study was to recognize the non-value adding activities that exist in construction processes and this was achieved by using 49 examples identified though literature review and also identifying through Survey A examples for non-value adding activities in the construction industry in Sri Lanka. Findings of this survey revealed that non-value adding activities significantly exist in the construction processes in Sri Lanka. The most critical of these non-value adding activities were identified by prioritizing them based on the findings of this Survey. The 15 most critical non-value adding activities so identified were then considered for developing the framework for implementing lean techniques that can minimize non- value adding activities in construction processes. The research problem of this study was confirmed through this survey and the first objective was achieved by recognizing non value adding activities in the construction processes.

The second objective of this study was to examine the current level of implementing lean techniques in the construction industry in Sri Lanka. Firstly, a preliminary literature Survey was carried out to explore lean implementation in different construction settings , its benefits and the associated challenges. Thereafter the most widely used lean techniques were identified by critically reviewing extant literature and the resulting findings were further improved through an opinion survey that selected 20 different lean techniques. As the next step, Survey B was carried out to examine the current level of lean implementation in the construction industry in Sri Lanka. The findings revealed that lean techniques are implemented in the construction industry in Sri Lanka at a significantly low level and that there is a gap to be bridged. This survey further confirmed that there is scope to improve lean implementation through the research approach.

The third objective of this study was to map widely used lean techniques with non-value adding activities in construction processes in order to identify the lean implementation. As the first step of achieving this objective, Survey C was carried out based on the findings of Surveys A and B and to map 20 lean techniques against the 15 most critical non-value adding activities. It was revealed that there is a strong relationship between lean techniques and non-value adding activities with a 'many to many' relationship. Furthermore, the finding of this survey revealed the suitability of implementing these lean techniques in different stages of construction. The benefits of implementing lean techniques, the associated challenges and the suggestions to overcome these challenges were also revealed through this survey.

The last and the 4th objective of this study was to propose a tool for assessing the lean maturity of a construction project. This was achieved by developing the tool as a computer program through which the user could focus on a particular construction project and apply the tool to assess the extent to which that particular project has become lean through the implementation of lean techniques. Findings from Surveys B and C were applied to develop this tool by identifying the implementation of 19 lean techniques in four different stages of construction processes. Weighted averages were assigned to each lean technique and a scoring system was defined using the

Capability Maturity Model (CMM) and based on the data obtained though Survey C. The proposed tool was further improved using expert opinions. Finally, this tool was applied to five construction projects to assess their lean maturity and the findings revealed that the projects were not at all matured in lean. Finally, the frame work for implementing lean techniques to minimize non-value adding activities was developed and improved through expert opinions.

Although the professionals in the construction industry were aware of the implementation of lean techniques, findings of this study revealed that these techniques are not implemented up to the required level and that non-value adding activities exist in construction processes. Therefore, this study presents a framework for implementing lean techniques that will minimize non-value adding activities and also proposes a tool to assess lean maturity of construction projects so that lean could be applied to improve the efficiency and performance of the construction industry in Sri Lanka.

8.2 Recommendations

Based on the findings of this research, a set of recommendations can be made for the benefit of professionals working in the construction industry under different categories of stakeholders such as clients, contractors and consultants . According to the main findings of this research, there is a considerable number of non-value adding activities taking place in the construction processes in the construction industry in Sri Lanka and professionals working as experts in the industry should be conscious of them. The most suitable of the widely used lean techniques were identified though this study and professionals have to be aware of these techniques and knowledgeable about them in order to implement them if the non-value adding activities are to be minimized as per the proposed framework developed through this study.

The framework consists of examples of non- value adding activities found in the construction industry in Sri Lanka, the most critical of them and the lean techniques most suitable for different stages of construction along with guidelines, benefits, challenges and the suggestions to overcome the challenges. Professionals working in the construction industry need to make use of the opportunities for implementing this frame work by encouraging mainly the contracting organizations to reap the benefits of becoming lean , i.e increasing profit margins and saving money by minimizing waste to give a better value for money for the final product. A lean culture should be developed from the beginning of a project, i.e at the very stage of identifying the client's requirements and lean construction should be practiced as explained in this study beginning with lean definition of a project, lean design, lean supply and finally lean assembly. It is the responsibility of the Project Manager of a project to take the lead role in implementing lean techniques. Considering the various stages of a construction project as per the RIBA plan of work, lean concepts can be overlaid by implementing lean techniques in each stage.

The second set of recommendations is for the governing bodies such as ICTAD to take initiatives to introduce this framework for implementing lean techniques for minimizing non-value adding activities in construction processes by disseminating the findings of this research. ICTAD can take steps to incorporate best practices identified through the framework when they grade contractors annually by evaluating their performance. Lean Implementation can be one area where they can score whenever they apply to upgrade their current status. Furthermore, lean implementation can be included in the prequalification criteria related to competitive tendering. Professional bodies such as IESL, IQSSL, and AISL can play a role here in disseminating this new knowledge by organizing awareness programs for implementing lean techniques in order to minimize non-value adding activities.

8.3 Limitations

There are several limitations of this study. These limitations were mainly related to the collection of data. Data collection was confined to the building projects that had recently commenced in Colombo and its suburbs. The sample size had to be limited to 30 based on the number of projects and the professionals working in the projects were taken as the whole population for these samples. There were limitations in gathering data as most of the respondents / interviewees were very busy with their own work. Most of them were also not much conversant with lean concepts and lean implementation as these two are new to the construction industry in Sri Lanka and the level of implementation of lean techniques in the country is low. Although there are some lean techniques that are being practiced they are not known by name as lean techniques. It took some time to explain lean implementation to them. Non-value adding activities are not considered as waste by professionals who took part in the surveys as most of them were aware of only material waste with flow waste being invisible and intangible. Almost all the findings from literature review were accepted through the survey with very little new findings revealed through data collection, lean implementation is quite new to the professionals who were questioned / interviewed.

8.4 Implication for Construction Industry

This framework developed for lean implementation in construction processes can benefit many parties in the construction industry by enabling them to improve the efficiency of their construction processes through the minimization of non value adding activities . In addition to clients, contractors and consultants who are the main stakeholders of the construction industry, there are also a considerable number of key professionals such as architects, engineers and quantity surveyors who are employed by various organizations involved in the construction industry. These professionals can play a vital role in the construction industry by using this framework to minimize non value adding activities found in the construction processes.

The clients, both individuals and organizations, can benefit through this framework as it helps them to reduce the cost of construction by minimizing non value adding activities and making construction processes lean. The return benefits they gain by spending their funds on a particular project which in other words can even be considered as an investment will increase if they can minimize non value adding activities in the project. The cost of construction per square foot of floor area in Sri

Lanka being higher than the corresponding values of many of the other countries, it becomes very important for clients to reduce the cost of their construction processes. They can use the framework developed through this study for this purpose which can result in an increase in their level of satisfaction compelling them to make more investments in the industry expecting higher returns.

In Sri Lanka, contracts in the construction industry are generally awarded through a competitive bidding process. The prospective contractors who take part in the bidding process do their best to lower as much as possible the amounts they quote for the services they offer. This framework if used by them will minimize their costs and they will be in a position to win the contracts by offering the lowest possible bid prices without compromising the workmanship and the quality of the materials they use. It is common in the construction industry for the contractors to use inferior quality material and poor workmanship to cut down their costs. By using lean techniques they can still reduce their costs and retain the profit margins expected at the time of bidding while maintaining the required standards in the quality of the material and the labor they use.

Consultants have to play a vital role in procurement related activities of construction projects where a considerable number of professionals are involved. Often it is the consultants who get criticized for project delays, cost overruns and under estimated budgets. When contractors adopt lean techniques these undesirable outcomes of a project are minimized resulting in client satisfaction . The clients will then begin to appreciate the services of the consultants without blaming them unnecessarily. This better recognition will create more job opportunities for the consultants.

8.5 Further Research

Throughout the course of this study, the researcher came across research opportunities that could be continued with or explored through further research.

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 the new cases would repeat the results already obtained through this research study which if so will strengthen the generalizability of this research.

Further research could be done for other types of construction projects related to roads, bridges, water supply etc. Non-value adding activities can be further investigated through observations from inception to completion of a project and through an action research on a particular stage of construction. The implementation framework developed for lean techniques can be further improved by concentrating on a particular technique in each stage of construction and by developing an appropriate model. The RIBA plan of work can be considered and lean techniques can be overlaid with a different version of RIBA plan of work with lean established similar to existing green overlay.

This study covered only 19 lean techniques and 15 most critical non- value adding activities in the construction processes. Another study can be made by choosing one particular technique and studying in depth its implementation and benefits.

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Appendices

Researcher aims to develop a framework to minimize non-value adding activities in construction processes using lean techniques.

1. Introduction to the questionnaire

All construction activities can be divided in two; one is **conversion activities** which produce tangible and the second is **flows activities** which bind such conversion activities during the delivery process of the output. Lean principles state that only conversion activities add value and these should be made more efficient Activities that do not add value are simply a waste and should be eliminated. Non-Value adding activities are the major reason behind schedule delays, cost overruns and other related problems in projects. Researcher has designed TWO Questionnaires to collect data from different two groups; (1) Questionnaire A to recognize non-value adding activities and (2) Questionnaire B to identify the current level of lean implementation.

This questionnaire attempts to collect the data in order **to recognize the non-value adding activities in construction processes** from the key professionals who have more than 10 years' experience in the construction field.

2. General information of the participants /professionals

Please mark ' X' to represent your answer.

2.1 Profession

Engineering	
Architecture	
Quantity Surveying	

2.2 Highest Educational Qualification

HND /HNC	
BSc	
MSc / PG Diploma	

2.3 Total number of experience after the basic qualification

5 to 10 years	
10 to 15 years	
More than 15 years	

3. Recognize the non- value adding activities

Waste is primarily defined in seven categories; defects (errors), delays, over processing, over production, excess inventory, unnecessary transport and conveyance of materials and equipment, and unnecessary motions and movement of people. The following non-value adding activities were identified through a comprehensive literature review and researcher seeks your view to recognize the non-value adding activities in Sri Lankan construction industry.

Therefore, please state that **how do you agree with the following list of non- value adding activities** generates in building construction processes according to your vast experience gained from the building construction industry in Sri lank..

3.1 Defects

Wherever defects occur, extra costs are incurred reworking the part, rescheduling the processes etc. This results in labour costs, more time in the "work in progress". Defects in practice can sometimes double the cost of one single activity. This should not pass on to the Client and should be taken as a loss.

How do you agree with the above statement? Mark 'X' within the suitable boxes given below by recognizing the non- value adding activities in construction process.

Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	**1**	**2**	**3**	**4**	**5**
1	Repair work					
2	Design errors					
3	Design changes					
4	Installation errors					
5	Vendors errors					
6	Damage by other crafts					
7	Incomplete installations					
8	Re handling materials					
9	Damaged materials on site					
10	Poor material allocation					
11	Rework					
12	Site layout is not carefully planned					
13	Uncompleted work					

Please specify any other

	Non- value adding activities	**1**	**2**	**3**	**4**	**5**
1						
2						
3						
4						
5						

3.2 Waiting

Whenever goods are not in transport or being processed, they are waiting. In traditional processes, a large part of an individual activity's duration is spent waiting to be worked on.

How do you recognize the following non-vale adding activities in construction processes? Please mark 'X' within the suitable boxes given

Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never – 1

	Non- value adding activities	1	2	3	4	5
1	Delay to schedules					
2	Waiting for instruction					
3	Waiting for equipment repair					
4	Waiting for equipment to arrive					
5	Equipment frequently breakdown					
6	Waiting for clarifications					
7	Waiting for people and material					
8	Activity delay					
9	Idle time					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

3.3 Motion

In contrast to transportation, which refers to damage to activities and transaction costs associated with moving.

How do you recognize the following non-vale adding activities in construction processes?
Please mark 'X' within the suitable boxes given
Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	1	2	3	4	5
1	Unnecessary material / people movement					
2	Unnecessary motion					
3	Excessive labour movement					
4	Excessive material movement					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

3.4 Inventory

Inventory, be it in the form of raw materials, work-in-progress or finished goods. How do you recognize the following non-vale adding activities in construction processes?

Please mark 'X' within the suitable boxes given
Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	1	2	3	4	5
1	Material stocks					
2	Inventory work					
3	Excess material inventory					
4	Inventories					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

3.5 Extra Procedures

Over-processing occurs any time more work is done on an activity than is required. This also includes using components that are more precise, complex, higher quality or expensive than absolutely required.

How do you agree with the above statement? Mark 'X' within the suitable boxes given below by recognizing the non- value adding activities in construction process.

Please mark 'X' within the suitable boxes given
Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	1	2	3	4	5
1	Unnecessary processing					
2	Long approvals					
3	Retests					
4	Excessive safety measures					
5	Excessive supervision					
6	Excessive information					
	Excessive training time					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

3.6 Transport

Each product is carried out it stands the risk being damaged, lost, delayed etc. as well as being a cost for no added value. Transportation does not make any transformation to the product for it is value.

How do you recognize the following non-value adding activities in construction processes? Please mark 'X' within the suitable boxes given
Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	1	2	3	4	5
1	Unnecessary material transport movement					
2	Travelling time					
3	Unnecessary transport					
4	Long transport time					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

3.7 Overproduction

Overproduction occurs when more products is produced than is required. This leads to excess inventories which require the expenditure of resources on storage space and preservation, activities that do not benefit to the customer.

How do you recognize the following non-value adding activities in construction processes? Please mark 'X' within the suitable boxes given
Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	1	2	3	4	5
1	Unwanted productions					
2	Unnecessary works					
3	Material waste					
4	Inefficient work					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

3.8 Others

There are other non-value adding activities which cannot be categorized onto the above waste categories and how you would recognize the following non-value adding activities. Please mark 'X' within the suitable boxes given

Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

	Non- value adding activities	1	2	3	4	5
1	Material does not meet specifications					
2	Taxes					
3	Pilferage					
4	Making -do					

Please specify any other

	Non- value adding activities	1	2	3	4	5
1						
2						
3						
4						
5						

Researcher aims to develop a framework to minimize non-value adding activities in construction processes using lean techniques.

1. Introduction to the questionnaire

All construction activities can be divided in two; one is **conversion activities** which produce tangible and the second is **flows activities** which bind such conversion activities during the delivery process of the output. Lean principles state that only conversion activities add value and these should be made more efficient Activities that do not add value are simply a waste and should be eliminated. Non-Value adding activities are the major reason behind schedule delays, cost overruns and other related problems in projects. Researcher has designed TWO Questionnaires to collect data from different two groups; 1) Questionnaire A to recognize non-value adding activities and 2) Questionnaire B to identify the current level of lean implementation.

This questionnaire attempts to collect the data in order **to identify the current level of lean implementation,** from the senior management of the construction related organizations who have more than 10 years' experience in the construction field in the capacity of Project Manager.

2. General information of the participants /professionals

Please mark ' X' to represent your answer.

2.1 Profession

Engineering	
Architecture	
Quantity Surveying	

2.2 Highest Educational Qualification

HND /HNC	
BSc	
MSc / PG Diploma	

2.3 Total number of experience after the basic qualification

10 to 15 years	
15 to 20 years	
More than 20 years	

3. Current level of implementation of lean techniques

The manufacturing industry has been a constant reference point and a source of innovation for construction over many decades. The lean concept is one of such strategies adopted by the construction industry from the manufacturing industry to improve performance. Lean is a new way to see, understand and act in the world. The lean concept has proven to be effective in increasing environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value. Lean is an innovative construction management approach which is linked closely to the overall life of the project to ensure project success. Lean principles argue that waste could be eliminated by certain techniques which provide more value with fewer resources. Researcher attempts to establish the current level of practice of Lean Techniques in Sri Lankan construction industry.

Therefore, please state that how you can agree with the practice of following lean techniques in Sri Lankan Construction Industry.

Almost always = 5, usually – 4, about 50% of the time – 3, very rarely – 2, Never - 1

Q 1 Last Planner

LP is a lean technique that has four main processes: Master Schedule, Phase Schedule, Look ahead plan, and Weekly plan. Last The LPS is based on extensive cooperation between different contractors and subcontractors who commit to coordinating their activities in increasing detail as the practical implementation approaches. LP is a production planning and control system implemented on construction projects to improve planning and production performance.

To which extent do you plan your construction activities using Last Planner Technique?

Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q2 Just in Time

The concept of just in time is utilized in construction wherein the inventories are kept to the bare minimum and new inventories are ordered based on the current demand. Stocking of material is wasteful. Its implementation requires good relationship with suppliers. JIT is a Japanese management philosophy which has been applied in practice since the early 1970s.

To which extent do you plan your construction activities using Just in Time Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q3 3D Modelling

3D Modelling is a computerized 3D design system to provide better, faster information provides isometric drawings of components and interfaces, fit co-ordination, planning of construction methods, motivation of the work crews through visualization. Having a constructible design, reduces the amount of contractors' requests for information and change orders related to field changes. Additionally, MEP (Mechanical, Electrical and Plumbing) contractors are able to use more prefabrication which improves productivity on site and improved safety. And also, 3D models can be used for accurate quantity takeoff. When quantities are taken off manually there is lot of waste in construction process because quantity takeoff needs to be performed each time the design is updated. 3D models can produce quantities automatically based on a means and methods database.

To which extent do you use 3d Modelling Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q4 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. This includes signs related to safety, schedule, and quality. This tool is similar to the lean manufacturing tool, Visual Controls, which is a continuous improvement activity that relates to the process control.

To which extent do you use visualization Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q5 BIM

BIM, or Building Information Modeling, is digital representation of physical and functional characteristics of a building creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition. BIM's ability to keep this information up to date and accessible in an integrated digital environment gives architects, engineers, quantity surveyors, builders, and owners a clear overall vision of their projects, as well as the ability to make better decisions faster.

To which extent do you use BIM Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q6 Value stream mapping

Normally maps are prepared at the project level and then decomposed to better understand how the design of planning, logistics and operations systems work together to support the customer value. A value stream map is a comprehensive model. Value stream maps can be identified as Process Flow Charts that identify what action releases work to the next operation of the project that reveals issues hidden in current approaches.

To which extent do you practice **Value stream mapping** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q7 Reverse Phase Scheduling

RPS is a pull technique is used to develop a schedule that works backwards from the completion date by team planning. 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.

To which extent do you practice **Reverse Phase Scheduling** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q8 Prefabrication

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

To which extent do you practice **Prefabrication** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q9 Kaizen

"kaizen" simply means "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes in manufacturing, engineering, and business management which improve the quality, technology, processes, company culture, productivity, safety and leadership Kaizen implicates cost reduction and zero defects in Final Product. Kaizen focuses on eliminating waste, improving productivity, and achieving sustained continual improvement in targeted activities and processes.

To which extent do you practice **Kaizen** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q10 Five S

5S is a set of techniques providing a standard approach to housekeeping within Lean. 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

To which extent do you practice **Five S** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q11 Fail safe for quality

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 and decisions are taken after defective parts have already been processed. Generation of ideas is alert for potential defects.

To which extent do you practice **Fail safe for quality** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q12 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 In the building sector, it has been customary for architects to work with customers to understand what they want, then produce facility designs intended to deliver what's wanted. The cost of those designs has then been estimated and too often, found to be greater than the customer is willing or able to bear, requiring designs to be revised, then re-estimated. This cycle of design – estimate – rework is wasteful and reduces the value customers get for their money.

To which extent do you practice **Target Value Design** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q13 First Run Studies

First run studies (as lean construction defines) are "used to redesign critical assignments, part of continuous improvement effort; and include productivity studies and review work methods by redesigning and streamlining the different functions involved. The studies commonly use video files, photos, or graphics to show the process or illustrate the work instruction. The first run of a selected craft operation should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work."

To which extent do you practice **First Run Studies** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q14 Relational Contracting

A relational contract is a contract whose effect is based upon a relationship of trust between the parties. The explicit terms of the contract are just an outline as there are implicit terms and understandings which determine the behaviour of the parties. Relational contract theory is characterized by a view of contracts as relations rather than as discrete transactions Thus, even a simple transaction can properly be understood as involving a wider social and economic context.

To which extent do you practice **Relational Contracting** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q15 Target costing

Target costing, which has subsequently been replaced by target Value Design for two reasons; 1)Target costing is a term used in the construction industry with a different meaning, and 2) Target value design better indicates the intent to deliver customer value, as opposed to mere cost cutting (Ballard 2011).

To which extent do you practice **Target costing** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q16 Set based design

Set based design builds on concurrent engineering principles (multifunctional, co-located team design) by establishing a design space for design optimization to meet a challenging set of requirements. Set based design involves exploring many design alternatives up-front to allow for trade-offs particularly important for integrated systems with competing requirements. Set based design improves on 'point design' with its' many shortfalls - fixation on first design selected, time delay before feedback, and locked in cost too early in the design process. The differences between point design and set based design can be best understood visually.

To which extent do you practice **Set based design** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q17 kanban

One-way to do this is to smooth and balance material flows by means of controlled inventories. Translated as signal this allows an organization to reduce production lead-time, which in turn reduces the amount of inventory required. A Kan-ban is a card containing all the information required to be done on a product at each stage along its path to completion and which parts are needed at subsequent processes. These cards are used to control work-in-progress (W.I.P.), production, and inventory flow. A Kan-ban System allows a company to use Just-In-Time (J.I.T) Production and Ordering Systems that allow them to minimize their inventories while still satisfying customer demands.

To which extent do you practice **kanban** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q18 Total Quality Management

Total Quality Management is a management approach that originated in the 1950's and has steadily become more popular since the early 1980's. Total Quality is a description of the culture, attitude and organization of a company that strives to provide customers with products and services that satisfy their needs. The culture requires quality in all aspects of the company's operations, with processes being done right the first time and defects and waste eradicated from operations. Total Quality Management, TQM, is a method by which management and employees can become involved in the continuous improvement of the production of goods and services. It is a combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices.

To which extent do you practice **Total Quality Management** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q19 Work Standardization

Standardized work is one of the most powerful lean tools. By documenting the current best practice, standardized work forms the baseline for kaizen or continuous improvement. As the standard is improved, the new standard becomes the baseline for further improvements, and so on. Improving standardized work is a never-ending process. Basically, standardized work consists of three elements:

- Takt time, which is the rate at which products must be made in a process to meet customer demand.
- The precise work sequence in which an operator performs tasks within takt time.
- The standard inventory, including units in machines, required to keep the process operating smoothly.

To which extent do you practice **Work Standardization** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Q20 Work Structuring

Work structuring in lean construction is defined as "the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts" with the goal of making "work flow more reliable and quick while delivering value to the customer" (Ballard 2000). Ballard (1999) initially equated the term "work structuring" to process design and has since broadened the scope of work structuring by equating it with production system design (Ballard et al. 2001). Contracts, history, and traditional practices of designers, suppliers, and building trades affect how planners conceive of the work required to complete a project. In particular, planners often use a WBS to decompose a project into work packages to create a framework for project planning, scheduling, and controls

To which extent do you practice **Work Structuring** Technique? Please select your answer and mark √

Almost always	
Usually	
About 50% of the time	
Very rarely	
Never	

Researcher aims to develop a framework to minimize non-value adding activities in construction processes using lean techniques.

1. **Introduction to the Study**

All construction activities can be divided in two; one is **conversion activities** which produce tangible and the second is **flows activities** which bind such conversion activities during the delivery process of the output. Lean principles state that only conversion activities add value and these should be made more efficient Activities that do not add value are simply a waste and should be eliminated. These Non-Value adding activities are the major reason behind schedule delays, cost overruns and other related problems in projects. Researcher has already completed TWO Surveys from different two groups;

Survey A was to recognize non-value adding activities in construction processes from the key professionals such as Engineers, Quantity Surveyors, Architects who have more than 10 years' experience in the construction field. Findings of the above survey showed that NVAAs are generated at a significant level in the construction processes in Sri Lankan construction industry. Further it was revealed through the survey the most significant categories NVAAs are defects and waiting. The following are the selected examples of NVAAs through Survey A to continue the study.

Repair Work, Design errors, Incomplete installations, Re-handling materials, Damaged Materials on site, Poor material allocation, Delay to schedules, Waiting for instructions, Waiting for equipment repair, Waiting for People and materials, Activity Delay, Idle Time, Excessive labour movement Retests, Excessive safety measurers

Survey B was to identify the current level of lean implementation, from the senior management of the construction related organizations who have more than 10 years' experience in the construction field in the capacity of Project Manager. All lean techniques are implemented in different levels in Sri Lanka construction industry and the average level reports as 40% which is at a substantially lower level. Literature findings revealed that lean techniques have been widely implemented and benefits have been appreciated in other countries. However, Sri Lankan construction industry significantly lags behind implementing lean techniques in construction processes and there is substantial scope to improve the implementation of lean techniques.

Lean Techniques selected for the study was as follows.

1	Planning and control system implemented on construction projects with Master Schedule, Phase Schedule, Look ahead plan, and Weekly plan **(LPS)**
2	Stock of Materials are kept to the bare minimum and new Quantities are ordered based on the current demand**(JIT)**
3	Computerized 3D design system to provide better, faster information provides isometric drawings of components and interfaces, fit co-ordination, planning of construction methods, motivation of the work crews through visualization **(3DM)**
4	Visualization through posting various signs and labels around the construction site related to safety, schedule, and quality. **Visualization**
5	Digital representation of physical and functional characteristics of a building creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition **BIM**
6	Maps are prepared at the project level and then decomposed to better understand how the design of planning, logistics and operations systems work together to support the customer value. **Value Stream Mapping**
7	A schedule that works backwards from the completion date by team planning. Reverse Phase scheduling. **(RPS)**
8	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. **Prefabrication / Off site manufacturing**
9	Kaizen / continuous improvement "good change". Kaizen refers to philosophy or practices that focus upon continuous improvement of processes in manufacturing, engineering, and business management which improve the quality, technology, processes, company culture, productivity, safety and leadership. **Kaizen**
10	Five S5S is a set of techniques providing a standard approach to housekeeping within Lean. 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. **5S**
11	Fail Safe Quality / Poka-yoke 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 and decisions are taken after defective parts have already been processed. Generation of ideas is alert for potential defects. **FSQ**
12	Target Value Design make customer constraints drivers of design for the sake of value delivery. TVD is a method that assures customers get what they need. **TVD**
13	First Run Studies The studies commonly use video files, photos, or graphics to show the process or illustrate the work instruction. The first run of a selected craft operation should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the work. **FRS**

14	Relational Contracting a relationship of trust between the parties. The explicit terms of the contract are just an outline as there are implicit terms and understandings which determine the behaviour of the parties. Relational contract theory is characterized by a view of contracts as relations rather than as discrete transactions. **Relational Contracting**
15	Target costing is a tool, and inherent process, that dramatically improves an organizations capability to reduce costs and improve the bottom line. This tool addresses all of the fundamental issues to improve a company's efficiency and effectiveness in cutting costs Target. Target value design better indicates the intent to deliver customer value, as opposed to mere cost cutting. **TC**
16	Set based design involves exploring many design alternatives up-front to allow for trade-offs particularly important for integrated systems with competing requirements. **Set based design**
17	Kanban One-way to do this is to smooth and balance material flows by means of controlled inventories. Translated as signal this allows an organization to reduce production lead-time, which in turn reduces the amount of inventory required. A Kan-ban is a card containing all the information required to be done on a product at each stage along its path to completion and which parts are needed at subsequent processes. These cards are used to control work-in-progress (W.I.P.), production, and inventory flow. **Kanban**
18	Total Quality Management It is a combination of quality and management tools aimed at increasing business and reducing losses due to wasteful practices. a description of the culture, attitude and organization of a company that strives to provide customers with products and services that satisfy their needs. **TQM**
19	Work standardization By documenting the current best practice, standardized work forms the baseline for kaizen or continuous improvement. As the standard is improved, the new standard becomes the baseline for further improvements, and so on. **WS**
20	Work structuring in lean construction is defined as "the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts" with the goal of making "work flow more reliable and quick while delivering value to the customer. **WST**

This is the third round of collection data based on face to face interviews based on a structured format including open ended questions to get the opinion from the Industry Experts who have more than 20 years' experience in the field of construction to develop the conceptual framework by mapping the recognized NVAAs and appropriate lean techniques in order to minimize NVAAS in construction processes by implementing suitable lean techniques.

Finally another opinion survey will be obtained to refine the framework and to proposes a tool for assessing lean maturity in construction processes as last step of this study.

Therefore, with this series of interviews, researcher attempts to establish the relationships between NVAAs and LTs and you as selected participant for this survey, are required to map the identified NVAAs with selected Lean Techniques based on your experience.

2. Minimizing NVAAS using Lean techniques

2.1 Which Lean technique / techniques will be appropriate to minimize each NVAAs Listed Below?
(Please Mark your opinion in the below table to indicate the relationship between NVAAs and LT which are stated in Page 2 and 3).

Please refer the page below

Mapping examples of NVAAs with Lean Techniques																					
Ref	Examples of NVAAs	Lean Techniques																			
		LPS	JIT	3D	VIs	BIM	VSM	RPS	OSM	KAIZ	5S	FSQ	TVD	FRS	RC	TC	SBD	KAN	TQM	WS	WST
		LT01	LT02	LT03	LT04	LT05	LT06	LT07	LT08	LT09	LT10	LT11	LT12	LT13	LT14	LT15	LT16	LT17	LT18	LT19	LT20
D01NA01	Repair Work																				
D02NA02	Design errors																				
D07NA07	Incomplete installations																				
D08NA08	Re-handling materials																				
D09NA09	Damaged Materials on site																				
D10NA10	Poor material allocation																				
W01NA14	Delay to schedules																				
W02NA15	Waiting for instructions																				
W03NA16	Waiting for equipment repair																				
W07NA20	Waiting for People and materials																				
W08NA21	Activity Delay																				
W09NA22	Idle Time																				
M01NA25	Excessive labour movement																				
W03NA33	Retests																				
W04NA34	Excessive safety measurers																				

3. What is your opinion in implementing the selected lean techniques in different stages of a construction project? You may select the best stage / stages to implement each Lean Technique and mark (X) in the given spaces.

Lean Techniques	Stage I Preparation Stage	Stage II Design Stage	Stage III Pre-contract Stage	Stage IV Constructi on stage	Not applicable to any stage
Last Planner System					
Just In Time					
3D Modeling					
Visualization					
BIM					
Value Stream Mapping					
Reverse Phase Schedule					
Off Site manufacturing					
Kaizan					
Five S					
Fail Safe Quality					
Target Value Design					
First Run Studies					
Relational Contracting					
Target Costing					
Set based Design					
Kanban					
Total Quality Management					
Work Standardizing					
Work Structuring					

4. Any other Lean Techniques that you can recommend for activities in construction processes ? Please state your answer.

----

5. What are the guidelines that you agree in implementing the above Lean Techniques in construction processes ? Please mark (x) against each guideline.

Ref	Guidelines for successful Lean Implementation	
A	Select partners or suppliers who are willing and able to adopt lean project delivery	
B	Structure the project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best project – level return	
C	Do target costing: define and align project scope, budget and schedule to deliver customer and stakeholders value	
D	Encourage thoughtful experimentation; explore adaptation and development of methods for perusing the lean ideal	
E	Celebrate breakdowns as opportunities for learning rather than occasions for punishing the guilty	
F	Do set based design: make design decision at the last responsible moment, with explicit generation of alternatives, and document the evaluation of those alternatives against stated criteria	
G	Practice production control in accordance with lean principles such as making the work flow predictable and using pull system to avoid over production	
H	Build quality and safety in to the projects by placing primary reliance and acting to prevent breakdowns	
I	Implement Just In Time and other multi organizational processes	
J	Use 3D modelling to integrate product and process design	

Any other guideline that you can propose to implementing lean techniques in to construction processes? Please state your answer.

----

6. What are the benefits that you appreciate in implementing the above Lean Techniques in construction processes ? Please mark (x) against each benefit suggested.

A	Reduce Sharing Of Non-Value Adding Activities	
B	Increase Sustainable Values	
C	Provide Better Value To The Customer	
D	Increase The Output Value Of Customer Requirement Through Systematic Construction	
E	Reduce Process Variability (Variations)	
F	Reduce Cycle Times	
G	Simplify By Minimizing The Number Of Steps Parts And Linkages	

H	Increase Output Flexibility	
I	Increase Process Transparency	
J	Focus On Complete Process	
K	Build Continuous Implement Into The Process	
L	Balance Flow Improvement With Conversion Improvement	
M	Reduce Human Effort	
N	Increase The Quality Of The Product / Project	
O	Improve The Downstream Operations	
P	Change People's Attitudes	
Q	Benchmarking	

Any other benefits that you think about in implementing lean techniques in to construction processes? Please state your answer.

----

7. What are the barriers that you anticipate in implementing the above Lean Techniques in construction processes ? Please mark (x) against each benefit suggested.

A	Lack Of Time For Implementing New Practices In The Projects	
B	Lack Of Training	
C	Challenge To Create Organizational Elements	
D	Lack Of Self Criticism To Learn From Errors, Respond To Some Deficiencies	
E	Low Understanding Of The Concepts	
F	Low Use Of Different Elements	
G	Inadequate Administration	
H	Weak Communication And Transparency	
I	Lack Of Integration Of The Construction Chain	
Please state any other barrier that you see in implementing Lean Techniques?		

8. How do you agree with the following suggestions to overcome the barriers in implementing Lean Techniques in construction processes
Fully Agreed – 3 partially agreed – 2 Not Agreed – 1

Ref	Suggestions	3	2	1
1	Senior Management / Decision makers contribution is significant			
2	Leadership of a project must have the lean vision from the beginning			
3	Lesson learned practices to avoid repeating the same mistakes			
4	Cultural changes with lean thinking / attitudes			
5	Bridging the gap between theory and practice			
6	Introduce a lean benchmark for construction materials			
7	Increase the pre assembling of building components			
8	Structure the project organization to engage downstream players in upstream processes and vice-versa			
9	Work with alternatives			
10				
11				
12				

9. **General information of the Interviewee**

Please fill the details required within the space given.

Name of the Organization	
Designation	
Qualification	
Number of projects involved	
Years of experience	
Duration of the Interview	

Annex 4: Summary of data on Survey A on Non-value adding activities

	NVAAs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1	2	3	4	5	1	2	3	4	5			
defects	D01NA01	2	5	4	5	5	3	2	2	3	3	3	1	4	3	2	3	3	0	0	12	6	4	0%	27%	40%	20%	13%	100%	17	55%
	D02NA02	3	5	3	4	5	2	3	4	4	5	4	2	2	4	2	2	3	0	0	9	10	3	0%	27%	30%	33%	10%	100%	17	57%
	D03NA03	2	2	4	4	2	2	2	4	4	4	3	2	2	3	3	4	3	0	0	9	12	0	0%	30%	30%	40%	0%	100%	16	53%
	D04NA04	4	5	5	1	5	3	4	3	3	4	4	2	4	4	4	4	4	3	3	9	13	4	3%	10%	30%	43%	13%	100%	19	63%
	D05NA05	4	5	3	5	5	3	4	2	3	2	2	2	2	4	3	3	4	5	5	11	11	4	0%	17%	37%	37%	10%	100%	18	60%
	D06NA06	3	5	2		5	3	3	2	3	3	4	2	3	3	3	3	4	6	6	13	9	3	0%	17%	43%	30%	10%	100%	18	58%
	D07NA07	4	5	5		5	3	4	2	4	4	4	2	4	4	4	4	5	0	2	7	16	5	0%	7%	23%	53%	17%	100%	21	70%
	D08NA08	3	5	4		4	3	3	3	4	5	4	2	4	3	4	3	4	0	1	11	15	3	0%	3%	37%	50%	10%	100%	20	67%
	D09NA09	3	5	5		5	4	3	2	4	5	5	2	4	5	3	5	4	0	2	5	11	12	0%	7%	17%	37%	40%	100%	23	78%
	D10NA10	4	5	5		5	2	4	2	4	5	4	3	4	3	4	5	4	0	2	7	13	8	0%	7%	23%	43%	27%	100%	22	73%
	D11NA11	2	5	3		5	4	2	2	4	4	4	3	4	3	4	4	4	0	4	6	18	2	0%	13%	20%	60%	7%	100%	20	65%
	D12NA12	3	4	3		4	3	3	3	4	4	3	2	3	3	4	4	4	0	2	14	14	0	0%	7%	47%	47%	0%	100%	18	60%
	D13NA13	3	4	3		3	3	3	2	4	3	4	2	4	3	3	3	3	0	4	14	11	0	0%	14%	48%	38%	0%	100%	16	54%
																								0%	14%	33%	41%	12%	100%	-	62%
Waiting	W01NA14	3	5	2	4	3	5	3	3	4	5	4	2	4	4	4	4	3	0	3	10	14	3	0%	10%	33%	47%	10%	100%	19	64%
	W02NA15	4	5	3	4	3	5	4	3	4	5	3	2	4	4	4	4	3	0	1	10	16	3	0%	3%	33%	53%	10%	100%	20	68%
	W03NA16	4	5	3	4	4	5	4	2	3	4	3	3	4	4	3	3	3	0	1	10	15	4	0%	3%	33%	50%	13%	100%	21	68%
	W04NA17	4	5	3	4	3	3	4	2	4	4	3	3	3	4	3	3	4	0	1	10	15	4	0%	3%	33%	50%	13%	100%	21	68%
	W05NA18	4	5	3	4	2	3	4	3	3	3	4	2	3	4	5	5	4	0	2	10	12	6	0%	7%	33%	40%	20%	100%	21	68%
	W06NA19	3	5	4	4	4	3	3	4	3	4	3	2	3	4	3	4	4	0	1	16	12	1	0%	3%	53%	40%	3%	100%	18	61%
	W07NA20	3	5	3	4	4	5	3	2	4	4	3	2	4	3	3	4	4	0	2	14	13	1	0%	7%	47%	43%	3%	100%	18	61%
	W08NA21	3	5	3	4	5	5	3	2	3	4	3	3	4	3	3	4	3	0	3	14	10	3	0%	10%	47%	33%	10%	100%	18	61%
	W09NA22	3	5	3	5	5	5	3	3	4	4	3	2	4	3	4	3	4	0	1	13	12	4	0%	3%	43%	40%	13%	100%	20	66%
																								0%	6%	40%	44%	11%	100%	-	65%
Motion	M01NA23	2	5	2	5	4	5	2	2	4	3	4	2	3	2	2	2	3	3	11	6	6	4	10%	37%	20%	20%	13%	100%	14	48%
	M02NA24	3	4	3	4	5	5	3	3	3	3	5	2	3	3	3	4	4	2	5	15	5	3	7%	17%	50%	17%	10%	100%	16	52%
	M03NA25	3	5	2	4	4	5	3	2	4	3	5	3	2	2	2	2	4	7	11	7	7	3	7%	37%	23%	23%	10%	100%	15	48%
	M04NA26	4	5	2	2	4	5	4	2	3	3	4	3	2	2	3	3	2	5	12	6	5	2	17%	40%	20%	17%	7%	100%	12	39%
																								10%	33%	28%	19%	10%	100%	-	47%
Inventory	I01NA27	3	3	2	4	3	4	3	2	4	3	4	3	3	3	4	4	3	0	4	14	11	1	0%	13%	47%	37%	3%	100%	17	58%
	I02NA28	3	3	1	2	3	4	3	3	3	3	3	3	3	4	3	3	3	1	2	18	9	0	3%	7%	60%	30%	0%	100%	16	54%
	I03NA29	3	3	1	1	4	4	3	2	3	3	2	2	3	3	3	3	2	2	12	12	4	0	7%	40%	40%	13%	0%	100%	12	40%
	I04NA30	3	3	1	1	3	3	3	2	2	3	2	2	3	3	2	3	2	2	11	16	1	0	7%	37%	53%	3%	0%	100%	12	38%
																								4%	24%	50%	21%	1%	100%	-	48%
Ex Proc	E01NA31	3	4	2	4	5	4	3	3	4	4	4	3	3	5	4	5	5	0	1	6	12	11	0%	3%	20%	40%	37%	100%	23	78%
	E02NA32	2	3	3	4	5	4	2	3	4	3	4	3	4	3	4	4	4	0	4	14	11	1	0%	13%	47%	37%	3%	100%	17	58%
	E03NA33	4	2	3	3	4	3	4	2	3	2	3	2	4	3	2	3	3	1	10	13	1	1	3%	33%	43%	17%	3%	100%	14	46%
	E04NA34	3	1	3	3	4	3	3	2	4	4	2	1	3	2	3	2	2	4	11	11	4	0	13%	37%	37%	13%	0%	100%	11	38%
	E05NA35	3	1	3	3	4	3	3	2	4	4	2	1	3	2	3	2	2	4	11	11	4	0	13%	37%	37%	13%				
	E06NA36	4	1	3	3	5	3	4	2	3	3	2	2	3	3	3	3	4	3	10	12	1	1	10%	33%	40%	13%	3%	100%	13	42%
	E07NA37	4	2	4	4	4	3	4	2	4	3	2	2	3	3	3	2	2	1	7	8	13	1	3%	23%	27%	43%	3%	100%	17	55%
																								6%	26%	36%	25%	7%	100%	-	53%
Transport	T01NA38	3	5	3	4	3	5	3	3	3	3	4	2	5	5	4	4	5	0	1	8	11	10	0%	3%	27%	37%	33%	100%	23	75%
	T02NA39	4	5	2	4	4	5	4	2	4	4	4	2	3	2	3	2	3	2	6	2	15	1	0%	20%	23%	50%	7%	100%	18	61%
	T03NA40	4	5	3	4	3	5	4	2	3	3	5	2	5	4	3	4	5	0	2	7	11	10	0%	7%	23%	37%	33%	100%	22	74%
	T04NA41	3	5	2	3	5	5	3	2	4	4	5	1	4	4	4	3	3	1	5	10	10	4	3%	17%	33%	33%	13%	100%	18	59%
																								1%	12%	27%	39%	22%	100%	-	67%
Overproduct	OV1NA42	4	5	2	3	5	4	4	2	2	2	2	2	4	4	4	4	3	0	6	4	13	7	0%	20%	13%	43%	23%	100%	20	68%
	OV2NA43	4	5	2	4	5	3	4	2	2	2	3	2	3	4	4	4	3	0	5	8	14	3	0%	17%	27%	47%	10%	100%	19	63%
	OV3NA44	3	5	3	3	5	3	3	3	3	4	4	3	3	4	4	4	3	0	1	16	9	4	0%	3%	53%	30%	13%	100%	19	63%
	OV4NA45	3	5	3	4	4	3	3	3	3	5	4	2	2	1	4	2	2	3	13	8	4	2	10%	43%	27%	13%	7%	100%	12	41%
																								3%	21%	30%	33%	13%	100%	-	59%
Others	OT1NA46	4	4	4	4	2	4	4	4	4	4	3	3	4	4	4	5	5	0	1	3	18	8	0%	3%	10%	60%	27%	100%	23	78%
	OT2NA47	3	3	3	3	3	2	3	3	4	5	3	2	3	3	3	3	4	0	4	18	7	1	0%	13%	60%	23%	3%	100%	16	54%
	OT3NA48	4	3	2	3	3	2	4	2	3	5	4	2	3	4	4	4	3	0	11	10	7	2	0%	37%	33%	23%	7%	100%	15	50%
	OT4NA49	4	3	2	4	3	2	4	2	3	3	2	2	3	2	3	4	3	2	9	11	6	2	7%	30%	37%	20%	7%	100%	14	48%
																								2%	21%	35%	32%	11%	100%	-	45%
																														-	
																								3%	19%	35%	33%	11%	100%		59%

Annex 5: Summary of Data Collection on Survey B on Lean Techniques

Data Collection from 30 Participants to establish the current level of lean implementation in

Lean Techniques		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5		1	2	3	4	5		
1	LT01	4	3	4	4	4	3	3	4	1	2	4	3	3	3	4	3	2	1	2	2	2	3	3	4	4	3	2	4	4	4	2	6	10	12	0	30	7%	20%	33%	40%	0%	100%	52%
2	LT02	4	2	4	4	3	4	3	4	2	3	3	1	2	2	2	3	3	1	2	2	3	4	4	3	4	4	3	3	3	3	2	7	12	9	0	30	7%	23%	40%	30%	0%	100%	48%
3	LT03	2	1	2	1	2	2	1	4	1	2	2	1	2	2	2	3	2	2	2	2	4	1	1	2	3	3	2	1	2	3	8	16	4	2	0	30	27%	53%	13%	7%	0%	100%	25%
4	LT04	2	2	2	3	3	3	2	4	2	4	5	3	2	1	2	2	1	2	3	3	3	3	3	3	4	4	3	3	4	4	2	9	12	6	1	30	7%	30%	40%	20%	3%	100%	46%
5	LT05	2	1	2	2	1	2	1	5	1	2	1	1	2	2	1	2	2	2	2	2	2	2	1	2	2	1	1	2	1	1	12	17	0	0	1	30	40%	57%	0%	0%	3%	100%	18%
6	LT06	2	2	2	1	1	2	3	4	1	1	3	1	2	2	2	2	3	3	2	2	2	1	2	1	1	1	2	1	1	1	12	13	4	1	0	30	40%	43%	13%	3%	0%	100%	20%
7	LT07	4	4	4	1	2	3	3	4	1	3	4	3	2	3	3	2	2	1	1	2	2	1	2	2	2	1	2	2	1	2	7	12	6	5	0	30	23%	40%	20%	17%	0%	100%	33%
8	LT08	3	2	3	2	2	3	2	3	3	5	4	3	3	4	3	4	4	3	3	3	3	2	2	2	2	2	2	2	1	2	1	12	12	4	1	30	3%	40%	40%	13%	3%	100%	43%
9	LT09	3	2	3	2	3	4	1	5	1	3	4	1	2	1	2	2	2	1	3	4	1	1	1	2	2	1	3	3	4	4	9	8	7	5	1	30	30%	27%	23%	17%	3%	100%	34%
10	LT10	2	3	2	4	4	5	4	4	4	3	4	3	2	2	3	3	4	4	2	2	2	4	3	4	4	3	5	4	4	4	0	7	7	14	2	30	0%	23%	23%	47%	7%	100%	59%
11	LT11	4	2	2	2	2	4	5	4	1	3	1	3	2	1	2	2	3	2	2	2	1	2	2	1	1	2	2	2	1	2	7	16	3	3	1	30	23%	53%	10%	10%	3%	100%	29%
12	LT12	4	4	4	4	2	4	3	4	2	3	4	4	2	2	2	1	2	2	3	2	1	3	4	4	3	4	2	2	1	2	3	11	5	11	0	30	10%	37%	17%	37%	0%	100%	45%
13	LT13	2	2	2	2	3	4	2	4	1	2	4	2	1	2	2	2	1	2	2	2	2	2	2	1	2	2	3	3	4	3	4	18	4	4	0	30	13%	60%	13%	13%	0%	100%	32%
14	LT14	5	2	5	1	1	4	2	3	2	3	1	2	2	2	3	2	2	1	2	3	2	2	1	2	2	3	1	2	2	1	7	15	5	1	2	30	23%	50%	17%	3%	7%	100%	30%
15	LT15	5	4	5	3	3	4	4	3	1	3	1	2	3	4	4	3	3	3	4	2	4	3	4	3	4	3	4	3	4	3	2	2	13	11	2	30	7%	7%	43%	37%	7%	100%	58%
16	LT16	4	2	4	2	3	5	4	3	1	3	3	1	2	1	2	2	2	2	3	3	2	2	2	1	2	2	3	3	3	3	4	12	10	3	1	30	13%	40%	33%	10%	3%	100%	38%
17	LT17	1	2	1	2	4	4	1	4	2	1	1	1	1	2	2	1	1	2	2	1	1	2	2	2	2	1	2	1	1	2	14	13	0	3	0	30	47%	43%	0%	10%	0%	100%	18%
18	LT18	4	3	4	4	1	5	3	5	2	3	5	2	4	3	4	4	3	4	3	3	3	4	4	3	4	3	3	3	2	3	1	3	13	10	3	30	3%	10%	43%	33%	10%	100%	59%
19	LT19	4	3	4	2	3	4	3	5	2	3	5	2	3	4	3	3	4	4	3	4	4	2	2	1	2	2	3	4	3	4	1	7	10	10	2	30	3%	23%	33%	33%	7%	100%	54%
20	LT20	4	2	4	2	4	5	2	4	2	4	4	2	4	4	3	3	4	5	5	4	3	2	2	1	3	2	5	4	3	4	1	8	5	12	4	30	3%	27%	17%	40%	13%	100%	58%
																																						17%	35%	24%	21%	4%	100%	40%

Reference		Int 1	Int 2	Int 3	Int 4	Int 5	Int 6	Int 7	Int 8	Int 9	Int 10	Int 11	Int 12	Int 13	Int 14	Int 15	Int 16	Int 17	Int 18	Int 19	Int 20	Mode
1	D01NA01	10	13	10	10	11	11	10	15	16	15	10	15	15	15	10	15	15	11	11	11	15
2	D02NA02	8	7	8	8	7	6	8	14	14	14	9	13	14	16	9	16	15	7	7	6	8
3	D07NA07	11	10	11	11	11	10	11	12	12	12	11	12	12	12	11	12	12	10	11	10	11
4	D08NA08	7	11	7	7	9	9	7	10	11	11	7	11	11	11	8	11	11	10	10	9	11
5	D09NA09	8	11	8	8	9	9	8	14	14	14	8	14	14	14	8	14	14	11	10	9	14
6	D10NA10	5	10	5	5	6	8	5	14	14	15	5	14	14	15	5	14	13	10	9	8	5
7	W01NA14	9	9	9	9	9	8	9	15	15	14	9	16	15	16	9	16	16	10	10	8	9
8	W02NA15	4	10	4	4	4	10	4	15	13	13	4	16	15	16	4	16	16	11	11	10	4
9	W03NA16	6	8	6	6	6	7	6	15	14	15	5	15	15	16	5	16	16	9	9	7	6
10	W07NA20	6	9	6	6	7	7	6	16	16	17	6	16	16	16	6	16	16	9	9	7	16
11	W08NA21	7	13	7	7	7	12	7	16	16	16	7	15	16	16	6	16	16	13	13	12	16
12	W09NA22	7	10	7	7	6	9	7	16	16	16	7	16	16	16	7	16	16	9	10	9	16
13	M03NA25	7	8	7	7	7	8	7	11	11	9	7	15	11	11	7	11	11	9	9	8	7
14	E03NA33	4	7	4	4	3	6	4	10	9	9	4	9	9	9	4	9	8	9	7	7	9
15	E04NA34	7	6	7	7	4	6	7	3	3	3	7	3	3	2	7	3	2	8	6	6	7
	Mean	7.0667	9.4667	7.0667	7.0667	7.0667	8.4	7.0667	13.067	12.933	12.867	7.0667	13.333	13.067	13.4	7.0667	13.4	13.133	9.7333	9.4667	8.4667	

Annex 7: Calculation of Weighted Averages on Implementation of Lean Techniques

Implementation of Lean Techniques in different stages			Weighted Average	Implementation of LT in different stages				No of stages	Weighted Average for each stage
				1	2	3	4		
1	LT01	Last Planner System	**0.093**				LT01	1	0.093
2	LT24	Total Quality Management	**0.077**			LT02	LT02	2	0.038
3	LT28	Work standardization	**0.073**		LT03	LT03	LT03	3	0.024
4	LT04	Visualization	**0.070**		LT04	LT04	LT04	3	0.023
5	LT11	Five S	**0.066**		LT05	LT05	LT05	3	0.022
6	LT05	BIM	**0.063**			LT07	LT07	2	0.032
7	LT02	Just in Time	**0.062**		LT09	LT09	LT09	3	0.021
8	LT09	Prefabrication / Off site manufacturing	**0.062**		LT10	LT10	LT10	3	0.021
9	LT42	Work structuring	**0.057**		LT11	LT11	LT11	3	0.019
10	LT07	Value Stream Mapping	**0.052**	LT12	LT12	LT12	LT12	4	0.013
11	LT10	Kaizen / Continiuos improvement	**0.049**		LT13	LT13	LT13	3	0.016
12	LT17	Target Costing	**0.048**	LT14	LT14			2	0.024
13	LT14	First Run Studies	**0.044**			LT15	LT15	2	0.022
14	LT08	Reverse Phase schedulling	**0.043**		LT17	LT18	LT19	3	0.014
15	LT03	3D Modelling	**0.042**	LT18	LT18	LT18	LT18	4	0.010
16	LT15	Relational Contracting	**0.040**				LT22	1	0.040
17	LT12	Faile Safe Quality / Poka-yoke	**0.036**		LT24	LT24	LT24	3	0.012
18	LT22	Kanban (Material Card)	**0.016**		LT28	LT28	LT28	3	0.005
19	LT13	Target Value Design	**0.008**		LT42	LT42	LT42	3	0.003

Annex 8: Data derived from Surveys for Designing the Tool

Lean Techniques implemented in Construction Project Delivery System				Weighted Average		Weighted Average in each stage		Level of Implementation of Lean Techniques				
								5	4	3	2	1
1	Stage 1	Five S	LT12	0.066	66.00	4	16.500	82.50	66.000	49.500	33.000	16.500
2		Target Value Design	LT14	0.008	8.00	2	4.000	20.00	16.000	12.000	8.000	4.000
3		Target Costing	LT18	0.048	48.00	4	12.000	60.00	48.000	36.000	24.000	12.000
1	Stage 2	3D Modelling	LT03	0.042	42.00	3	14.000	70.00	56.000	42.000	28.000	14.000
2		Visualization	LT04	0.070	70.00	3	23.333	116.67	93.333	70.000	46.667	23.333
3		BIM	LT05	0.063	63.00	3	21.000	105.00	84.000	63.000	42.000	21.000
4		Reverse Phase schedulling	LT08	0.043	43.00	3	14.333	71.67	57.333	43.000	28.667	14.333
5		Prefabrication / Off site manufacturing	LT10	0.062	62.00	3	20.667	103.33	82.667	62.000	41.333	20.667
6		Kaizen / Continiuos improvement	LT11	0.049	49.00	3	16.333	81.67	65.333	49.000	32.667	16.333
7		Five S	LT12	0.066	66.00	4	16.500	82.50	66.000	49.500	33.000	16.500
8		Faile Safe Quality / Poka-yoke	LT13	0.036	36.00	3	12.000	60.00	48.000	36.000	24.000	12.000
9		Target Value Design	LT14	0.008	8.00	2	4.000	20.00	16.000	12.000	8.000	4.000
10		Relational Contracting	LT16	0.040	40.00	3	13.333	66.67	53.333	40.000	26.667	13.333
11		Target Costing	LT18	0.048	48.00	4	12.000	60.00	48.000	36.000	24.000	12.000
12		Total Quality Management	LT24	0.077	77.00	3	25.667	128.33	102.667	77.000	51.333	25.667
13		Work standardization	LT28	0.073	73.00	3	24.333	121.67	97.333	73.000	48.667	24.333
14		Work structuring	LT42	0.057	57.00	3	19.000	95.00	76.000	57.000	38.000	19.000
1	Stage 3	Just in Time	LT02	0.062	62.00	2	31.000	155.00	124.000	93.000	62.000	31.000
2		3D Modelling	LT03	0.042	42.00	3	14.000	70.00	56.000	42.000	28.000	14.000
3		Visualization	LT04	0.070	70.00	3	23.333	116.67	93.333	70.000	46.667	23.333
4		BIM	LT05	0.063	63.00	3	21.000	105.00	84.000	63.000	42.000	21.000
5		Value Stream Mapping	LT06	0.052	52.00	2	26.000	130.00	104.000	78.000	52.000	26.000
6		Reverse Phase schedulling	LT08	0.043	43.00	3	14.333	71.67	57.333	43.000	28.667	14.333
7		Prefabrication / Off site manufacturing	LT10	0.062	62.00	3	20.667	103.33	82.667	62.000	41.333	20.667
8		Kaizen / Continiuos improvement	LT11	0.049	49.00	3	16.333	81.67	65.333	49.000	32.667	16.333
9		Five S	LT12	0.066	66.00	4	16.500	82.50	66.000	49.500	33.000	16.500
10		Faile Safe Quality / Poka-yoke	LT13	0.036	36.00	3	12.000	60.00	48.000	36.000	24.000	12.000
11		First Run Studies	LT15	0.044	44.00	2	22.000	110.00	88.000	66.000	44.000	22.000
12		Relational Contracting	LT16	0.040	40.00	3	13.333	66.67	53.333	40.000	26.667	13.333
13		Target Costing	LT18	0.048	48.00	4	12.000	60.00	48.000	36.000	24.000	12.000
14		Total Quality Management	LT24	0.077	77.00	3	25.667	128.33	102.667	77.000	51.333	25.667
15		Work standardization	LT28	0.073	73.00	3	24.333	121.67	97.333	73.000	48.667	24.333
16		Work structuring	LT42	0.057	57.00	3	19.000	95.00	76.000	57.000	38.000	19.000
1	Stage 4	Last Planner System	LT01	0.093	93.00	1	93.000	465.00	372.000	279.000	186.000	93.000
2		Just in Time	LT02	0.062	62.00	2	31.000	155.00	124.000	93.000	62.000	31.000
3		3D Modelling	LT03	0.042	42.00	3	14.000	70.00	56.000	42.000	28.000	14.000
4		Visualization	LT04	0.070	70.00	3	23.333	116.67	93.333	70.000	46.667	23.333
5		BIM	LT05	0.063	63.00	3	21.000	105.00	84.000	63.000	42.000	21.000
6		Value Stream Mapping	LT06	0.052	52.00	2	26.000	130.00	104.000	78.000	52.000	26.000
7		Reverse Phase schedulling	LT08	0.043	43.00	3	14.333	71.67	57.333	43.000	28.667	14.333
8		Prefabrication / Off site manufacturing	LT10	0.062	62.00	3	20.667	103.33	82.667	62.000	41.333	20.667
9		Kaizen / Continiuos improvement	LT11	0.049	49.00	3	16.333	81.67	65.333	49.000	32.667	16.333
10		Five S	LT12	0.066	66.00	4	16.500	82.50	66.000	49.500	33.000	16.500
11		Faile Safe Quality / Poka-yoke	LT13	0.036	36.00	3	12.000	60.00	48.000	36.000	24.000	12.000
12		First Run Studies	LT15	0.044	44.00	2	22.000	110.00	88.000	66.000	44.000	22.000
13		Relational Contracting	LT16	0.040	40.00	3	13.333	66.67	53.333	40.000	26.667	13.333
14		Target Costing	LT18	0.048	48.00	4	12.000	60.00	48.000	36.000	24.000	12.000
15		Kanban (Material Card)	LT21	0.016	16.00	1	16.000	80.00	64.000	48.000	32.000	16.000
16		Total Quality Management	LT24	0.077	77.00	3	25.667	128.33	102.667	77.000	51.333	25.667
17		Work standardization	LT28	0.073	73.00	3	24.333	121.67	97.333	73.000	48.667	24.333
18		Work structuring	LT42	0.057	57.00	3	19.000	95.00	76.000	57.000	38.000	19.000
Total Score							100	5.00	4.00	3.00	2.00	1.00

Annex 9: Tool for Assessing Lean Maturity in a Construction Project

Software Programme CD is attached as Annex 9.

Annex 10

SIGNIFICANCE OF MINIMIZING NON-VALUE ADDING ACTIVITIES IN CONSTRUCTION PROCESSES USING LEAN TECHNIQUES

N. Thilakarathna[1], De Silva L.[2],
[1]Department of Quantity Surveying, Prime Homes (Pvt) Ltd, Sri Lanka
E-mail: nrkthilaka@yahoo.com
[2]Department Building Economics, University of Moratuwa, Sri Lanka
E-mail: lalith.consultantarch@hotmail.com

Abstract:

Non value- adding activities (NVAAs) generated in the construction processes are recognized as major weaknesses that hinder performance and efficiency. Activities that do not add value to the final product are simply a waste and should be minimized or eliminated. The greatest obstacle to minimize NVAAs in general is failure to recognize it. Most of these activities are intangible and invisible. However fewer attempts have been made to minimize the NVAAs in construction processes. Lean construction is an effort to apply lean production principles to the construction industry to eliminate NVAAs from the construction processes and to maximize value to clients. However, the industry lacks an implementation framework to minimize NVAAs in construction processes and this research aims to develop a framework for minimization of non-value adding activities in construction processes using lean techniques. A detailed literature review was carried out to investigate the lean implementation in construction processes in order to identify the widely used lean techniques and to identify the NVAAs in construction processes. Quantitative research techniques were adopted aiming data collection from two different groups of professionals in order to recognize NVAAs in the construction processes in Sri Lanka and to investigate the current level of implementation of lean techniques in construction processes. This paper reports the level of existence of non-value adding activities and the level of implementing the lean technique in Sri Lankan construction industry and emphasizes the need for developing a framework for minimizing NVAAs in construction processes using lean techniques. Data collection of this study was limited to Sri Lankan construction projects initiated recently and their professionals by focusing the construction stage of building projects.

Key Words: *NVAAs, Construction Processes, Lean Techniques*

1.0 INTRODUCTION

Low productivity, insufficient quality, time over-runs, poor safety are the problems which have been illustrated by several studies (Latham, 1994; Egan, 1998). Singleton and Hamzeh (2011) revealed that over the past 20 years, innovations have brought major changes to the project organization and commercial terms, such as Design and Build and Partnering. However, these changes have done very little to improve construction in terms of efficient use of labour, equipment, and material. The project operating system has been largely neglected in construction. This situation contributes significantly to inefficiency and waste and lead to construction's low productivity rates (Thomsen *et al*., 2010). According to

Emuze and Smallwood (2011), clients are neutral or dissatisfied with the performance of contractors on 18% of the projects surveyed in 2009 and around 12% of the projects surveyed had levels of defects that are regarded as inappropriate, health and safety on construction sites remaining a concern. Further, Thomsen *at al* (2009) argued that construction projects frequently suffer from in dimensions; adversarial relationships, low rates of productivity, high rates of inefficiency and rework, frequent disputes, and lack of innovation, injury or fatalities among workers. Similarly, Rahman (2012) stresses that the main reasons for construction industry low performance were due to the temporary organizational structure of construction team and inefficient construction process. Consequently, the construction industry is backward while other industries have modernized their practices (Vilashini *et al*, 2011). The construction Industry still maintain its craft methods of operation, and continues to lag behind in productivity, quality and delivering value for money to its clientele (Alinaitwe, 2008; Pheng & Li, 2011;Howell & Ballard, 1997; Koskela, 2000). Most construction managers agree that the industry is vulnerable to multiple wastes, overruns, delays, errors, and efficiency (Al-Aomar (2012). In manufacturing defective parts are largely discarded rather than reworked due to the simplicity and flexibility of the product where as in construction, rework is a common practice since only one final product is delivered. Moreover, the labour intensity increases the risk of human errors and quality issues are widespread in the industry. In manufacturing manufacturer-supplier relationships are clear, more manageable and open to repetition. However, in construction, these relations are more dynamic and complex.

Construction sector includes a wide range of activities including provision of professional and technical input .All construction activities can be divided in two categories; one is conversion activities which produce tangible output and the second is flow-based activities which bind such conversion activities during the delivery process of the output (Koskela, 2004; Thomsen *et al.*, 2010). According to Senaratne & Wijesiri (2008), traditional thinking of most of the Construction related organizations focuses on conversion activities and ignores flow-based activities which do not add value to the final product. Waste is generally identified as waste of material in the construction process while activities such as rectification of defects, rework, inspection, delays, transportation of materials and others are not recognized as NVAAs that may lead to waste. Hence, there is considerable scope for minimizing NVAAs in construction processes especially in terms of cost, H & S, quality, and time. Previous studies (Senaratne & Wijesiri, 2008; Vilashini et al, 2011; Rahman et al 2012), disclose that the domestic construction industry workforce is ignorant of these NVAAs that create waste and hinder construction performance. Waste is a major problem in the construction industry which amounts to 60% of the construction effort (Vilashini et all, 2011). Many researches (Mosman, 2009; Horman and Kenley, 2005; Vilashini et al, 2011) revealed that a major portion of time in construction is devoted to wasteful activities.

Mosman (2009) has found that Proportion of construction effort creating value is (5-10%), supporting value creation (30-35%) and wasted (55-65%).

The manufacturing industry has been a constant reference point and a source of innovation for construction over many decades (Vilashini and Neitzert 2012). Taiichi Ohno identified two types of activities as Value adding activities and non-value adding activities. Activities that do not add value are simply a waste and should be eliminated. Wastes that are mentioned are identified by Taichi Ohno as seven wastes that are part of lean manufacturing. In the context of both construction and productions, waste is primarily defined in seven categories; defects (errors), delays, over processing, over production, excess inventory, unnecessary transport and conveyance of materials and equipment, and unnecessary motions and movement of people (Ohno, 1988).The lean concept is one of such strategies adopted by the construction industry from the manufacturing industry to improve performance (Vilashini and neitzert (2012). Previous studies shown that tremendous productivity improvements can be achieved by simply targeting at reducing or eliminating the NVAAs in construction processes.. Although all activities expend cost and consume time, Lean Principles state that only conversion activities add value and these should be made more efficient, where as non- value adding flow activities should be reduced or eliminated (Koskale, 1993). . By eliminating waste activities, processes can become 'lean' which provide 'more with less' resources (Womack and Jones, 2003).

In recent past, researches have put greater focus on developing ways in which a construction project operating system can be improved and one such method is known as Lean Construction (Singleton and Hamzeh, 2011).Lean construction results from the application of this new form of production management to construction, which has the goal of meeting the customer's needs while using the least of everything (Rahman et al, 2012). Further, Shang et al (2012) revealed that lean is an innovative construction management approach which is linked closely to the overall life of the project to ensure project success. Through an opinion survey of construction workforce, Senaratne and Wijesiri (2008) establish that lean construction is suitable and acceptable in the Sri Lankan context.

The background study reveals that the NVAAs are recognized as a major weakness, which hinders performance and efficiency in the Construction Industry However, the industry lacks an implementation framework to minimize NVAAs in construction processes. Therefore, this research aims to develop such a framework for minimization of NVAAs in construction processes and achieve long-term benefits by becoming lean.

2.0 RESEARCH METHODOLOGY

A Preliminary literature review into lean construction implementation was carried out to explore the lean techniques and their applications with benefits and barriers as the first step of the study. Secondly a detailed literature review was carried out to investigate the lean implementation in construction processes in order to identify the widely used lean techniques and to identify the NVAAs recognized in construction processes. Accordingly three hypotheses were established through the detailed literature review in order to achieve the aim and objectives of the study; H1: Non-value adding activities are generated in the construction processes, H2: Lean Techniques are implemented in the construction processes, H3: Non- value adding activities in construction processes can be minimized using lean Techniques. Finally the research was designed to collect the data through questionnaire survey within the Quantitative research approach to develop a framework for minimization of NVAAs in construction process using lean techniques in construction industry. Three different questionnaires were designed to test the three hypothesis established as explained above. As the first stem, a survey was carried out based on Questionnaire One among the construction professionals to recognize the NVAAs in the construction processes in Sri Lankan construction industry. The second survey was carried out based on Questionnaire Two to investigate the current level of implementation of lean techniques in construction processes in Sri Lankan construction industry. Collected data was analyzed using SPSS software. The next step of the study is to collect the data based on questionnaire three from the senior project managers of grade one construction organizations in Sri Lanka to develop the framework for minimization of NVAAs in construction processes using lean techniques in construction industry. Finally, expert opinions will be obtained to refine the framework in order to assess the lean maturity in construction processes as last step of the study. This paper presents the research conducted to test Hypothesis 1 to recognize the NVAAs in construction processes and Hypothesis 2 to establish the current level of implementation of Lean techniques in Sri Lankan Construction Industry. Significance of developing a framework for minimizing NVAAs in construction processes using lean techniques is further emphasized.

3.0 TESTING HYPETHESIS 1: NVAAS ARE RECOGNIZED

THEORITICAL FRAMEWORK

The researcher dealt with 200 publications related to construction industry to identify the examples of NVAAs.17 publications out of this 200 were identified for critical review as these literatures broadly define the issues related to NVAAs. According to this literature review 48 examples of NVAAs were explored as indicated in figure 1.

No.	Non value-adding activity	Category
1	Repair work	Defects
2	Design errors	Defects
3	Design changes	Defects
4	Installation errors	Defects
5	Vendors errors	Defects
6	Damage by other crafts	Defects
7	Incomplete installations	Defects
8	Re handling materials	Defects
9	Damaged materials on site	Defects
10	Poor material allocation	Defects
11	Rework	Defects
12	Site layout is not carefully planned	Defects
13	Uncompleted work	Defects
14	Delay to schedules	Waiting
15	Waiting for instruction	Waiting
16	Waiting for equipment repair	Waiting
17	Waiting for equipment to arrive	Waiting
18	Equipment frequently breakdown	Waiting
19	Waiting for clarifications	Waiting
20	Waiting for people and material	Waiting
21	Activity delay	Waiting
22	Idle time	Waiting
23	Unnecessary material / people movement	Motion
24	Unnecessary motion	Motion
25	Excessive labour movement	Motion
26	Excessive material movement	Motion
27	Material stocks	Inventory
28	Inventory work	Inventory
29	Excess material inventory	Inventory
30	Inventories	Inventory
31	Unnecessary processing	Extra Processing
32	Long approvals	Extra Processing
33	Retests	Extra Processing
34	Excessive safety measures	Extra Processing
35	Excessive supervision	Extra Processing
36	Excessive information Excessive training time	Extra Processing
37	Unnecessary material transport movement	Transport
38	Travelling time	Transport
39	Unnecessary transport	Transport
40	Long transport time	Transport
41	Unwanted productions	Overproduction
42	Unnecessary works	Overproduction
43	Material waste	Overproduction
44	Inefficient work	Overproduction
45	Material does not meet specifications	Others
46	Taxes	Others
47	Pilferage	Others
48	Making -do	Others

Figure 1. Examples of Non value-adding activities

These examples of NVAAs were further categorized into seven type of wastes which was brought forward by Taichi Ohno with the addition of an eighth category as “other “for wastes which do not fall into the above seven categories. This Literature review informs that NVAAs are the major reason behind schedule delays, cost over runs and other related problems in construction processes (Emuze and Smallwood 2011). An alternative way to tackle the problem is to identify activities, which do not add value to the customer

(Josephson and Saukkoriipi, 2001). According to Salem et al (2006), there are lots of wastes in construction processes which were left unnoticed. Previous studies (Senaratne & Wijesiri, 2008; Vilashini et al, 2011; Rahman et al 2012), disclose that the domestic construction industry workforce is ignorant of these NVAAs that create waste and hinder construction performance. NVAAs in various forms have a detrimental effect on construction projects (Alwi et al, 2002). Any form of NVAAs impact cost and productivity negatively.

DATA COLLECTION AND ANALYSIS

Figure 2 illustrates the data obtained through the survey. It is revealed that all 48 examples pre-selected in literature survey were accepted by the respondents and the average of the existence of NVAAs in Sri Lankan construction industry was found to be 59%.

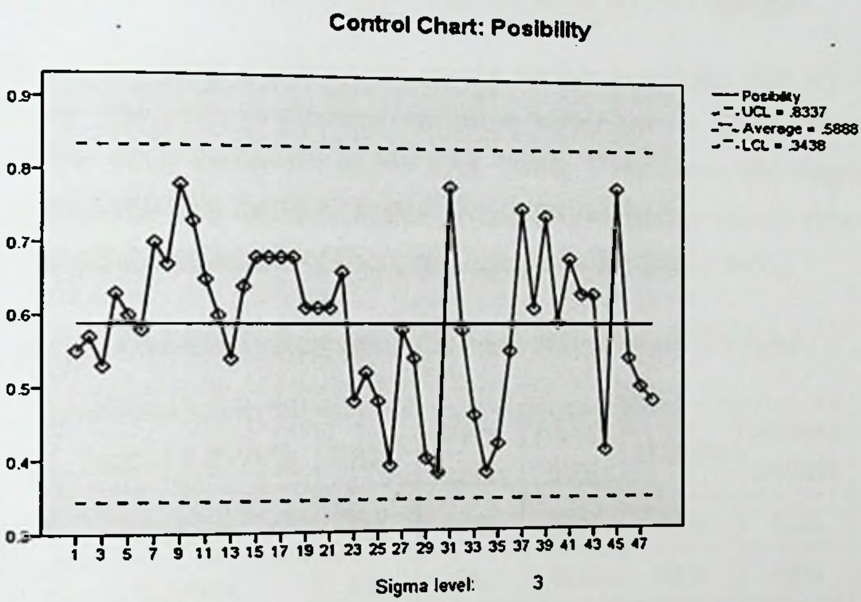

Figure 2. NVAAs in Sri Lankan construction industry

The target sample was 30 number of construction professionals who represent the middle management of construction related organizations. Site Engineers, Project Quantity Surveyors, and Project Architects of both construction and consultant organizations who have more than 10 years' experience in the construction field were based on the structured questionnaire with comprises of 8 main questions to cover all 48 examples identified thought literature survey. The respondents were asked to rate the significance of each of these wastes on a qualitative scales of never, very rarely, about 50% usually, almost always as per their perception. Figure 3 demonstrates the frequency of the identified 48 examples of NVAAs in terms of their rating with a mean of 59%.

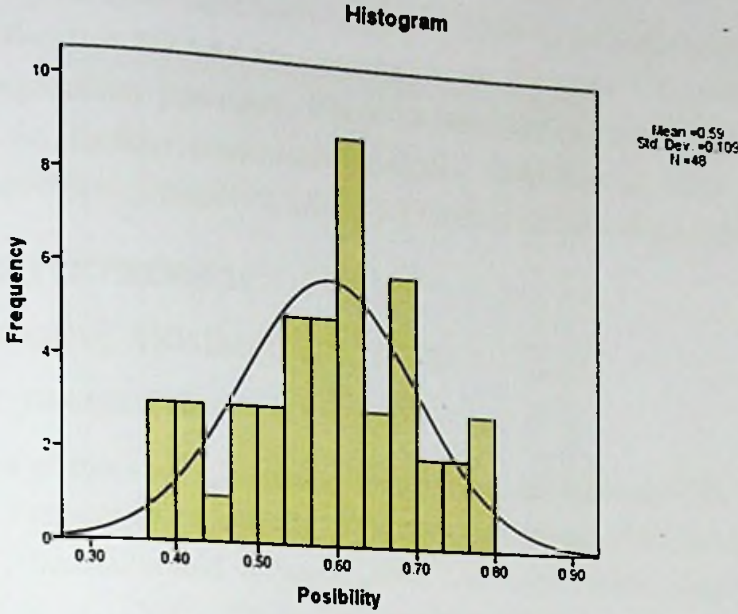

Figure 3. Frequency of the response for 48 NVAAs examples

Research findings from questionnaire survey further highlights that NVAAs related to defects, waiting and extra procedures are more significant in Sri Lankan construction industry than the other categories of NVAAs. Table 1 illustrates the responses for each category based on the five different scales given. The highest response reports for defects and waiting and all the examples of these two categories are above 50%.

TABLE 1: Responds for each category of NVAAs

Types of NVAAs	Never	Very Rarely	About 50%	Usually	Almost always
Defects	0%	14%	33%	41%	12%
Waiting	0%	6%	40%	43%	11%
Motion	10%	33%	28%	19%	10%
Inventory	4%	24%	50%	21%	1%
Extra Procedures	5%	24%	36%	27%	8%
Transport	1%	12%	26%	39%	22%
Overproduction	3%	21%	30%	33%	13%
Others	2%	20%	35%	32%	11%

FINDINGS

It can be summarized that almost all 48 examples of NVAAs identified through literature review were recognized by the respondents as prevalent in Sri Lankan construction industry. Findings of the above survey shows that NVAAs are generated at a significant level in the construction processes in Sri Lankan construction industry. Further it is revealed through the survey the most significant categories NVAAs are defects and waiting. Further it can be identified that NVAAs are occurred to an extent of 57% while performing the activities in construction processes. Hence, it can be concluded that Hypothesis 1 is acceptable for Sri Lankan construction industry underpinning need for developing a framework for minimizing these NVAAs in Sri Lankan construction industry.

4.0 TESTING HYPETHESIS 2:

LEAN TECHNIQUES ARE IMPLEMENTED

THEORITICAL FRAMEWORK

Literature review of this study (Koskela,1992; Howell and Ballard,1998; Tzortzopoulos and Formoso,1999; Pasquire and Connolly; 2002; Alarcon et al, 2005; Salem et al, 2006; Bae and Kim, 2007; Senaratne and Wijesiri, 2008; Mossman ,2009; Singleton and Hamzeh, 2011; Vilahsini et al , 2011; Zimina et al 2012 and many others) informs that lean philosophy a new paradigm for managing work in projects from concept to completion. Similarly, lean construction is a concept still new to many construction industries in the world. Consequently, lean construction is an effort to apply lean production principles to the construction industry to eliminate NVAAs from the construction processes and to maximize value to clients. Although all activities expend cost and consume time, lean principles state that only conversion activities add value and these should be made more efficient, whereas non value adding flow activities should be reduced or eliminated. Several lean techniques were developed for Manufacturing Industry by many authors. Lean principles argue that waste could be eliminated by certain techniques which provide more value with fewer resources. 34 number of journal articles were critically analyzed among 200 numbers of different literatures on construction and 54 numbers of lean techniques were identified. These lean techniques were further reviewed and filtered to 20 numbers on the basis that they were discussed by more than one author. Table 2 illustrates these 20 widely used lean techniques in construction processes.

TABLE 2: Widely Used Lean Techniques for construction processes

1	Last Planner System	11	Fail Safe Quality / Poka-yoke
2	Just in Time	12	Target Value Design
3	3D Modeling	13	First Run Studies
4	Visualization	14	Relational Contracting
5	BIM	15	Target Costing
6	Value Stream Mapping	16	Set based design
7	Reverse Phase scheduling	17	Kanban
8	Prefabrication / Off site manufacturing	18	Total Quality Management
9	Kaizen / continuous improvement	19	Work standardization
10	Five S	20	Work structuring

DATA COLLECTION AND ANALYSIS

A sample of 30 number of project managers was selected among the population of project manages of building projects which were completed recently where the adjusted contract value is more than 100 million in the Colombo District of Sri Lanka. It was presumed that this sample will have a thorough knowledge of recently developed construction management practices and will be aware of the current level of implementation of lean techniques in construction processes in Sri Lankan construction industry. Questionnaire was designed with 20 questions to represent each lean technique with five scales rating; never, very rarely, were about 50% usually, almost always given to rate. Data collected from the survey revealed that level of implementation of lean techniques differ one to another and average level of implementation is 40%. Further it is revealed that almost all lean techniques are implemented in Sri Lankan construction industry in different levels and none of them were at zero level. Figure 4 illustrates the level of implementing 20 numbers of lean techniques in construction processes in Sri Lankan construction industry.

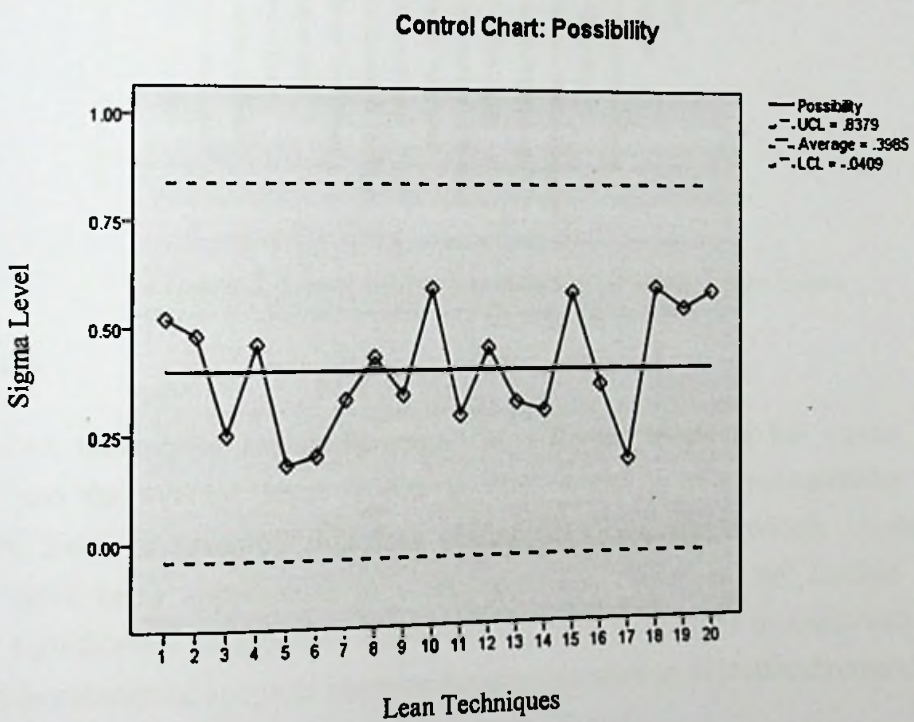

Figure 4. Current level of implementing lean techniques in Sri Lankan Construction Industry

Research findings from survey further highlights that the level of implementation lean techniques in Sri Lankan construction industry is in different levels. Figure 5 exhibits the level of implementation of 20 lean techniques with count of responses to illustrate the proceedings of implementation of lean techniques. Y axis of the graph shows the cumulative count of the responses against the lean techniques selected for the study. Moreover, it is obvious that all these 20 lean techniques are significant as per the data analysis indicated in figure 5. Five S, Total Quality Management, Target costing, work structuring, work standardization and last planner are techniques that implemented at a higher level where BIM, kanban, Value stream mapping and 3D modeling are implemented at minimum levels.

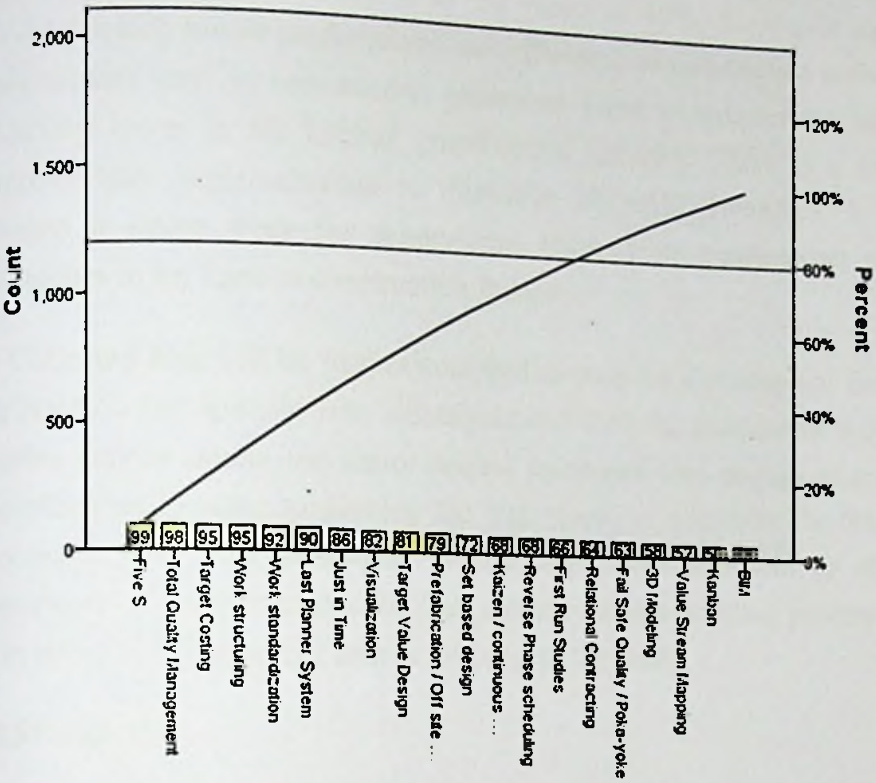

Figure 5. Level of implementation of Lean Techniques

FINDINGS

All 20 lean techniques are implemented in different levels in Sri Lanka construction industry and the average level reports as 40% which is at a substantially lower level. Literature findings revealed that lean techniques have been widely implemented and benefits have been appreciated in other countries. However, Sri Lankan construction industry significantly lags behind implementing lean techniques in construction processes and there is substantial scope to improve the implementation of lean techniques.

5.0 CONCLUSION AND WAY FORWARD

As explained above, 48 types of NVAAs were identified through a detailed literature review and Hypothesis 1 (H1) was established as NVAAs are generated in the construction processes and further this H1 was tested through a survey based on structured questionnaire. Findings of the survey revealed that almost all NVAAs are occurred in the construction processes and level of existence is at a level 57%. The most significant categories of NVAAs have been identified as defects and waiting. On the other hand, 20 numbers of lean techniques were identified as commonly used lean techniques in construction industry through literature survey and Hypothesis (H2) was established as Lean techniques are implemented in the construction industry. Subsequently H2 was tested and it was revealed through the study lean techniques are implemented in the construction industry in Sri Lanka and the level of implantation is in the range of 40%. Hence, it can be concluded that NVAAS which hinder performance and efficiency in constriction activities are generated at a significant level in construction processes. Lean techniques are implemented only at a relatively lower in Sri Lankan construction industry. There is a considerable scope to improve lean implementation to minimize NVAAS. Therefore, it is very pertinent to develop a frame work for minimizing NVAAs in construction processes using lean techniques in Sri Lankan construction Industry.

Collected data will be further analyzed to propose a conceptual framework by mapping the NVAAs and specific lean techniques and then the framework will be developed using another survey among the senior project managers who engage in grade one construction organizations in order to develop the framework to minimize the NVAAs in construction processes using lean techniques Finally, expert opinions will be obtained to refine the framework in order to assess the lean maturity in construction processes and achieve long-term benefits by becoming lean as last step of the study.

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Literature Review On Lean Implementation Cases In The Construction Process

Nilmini Thilakarathna*
Department of Quantity Surveying, British College of Applied Studies, Sri Lanka
Sepani Senaratne
Department of Building Economics, University of Moratuwa. Sri Lanka.

Abstract

Lean construction is a concept still new to many construction industries in the world. All construction activities can be divided into two; conversion activities which produce tangible and flows 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 more efficient, where as 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, the 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, Sri Lankan construction industry lacks an implementation framework to implement lean principles into the 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 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 process 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). 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, perfection shifts the improvement focus from the activity to the delivery system (Howell, 1999). Similarly, Koskela (2004) defined that lean production is 'lean' because it uses less of everything 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 construction industries in the world (Senaratna and Wijesiri, 2008). All construction activities can be divided into two; conversion activities which produce tangible and flows 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, where non value adding flow activities should be reduced or eliminated (Koskale,1993). Research into these lean principles in construction has found 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

The recent findings (Senaratne and Wijesiri, 2008; Senaratne & Nissanka, 2009) reveal frequent flow activities that generate waste and their causes in the Sri Lankan Construction Industry. Traditional thinking of most of the Construction organisations focuses on conversion activities and *ignores flow and value considerations*. Waste is generally associates 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 are*; Waste due to wait periods, Defects, Waste due to design errors, Transport/ handling time, Activity delays, Waste due to operations, Excessive space / stock, Rework. *Causes of Wastes* are; Late

Information, Environmental causes, Poor management control, Poor Planning, Poor Quality of resources, Shortage of Resources, Defective information, unclear information. Majority of flow wastes and their causes are identified as controllable.

These flow wastes are recognized as a major weakness, which hinder performance and efficiency in the Sri Lankan Construction Industry. Previous studies 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 construction workforce, Senaratne and Wijesiri (2008) establish that lean construction is suitable and acceptable in the Sri Lankan context. However, the industry lacks an implementation framework to implement lean principles into the construction processes. This research aims to develop such an implementation framework through action research study for Sri Lankan construction contractors and achieve long-term sustainable benefits by becoming lean.

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. 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 process 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.

1.4 Lean Techniques

Eagan (1998) defined 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. Lean principles determine the goals of lean manufacturing. Several lean techniques were developed for manufacturing industry by many authors and Table 1.1 summarizes lean techniques that relate to 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)
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 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. Generation of ideas that alert for potential defects. 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 and
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
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 drives 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 the construction projects. Most companies and researches have reported satisfactory results from their implementation (Alarcon et al, 2005). However, there is a still need to provide more extensive analysis of the empirical evidence available to assess the impact of the implementation of the 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 can cure the shortcomings of the mainstream cost 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 projects 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 rise.
Sustainable Value on Construction project and Application of lean construction	To examine how current lean construction tools and methods impact the	Literature Synthesis	Target Costing Just-in-time Prefabrication Value stream	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

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Methods ***Bae,J.W., and Kim, Y.W., 2007***	construction and operation of sustainable facilities		mapping kaizen	image improvement Environmental Perspective; reduce resource depletion, pollution prevention by eliminating wastes, and resource preservation
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 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, consultant 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	To identify the contribution of the lean concept to achieve sustainability in Precast Concrete Factories. By using appropriate lean	Quantitative assessment of each non-value adding activity and Qualitative assessment of activities that cannot be quantitative though semi-	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 which is long term comparison. Lean Production philosophy has practical contributions to sustainable development. By eliminating non-vale activities pre-casters can

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Peng, W. And Pheng, S. 2010	principles, the precast concrete industry can move closer towards sustainability	structured interviews of 17 pre-casters		achieve more environmental friendly construction materials
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 outcome 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 Las Planner

Overall, 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 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 more relevant compared to other phases considering the ultimate aim of the research which 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 this activity (Salem et al (2006). Sri Lankan industry lacks an implementation framework to implement lean principles into the construction processes. Previous studies 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 Sri Lankan Construction Industry. This research aims to develop such an implementation framework through action research study for Sri Lankan construction contractors and achieve long-term sustainable benefits by becoming lean. Hence, it is vital 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 discuss the similarities and deviations of the lean implementation of the above three studies and finally a summary is 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 the 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, different bid package from the garage project. This was 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. Participating trades in the lean construction implementation study were limited to the general contractor, the formwork subcontractor and the rebar subcontractor.

Findings revealed that Last Planner, increased visualization, Daily Huddle Meetings and First Run Studies achieved more effective outcome and 5S and Fail Safe for Quality 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. 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 changing mind sets and behaviour with lean thinking became a challenge initially in this project, and these also 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 GC had offered training classes, provided recognition to promote behavioural change. Encourage employee involvement and rewarded real improvement. As a result, the work force has shown a tremendous amount of learning and improving curves on lean thinking and implementation. Findings suggested further, training will be a key aspect of implementation and success of the Last Planner at the site. The staff and workers will need to be trained to use this toll effectively. This training may results in an increased burden in early stages of implementation but over the long haul, it will serve to increase the efficiency of construction companies and more than make up for the initial investment in training.

The authors had found that the lean manufacturing tools can be modified for 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 in successful implementation of these tools. The authors observed a complete attitudinal shift in the project participants in this project. At the beginning of the project, the project manager questioned the applicability of these lean tools at the site. However, by the end of the project, everyone on the 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 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.

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

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 Chilie, 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, Plenary 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 construction. Data was collected during a 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 during 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 emphasis on the Weekly Work Plan, and only informal lookahead planning. The second group included 6 projects that formal lookahead planning process and one case formal workable backlog and learning processes.

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 (Choo et al 1999) for Last Planner System implementation. 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 in a continuous interaction with them during system design. The one of the main impact 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; working in a collaborative approach, with different training actions, sharing experiences and information among the companies. It produces a number of benefits; development of skills for implementation, development of healthy competition among companies that are working together, fast learning from successes and failures. Further, they have realized that things are possible because there is always a project that could do it and they can learn how to do it better the next time. Some implementations barriers were also identified in this study with regard to the implementation of LPS. Barriers are; 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) explore the current implementation of Lean principles within construction projects in Sri Lanka Lack of Self Criticism 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

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 other two are not directly relate with lean implementation.

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 and first hypothesis "*if a project implements last Planner more, it achieves better project performance better than those employing LP less*" is considered for this evaluation since 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 problem 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).

These indicators were transformed into survey questions and answer type with scoring rules were established. 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			
Attitudinal 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 an effective lean technique in construction process. Findings revealed further changing mind sets, low understanding of the concepts and behaviour with lean thinking are the challenges to implement lean technique and training will be a key aspect to overcome most of the 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 Sri Lankan Construction Industry. Lean Implementation cases obtained from 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 and 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 is 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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A Preliminary Literature Review Into Lean Construction Implementation

Abstract

Nilmini Thilakarathna*
Department of Quantity Surveying, British College of Applied Studies, Sri Lanka
Sepani Senaratne
Department of Building Economics, University of Moratuwa. Sri Lanka.

Although all activities expend cost and consume time, Lean Principles state that only conversion activities add value and these should be made more efficient, whereas non value adding flow activities should be reduced or eliminated. Research into these lean principles in construction has found that considerable waste lies in flow processes of construction. By eliminating waste activities, processes can become 'lean' which provide 'more with less' resources. These flow wastes are recognized as a major weakness, which hinder performance and efficiency in the Construction Industry. Previous studies conclude that the construction industry workforce is ignorant of these flow activities that create waste and hinder construction performance.

However, the industry lacks an implementation framework to implement lean principles into the construction processes. This research aims to develop such an implementation framework through action research study for Sri Lankan construction contractors and achieve long-term sustainable benefits by becoming lean. The research is in its initial stage and the aim of this paper was to explore the literature on how LC is implemented in different contexts in construction industries in the world.

The findings reveal several benefits when applying lean principles in construction such as reduce sharing of non-value adding activities, increase the output value through systematic construction of customer requirement and reduce process variability. The paper finally, identify the few barriers for implementing lean principles and provides some guidelines on how to overcome the identified barriers for effective implementation of lean principles.

Key words: Implementation, Lean Principles, Construction Industry, Literature review

*Corresponding Author :E-mail-nilmini@bcas.lk, Tel- 0094112735977, Fax-0094112559255

INTRODUCTION

Construction project delivery system consists of three domains; the contract, the project organization and the project operating system (Thomsen *et al.*,2010). Within the typical project structure the parties involved in a project such as Client, Contractor and Designer generally worry about their own interests and communication which usually occur along contractual lines. Singleton and Hamzeh (2011) stated that over the past 20 years, innovations have brought major changes to the project organization and commercial terms, such as Design and Build and Partnering. However, these changes have done very little to improve construction in terms of efficient use of labour, equipment, and material. The project operating system has been largely neglected in construction. Thomsen *et al.*, (2010) revealed that this situation contributes significantly to inefficiency and waste and lead to construction's low productivity rates. In recent past, researches have put greater focus on developing ways in which a construction project operating system can be improved and one such method is known as Lean Construction (Singleton and Hamzeh, 2011).

First, the paper explains the implications of the lean principles, and how when taken together they result in different ways to manage construction activities. Second, the literature on lean construction implementations are explored in different construction settings. Third, their effectiveness together with benefits offered and implementation issues are investigated. Implementing lean in construction in any setting then becomes a matter of developing and acting on this already available knowledge and good practices. It is hoped that the key literature findings arising from this stage, will assist to develop a conceptual implementation framework using lean principles for the construction process.

LEAN CONSTRUCTION

Although all activities expend cost and consume time, Lean Principles state that only conversion activities add value and these should be made more efficient, whereas non value adding flow activities should be reduced or eliminated (Koskale, 1992). Similarly, Ballard and Howell (2003) stated that lean constriction is aimed to maximize value and to minimize waste of money, time and materials. Lean construction is a concept still new to many construction industries in the world (Senaratne and Wijesiri, 2008). All construction activities can be divided into two; *conversion activities* which produce tangible and flows activities which bind such conversion activities during the delivery process of the output. Research into these lean principles in construction has found 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). Further, Salem and Zimmer (2005) defined that lean construction is a continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project.

UNDERSTANDING WASTE

When focusing on waste, attention is on what is not needed. So, it is easy to lose sight of value what the customer wants (Mossman, 2009). Further, he states that when there are more demanding problems or emerging waste, the initial waste that was aimed to eliminate can re-emerge. The waste emerging cycle demonstrated in Figure 1 illustrates when focused on waste elimination, how it gets into an oscillation in which the amount of waste increases and decreases. This pattern can be seen very clearly on construction sites. For example, when one trade falls behind, a special pressure is put on to catch up. Pressure is then reduced as attention shifts to another trade that is now more behind. Now in the first trade things slip again and the, pressure is increased again. Therefore, Mossman (2009) stressed that value should be focused rather than waste. Focusing on the value is more rewarding and more effective. Value is delivered and waste is eliminated or perhaps not even created in the process.

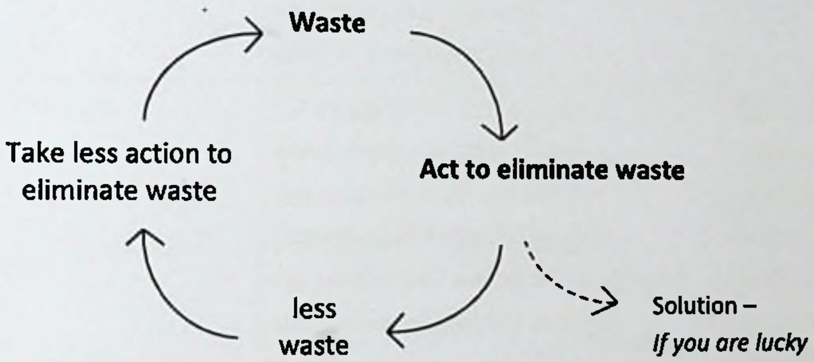

Figure 1 : Waste elimination Cycle Source: Mossman (2009)

Waste that generate in flow activities are recognized as major weakness, which hinder performance and efficiency in constriction activities. Several authors including Cornick (1991), Austin et al. (1994), and Koskela *et al* (2001) have discussed the main causes for the poor performance of building design process are poor communication; Lack of adequate documentation; Deficient or missing allocation; Lack of co-operation between disciplines; Unbalanced resource allocation; and, Erratic decision making. Lean principles argue that waste could be eliminated by certain techniques which provide more value with fewer resources. These are discussed in the next section.

LEAN TECHNIQUES AND THEIR IMPLEMENTATION IN CONSTRUCTION

Several lean techniques were developed for Manufacturing Industry by many authors. These are summarized in Table 1 and their implementation in construction industry is discussed next.

Lean Techniques	Definition	Application
Last Planner (LP)	Production Planning and Control system implemented on construction projects to improve planning and production performance (Hamzeh, 2009)	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 is a Japanese management philosophy which has been applied in practice since the early 1970s in many Japanese manufacturing organisations. It was first developed and perfected within the Toyota manufacturing plants by Taiichi Ohno as a means of meeting consumer demands with minimum delays (Monden, 1993)	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 modeling 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)
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).	This includes signs related to safety, schedule, and quality. This tool is similar to the lean manufacturing tool, Visual Controls, which is a continuous improvement activity that relates to the process control
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.

Lean Techniques	Definition	Application
Stopping the line	Stopping the line in manufacturing prevents the release of defective work down stream	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 Final Product
Five S	5S 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

Lean Techniques	Definition	Application
Fail Safe Quality	Shingo (1986) introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process. Generation of ideas that alert for potential defects.	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 and decisions are taken after defective parts have already been processed
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
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 (Ballard, 2011)

Table 1:Lean Construction Techniques

Last Planner is a lean technique that has four main processes: Master Schedule, Phase Schedule, Look ahead plan, and Weekly plan (Hamzeh, 2009). Many researches have proved reducing plan variability helps increase productivity. Alarcon et al. (2006) suggested a regression line between plan reliability and production and Alarcon et al. (1997) showed difference in productivity after implementing Last Planner. In construction, the effective point of intervention has proven to be the Weekly Work Plan, because that is where work is selected and commitments are made, and the key to reduction of uncertainty is improving the ability to keep commitments through better selection of work to be done (Howell, 1994).

With **the pull approach**, the concept of **just in time** is utilized in construction wherein the inventories are kept to the bare minimum and new inventories are ordered based on the current demand (Ballard and Howell, 1998). Stocking of material is wasteful. Its implementation requires good relationship with suppliers.

According to Egan (1998), Pacific Contracting of San Francisco, a specialist cladding and roofing contractor have used the principle of lean thinking to increase their annual turnover by 20%in 18 months. The key to this success was improvement of the design and procurement process in order to facilitate the construction site. They used a computerized ***3D design*** system to provide better, faster information provides isometric drawings of components and interfaces, fit co-ordination, planning of construction methods, motivation of the work crews through ***visualization***. Further Khanzode (2005) states that having a constructible design, reduces the amount of contractors' requests for information and change orders related to field changes. Additionally, MEP (Mechanical, Electrical and Plumbing) contractors are able to use more prefabrication which improves productivity on site and improved safety. And also, Staub-French et al. (2003) revealed that 3D models can be used for accurate quantity takeoff. When quantities are taken off manually there is lot of waste in construction process because quantity takeoff needs to be performed each time the design is updated. **3D models** can produce quantities automatically based on a means and methods database.

In the building sector, it has been customary for architects to work with customers to understand what they want, then produce facility designs intended to deliver what's wanted (Ballrad, 2011). The cost of those designs has then been estimated and too often, found to be greater than the customer is willing or able to bear, requiring designs to be revised, then re- estimated. This cycle of design – estimate – rework is wasteful and reduces the value customers get for their money. Cho and Bollard (2011) further stressed that cost, time, location and other constraints are conditions that must be met in order to deliver value to customers and implementation of ***Target Value Design*** has also consistently resulted in the delivery of projects faster and under budget, both market benchmarks and project targets.

Current practice in construction generally ignores or accepts large inventories or backlogs as the natural consequence of the commercial situation. According to Howell and Ballard (1998), lean works to eliminate those places where value adding work on material or information is interrupted. The Lean principle ***Make it Flow*** says that value development and therefore 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 and / or assure that resources are delivered in order required directly to the installation location.

According to Kobayashi 1998; Hirano (1989) Seiri (Sort) refers to separate needed tools / parts and remove unneeded materials (trash). Seiton (Straighten or set in order) is to neatly arrange tools and materials for ease of use (stacks/bundles). Seiso (shine) means to clean up. Seiketsu (standardize) is to maintain the first 3Ss and develop a standard ***5S's*** work process with expectation for the system improvement. Shitsuke (sustain) refers to create the habit of conforming to the rules. Spoore (2003) indicates that 5S is an area-based system of control and improvement. The benefits from implementation of 5S include improved safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (kaizen activities).

Howell and Ballard (1998) revealed that ***Value stream mapping*** brings choices to the surface and raises the possibility of maximizing performance at the project level. Normally maps are prepared at the project level and then decomposed to better understand how the design of planning, logistics and operations systems work together to support the customer value.

According to Koskela (1992), a specialist who transforms his/her perception on the client requirements i to Design Decision Previous researches confirm that the adoption of lean principles facilitate manufacturing through increasing productivity, reduction of manufacturing space, improving quality and safety, reducing lead time, reduce human effort, reduce investments in tools, reduce engineering hours to develop a new product and ultimately increasing of sustainability values. Vilashini et al, (2010) argued that many problems persistent with ***Prefabrication*** Production Process can be solved or reduced by adopting lean principles.

Terry and Smith (2011) state that taking a construction company, lean involves two significant paths; best people and the systems in place to control them. Figure 2 illustrates these two paths.

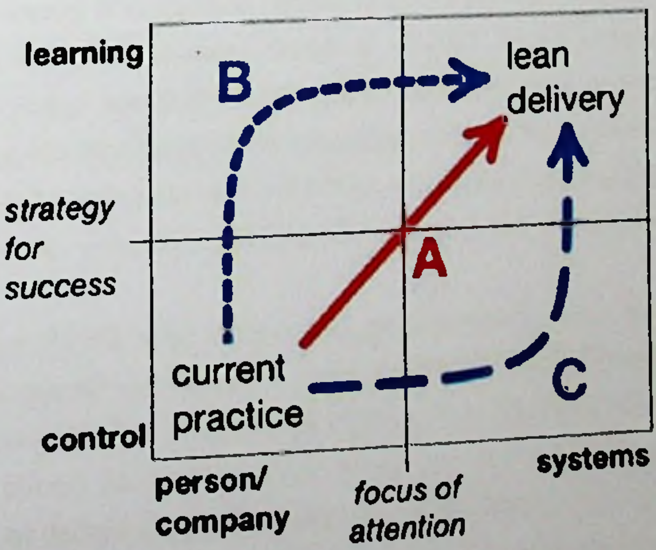

Figure 2: Paths to Implementation (Terry and Smith, 2011)

However, Howell (2011) argues that "successful transformations in my experience begin with action and study and lean construction focused on improving systems instead of individual motivation and training rather than control". According to Howell and Ballard (1998), both construction and manufacturing require prototyping, that is the design of both product and process. Thus, implementing lean production does not require making construction manufacturing by standardizing products, rather implementation starts by accepting the ideal of perfection offered by lean and understanding the application of each principle and technique to construction. Implementation of lean means adopting a "project-as-production-system" approach to construction.

On the whole, there is sufficient evidence on implementation of above discussed lean techniques in construction. However, some are implemented without the awareness on 'lean philosophy' and as a requirement of 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 as discussed next.

BENEFITS AND BARRIERS OF LEAN CONSTRUCTION IMPLEMENTATION

Significant variations generally occur at every stage of construction process. Plans change and materials are late. Howell and Ballard (1994) stated that in compressed circumstances, variation becomes more apparent and critical as it exposes the interdependence between activities. When lean construction is implemented and the work environment is stabilized through modifying the planning system, it becomes possible to reduce variation in flows that improve the downstream operations. However, many researchers concluded that there is lack of interest among construction parties to sit for a weekly review meeting to solve the problems causing the plan failures (Salem et al.2005 and Tzortzopoulos and Formoso, 1998). The other major problem which lies in the way is to make people change their mindset and be open to new ideas about managing construction projects. Salem et al. (2005) revealed that changing mindsets and behaviour with lean thinking become a challenge and to eliminate this barrier contractor need to offer training and recognition.

Howell and Ballard (1998) believed that lean production is a new way to coordinate action that rests on a new mental model and as problems are solved by "lean" the non-value adding flows would be recognized as problems in construction. Tzortzopoulos and Formoso (1998) stated that some clients have their needs which are not explicitly represented and some important aspects of design are abstracted away in the conceptualization. Further, persisting problems in conversion may be identified as: not all requirements are identified at the beginning of the project, design errors are detected in later phases leading to costly rework and time delays. Lean thinking can address these problems.

Formoso et al.(1999), identified other general benefits when applying lean principles in construction; i) Reduce sharing of non-value adding activities, ii)Increase the output value through systematic construction of customer requirement, iii) Reduce process variability, iv) Reduce cycle times, v) Simplify by minimizing the number of steps parts and linkages, vi) Increase output flexibility, vii) Increase process transparency, viii) Focus on complete process, ix) Build continuous implement into the process, x)Balance flow improvement with conversion improvement, xi) Benchmarking.

However, Alarcon et al. (2006) revealed that there are barriers in implementation the lean construction. These barriers are; ***Time***: The main difficulty is lack of time for implementing new practices in the projects, ***Training***: Lack of Training, ***Organization:*** Challenge to create organizational elements, ***Self Criticism***: Lack of self criticism to learn from errors, respond to some deficiencies, ***Low understanding*** of the concepts, Low use of Different elements, Inadequate administration, Weak Communication and transparency and ***lack of integration*** of the construction chain.

Further, Koskela et al.,(2010) stressed that the application of lean construction principles offer ***key benefits*** to prefabrication such as increase productivity, increase quality, increase sustainable values, provide better value to the customer and reduce human effort. On the other hand, Koskela et al.,(2010) concluded that there are issues in implementing lean construction techniques, especially in prefabrication such as: waiting times, inventorying, moving, high quality controlling, requirement of efficient testing, stock keeping, less flexibility to varying design, standardization and requirement of well trained people and resources.

Further, some researchers have attempted to apply lean principles in different construction delivery methods to get higher benefits. For example, Singleton and Hamzeh (2011) and Eagan (2004) have attempted to apply lean principles play a crucial to integrated project delivery (IPD) approaches such as in partnering and strategic alliances in order to maximize value and minimize waste on such projects. Further, Lamming (1996) relates lean principles to construction supply chain and Howell and Ballard (1998) to design process protocol and showed how benefits such as reduce variation in flows that improve the downstream operations and change people's attitudes could be achieved. Next section discusses suggestions offered by researchers in implementing lean principles in different construction contexts.

SUGGESTIONS OFFERED BY RESEARCHES ON SUCCESSFUL LEAN IMPLEMENTATION

Koskela and Siriwardena (2009) founded out that changes are needed in terms of the proper implementation of lean principles such as top management commitment to the implementation, sufficient technical experts regarding the lean production, a quest for a culture of continuous improvement the company, fullest dedication of workers towards the implementation, awareness of employees regarding the lean principles, change people's attitudes and sufficient management expertise to induce the changes in the production flow process. Further Salem et al. (2005) stress that the commitment of the top management of the construction firms for implementation of these lean tools may prove to be most important factor in successful implementation.

Some other studies offer guidelines for effective implementation of lean approaches. For example, Singleton and Hamzeh (2011) offer the following guidelines when implementation Integrated Project Delivery linking lean.

a) Avoid a segmented and rigid sequence of design activities
b) Explicit internal Client supplier relationships between sub processes
c) Involve designers in joint solutions
d) Work with a set of design alternatives
e) Introduce control focus on flow activities

Further, Ballard and Kim (2006) offer guidelines for implementing lean;

1. Select partners or suppliers who are willing and able to adopt lean project delivery
2. Structure the project organization to engage downstream players in upstream processes and vice-versa, and to allow money to move across organizational boundaries in pursuit of the best project – level returns
3. Do target costing: define and align project scope, budget and schedule to deliver customer and stakeholders value
4. Encourage thoughtful experimentation; explore adaptation and development of methods for perusing the lean ideal
5. Celebrate breakdowns as opportunities for learning rather than occasions for punishing the guilty
6. Do set based design: make design decision at the last responsible moment, with explicit generation of alternatives, and documented evaluation of those alternatives against stated criteria.
7. Practice production control; in accordance with lean principles such as making work flow predictable and using pull system to avoid over production

8. Build quality and safety in to the projects by placing primary reliance by acting to prevent breakdowns
9. Implement Just In Time and other multi organizational processes
10. Use 3D modelling to integrate product and process design

These lean implementations and guidelines on different context could be useful in exploring lean implementation in Sri Lankan construction industry. Next section discusses Lean construction approach in Sri Lanka and the research problem of the study.

CONCLUSIONS AND WAY FORWARD:

The aim of this paper was to explore the literature on how lean construction is implemented in different contexts in construction industries in the world.

The findings revealed several benefits when applying lean principles in construction such as

- Reduce sharing of non-value adding activities
- Increase the output value through systematic construction of customer requirement
- Reduce process variability
- Reduce cycle times
- Simplify by minimizing the number of steps parts and linkages
- Increase output flexibility
- Increase process transparency
- Focus on complete process
- Build continuous implement into the process
- Balance flow improvement with conversion improvement
- Benchmarking

The paper identified few barriers for implementing lean principles as ***Time***: The main difficulty is lack of time for implementing new practices in the projects, ***Training***: Lack of Training, ***Organization:*** Challenge to create organizational elements, ***Self Criticism***: Lack of self criticism to learn from errors, respond to some deficiencies, ***Low understanding*** of the concepts, Low use of Different elements, Inadequate administration, Weak Communication and transparency and ***lack of integration*** of the construction chain. Finally, the paper provided some guidelines on how to overcome the identified barriers for effective implementation of lean principles. These lean implementations and guidelines on different context could be useful in exploring lean implementation in Sri Lankan construction industry.

There are few studies conducted in Sri Lanka on lean construction. For example, through an opinion survey of construction workforce, Senaratne and Wijesiri (2008) establish that lean construction is suitable and acceptable in the Sri Lankan context. Further, Ekanayaka and Senaratne (2010) and Vilashini et al. (2011) have applied lean to Sri Lankan prefabrication production processes. Also, Ekanayake and Senaratna (2010) discussed the sustainable benefits in application of lean in prefabrication production process. All these studies show that the Sri Lankan industry is behind in effectively implementing lean in construction processes. The industry lacks an implementation framework to implement lean principles into the construction processes. This research aims to develop such an implementation framework through action research study for Sri Lankan construction contractors and achieve long-term sustainable benefits by becoming lean. It is expected that the key literature findings arising from this stage, will assist to develop a conceptual implementation framework using lean principles for the construction process.

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