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Developing Model for Building Project Performance Evaluation

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Abstract - The goal of this study is to test the effectiveness of some lean construction tools, in particular, those tools that can be applied in medium size construction firms. Due to the success of the lean production system in manufacturing, the construction industry has adapted lean techniques to eliminate waste and increase profit. This study provides a history of evolution of production practices and philosophies through the construction industry from the traditional techniques to current lean production. The differences in production philosophies, their limits, and their impacts in the construction industry are also reviewed. A field study will be conducted to evaluate the effectiveness of some lean construction techniques including last planner, increased visualization, daily huddle meetings, first run studies, the 5s process, and fail safe for effective project management and site implementation.. The data collection methods included direct observations, interviews, questionnaires, and documentary analysis. The effectiveness of the lean construction tools will be evaluated through the lean implementation measurement standard and performance criteria.

Key Words**:** Lean Construction, Last Planner, Implementation Framework,

1.INTRODUCTION

1.1 General:

Lean Construction is a "way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value. Designing a production system to achieve the stated ends is only possible through the collaboration of all project participants (Owner, A/E, contractors, Facility Managers, End-user) at early stages of the project. This goes beyond the contractual arrangement of design/build or constructability reviews where contractors, and sometime facility managers, merely react to designs instead of informing and influencing the design.

Lean Construction recognizes that desired ends affect the means to achieve these ends, and that available means will affect realized ends. Essentially, Lean Construction aims to embody the benefits of the Master Builder concept.

1.2 Research problem:

Lauri Koskela, in 1992, challenged the construction management community to consider the inadequacies of the time-cost-quality tradeoff paradigm.[3] Another paradigm-breaking anomaly was that observed by Ballard (1994[4]), Ballard and Howell (1994aand 1994b), and Howell (1998). Analysis of project plan failures indicated that "normally only about 50% of the tasks on weekly work plans are completed by the end of the plan week" and that constructors could mitigate most of the problems through "active management of variability, starting with the structuring of the project (temporary production system) and continuing through its operation and improvement," (Ballard and Howell 2003[6]). Evidence from research and observations indicated that the conceptual models of Construction Management and the tools it utilizes (work breakdown structure, critical path method, and earned value management) fail to deliver projects 'on-time, at budget, and at desired quality' (Abdelhamid 2004). With recurring negative experiences on projects, evidenced by endemic quality problems and rising litigation, it became evident that the governing principles of construction management needed revisiting. One comment published by the CMAA, in its Sixth Annual Survey of Owners (2006), pointed to concern about work methods and the cost of waste:

1.3 Aim and Objectives:

The main of this study is to apply lean techniques in middle size construction organization to test its effectiveness

To fulfil this aim the following objectives will be achieved:

1. To identify the criteria of lean as they apply to construction projects.
2. To identify basic lean tools for process improvement.
3. To identify methodology for application lean tools
4. To investigate the impact of lean practices.

1.4. Lean Construction Management:

Lean construction is a combination of operational research and practical development in design and construction with an adaption of lean manufacturing principles and practices to the end-to-end design and construction process. Unlike manufacturing, construction is a project-based production process. Lean Construction is concerned with the alignment and holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging, and recycling (Abdelhamid 2007, Abdelhamid et al. 2008). This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela et al. 2002[1]), while it helps to achieve and maintain sustainability in construction sector (Solaimani & Sedighi, 2019[2]).

1.5 Integrated Lean Project Delivery (ILPD)

Integrated Lean Project Delivery (ILPD) is a process trademarked by The Boldt Group. It was created and is practiced by The Boldt Group's subsidiary, The Boldt Company. The process aims to eliminate waste across the construction value chain, through evaluation of initial planning and design, and examination of construction processes to predict where and when waste will occur, which is then eliminated through the use of lean tools in the IPD process.

An ILPD contract is a multi-party agreement that specifies the use of lean practices as conceived in the Lean Project Delivery System. This distinction is needed because Integrated Project Delivery (IPD) is nowonly referring to the multi-party agreement regardless of what practices are used, the so-called IPD-lite or IPD-ish.

1.6 Differences between LC and project management approaches:

There are many differences between the Lean Construction (LC) approach and the Project Management Institute (PMI) approach to construction. These include:

- Managing the interaction between activities and combined effects of dependence and variation is a first concern in lean construction because their interactions highly affects the time and cost of projects (Howell, 1999); in comparison, these interactions are not considered in PMI.
- In lean construction, optimization efforts focus on making work flow reliable (Ballard, LPDS, 2000); in contrast PMI focuses on improving productivity of each activity which can make errors and reducing quality and result in rework.
- The project is structured and managed as a value generating process (value is defined as satisfying customer requirements); while PMI considers less cost as value.
- In the lean approach, downstream stakeholders are involved in front end planning and design through cross functional teams (Ballard, LPDS, 2000). PMI doesn't consider this issue In lean construction, project control has the job of execution (Ballard, PhD thesis, 2000); whereas, control in PMI method relies on variance detection after-the-fact
- In the lean approach, pull techniques govern the flow of information and materials, from upstream to downstream; with PMI, push techniques govern the release of information and materials.
- Capacity and inventory are adjusted to absorb variation (Mura). Feedback loops, included at every level, help ensure minimal inventories and rapid system response;[27] in comparison, PMI doesn't consider adjustments.
- Lean construction tries to mitigate variation in every aspect (product quality, rate of work) and manage the remaining variation, while PMI doesn't consider variation mitigation and management.

1.7 Scope of the study:

The scope of this research work is to extent the implementation of lean construction and to explore the influencing factors of lean construction.

1.8 Need for study:

- The main purpose of Lean management is creating value to the customer by optimizing resources.
- Lean management principles aims to create a stable workflow based on actual customer's demand.
- Continuous improvement is a major part of Lean management, ensuring that every employee is involved in the process of improving.

1.9 Objectives

To fulfil this aim the following objectives will be achieved:

1. To identify the criteria of lean as they apply to construction projects.
2. To identify basic lean tools for process improvement.
3. To identify methodology for application lean tools
4. To investigate the impact of lean practices.

1.10 Motivation for the study:

India's rapid economic growth over the past few decades has placed a tremendous stress on its limited infrastructure. Construction industry is one of the largest industries which support the economy of a country. Since construction has a major and direct influence on many other industries reducing waste in construction can go a long way in helping the economy of the world.

2. LITERATURE REVIEW

2.1 Overview of literature:

The basic objective of this chapter is to get inside into the previous findings so that it will help to know the gap in earlier studies and to justify the research problem selected by me for the study purpose. The prominent areas covered in the present literature of reviewed are studies related to concept, model, system, functions, recommendations, specifications, guidelines for analysis and study on the principles and techniques of lean management currently used in civil industry to reduce various types of waste and discuss the obstacle of lean management in construction in construction. Project management techniques, planning and scheduling, construction costs etc. in Indian and international studies are studied.

The Lean philosophy begins to integrate into the construction industry as a new method of construction projects management aiming at eliminating waste and creating value to the customer. Here within this work we have enlisted past work for better enhancement and to represent gap between past and future work.

2.2 The Research Carried Out by Various Researchers-

The extensive literature review was carried out by referring standard journals, reference books, I.S. Code and conference proceeding. The major work carried out by different researchers is summarized below:

1) **Sam Solaimani, Mohamad Sedighi (2019), Toward a holistic view on Lean sustainable construction: a literature review:**
The literature is reviewed on the lean principals to focus on efficiency of the construction system, the practices have been revisited used to create and preserve social and environmental values. The aim of the author was to provide a comprehensive understanding of "how Lean helps achieve and maintain sustainability in construction sector". Author focused on stakeholders, construction phases, and profit. The economic values were properly analyzed in this study while more researching regarding social and environmental aspects of construction.
To more standardization which shows reduction in variability, leading to a lower production cost, a higher employee's safety, and more transparency means environmental information.
As last author mentioned that the Lean philosophy potentially can help optimize supply chain overall sustainability performance in different phases of construction, and enhance participation of stakeholders.

2) **Nowotarski, Jerzy Paslawskia, Jakub Matyja (2016), Improving Construction Processes Using Lean Management Methodologies – Cost Case Study:**
The author researched on the construction processes improved by using lean management. The author investigates on the factor influencing the total cost of selected process of managing storage area on the construction site. As per system construction deals with the deadlines, budget overruns etc. In this author taken a case study of construction office building in Poznan city center (Poland). With this new management system was introduced and analyzed.

3) **Shuquan Li, Xiuyu Wu, Yuan Zhou, Xin Liu (2016), A study on the evaluation of implementation level of lean construction in two Chinese firms:**
The literature reviewed by the author on evaluating of implementation level of lean construction in two Chinese firms. The author describes the study to manage the construction industries system in China on implementing the lean construction technology. As China wasnot well aware of lean construction management so the objective of the research was to improve and extent the lean construction in China and improvise the factors of lean management in China's construction firms. So author considered two firms to analyze and evaluate the system of construction. So the forms will have different sizes, organizational scope and culture which tends to implement the levels of lean construction, its organizational structure and market focus. As results, the influencing factors of lean construction implementation are the main aspects of that helps in managing the factors of large companies in China.

4) **Bhargav Dave, Sylvain Kubler, Kary Främling, Lauri Koskela (2015), Opportunities for enhanced lean construction management using Internet of Things standards:**
The author researched on the opportunities for enhanced lean construction management. The lean management in this study is discussed on the base of using internet on controlling the production control on construction sites. The author was looking for the communication framework underlying such construction management systems can be further improved. The improving of the management can be done fully or partially across the construction project lifecycle. Author enables lean and close to real time reporting of production and control information.

5) **Ahmad Huzaimi Abd Jamila,, Mohamad Syazli Fathi (2016), The Integration of Lean Construction and Sustainable Construction: A Stakeholder Perspective in Analyzing Sustainable Lean Construction Strategies in Malaysia:**
The author researched on the lean construction and sustainable construction. The main aim of the

author is to improve the concepts of accomplishing the reduction of waste deals with both positive environment and economic outcomes. The author used the construction industry in many countries to check and improve the poor condition by using the lean construction management system. Thus main focus was to lay the groundwork for future empirical study by investigating on various dimensions of SC and LC, where the theoretical and practical findings provided a foundation for integrating the two initiatives to yield the efficient use of valuable resources.

6) **David Carvajal-Arango, Sara Baham_on-Jaramillo, Paula Aristiz_abal-Monsalve,Alejandro V_asquez-Hern_andez*, Luis Fernando Botero Botero (2019), Relationships between lean and sustainable construction: Positive impacts of lean practices over sustainability during construction phase:**
The author researched on relationships between lean and sustainable construction. The author studied the increasing interest in sustainability in developing of construction projects. In this various practices framed under the lean management in reducing environmental, economic, and social impact during the construction phase. The philosophies of lean were established in relationship with sustainable constructions. Main focus is to determine the lean construction practices contribute to each dimension of sustainability during the construction phase of a project. As this study deals with the construction system to practices all the aspects mentioned by the author in the literature to overcome the economic, social and environmental benefits.

7) **Matthew Goh, Yang Miang Goh (2019), Lean production theory-based simulation of modular construction processes:**
The author researched on improving the efficiency of site operations using lean production theory. The author mentioned the lean principles have been widely applied to improve the construction operations and productivity. The method enhanced the analyzing and benefits of lean management. The management aimed to manage the modular construction operations with researching the barriers and adoption of prefabrication this study includes Total Quality Management, E-Kanban based Just-In-Time deliveries, cross training and the use of construction robotics.

8) **Richard Hannis Ansah, Shahryar Sorooshian (2017), Effect Of Lean Tools To Control External Environement Risks Of Construction Projects:**
The author researched on the control external environmental risks of construction projects. The author used the existing management concepts and methods implemented for solving construction project. The main aim of the author was to control framework based on AHP method for the evaluation of lean tools application in the external environment including political, economic, social, technological, legal and environmental aspects of the construction projects.

9) **Algan Tezel, Lauri Koskela, Zeeshan Aziz (2017), Current condition and future directions for lean construction in highways projects: A small and medium-sized enterprises (SMEs) perspective:**
The author researched on the lean construction in highways projects for the current and future conditions. The main aim of the author is to identify the parameters defining how Lean Construction (LC) is being implemented (current condition) and how LC can be further promoted (future direction) from a Small-Medium Sized Enterprises (SMEs) perspective.

10) **Qing Gao, Rongbo Shi, Gang Wang (2016), Construction of Intelligent Manufacturing Workshop Based on Lean Management:**
The literature is reviewed by the author on lean management construction system based with intelligent manufacturing workshop. The main purpose of this study is key elements based on the informatization and industrialization which deals with the transformation of enterprises, use of technology and scientific management. The author the flow chart of the process management.

3. METHODOLOGY

3.1 General:

This study presents an overview of the key Lean tools and activities that have proven to deliver real benefits to the performance and delivery of construction projects. Each tool will be introduced and sufficient detail provided to understand what it is, when and where to apply it and the associated benefits. Many of the tools in this report can be used in isolation to help resolve a specific issue or to make an improvement. However, the tools provide maximum benefit if they are used as part of a Lean end-to-end project delivery strategy and system of improvement for construction companies to develop their people, their supply chains and improving performance.

Lean has great synergy with collaborative working – the basis of establishing the truly integrated and high performing construction team. Project performance will be optimized where Lean processes and practices are integrated with effective collaborative working between all parties.

Through the literature survey following types of wastes is identified on any construction firm and these issues will be addressed using lean techniques in this study, they are as follows:

Transportation: unnecessary movement and handling of goods

Inventory: poor planning and control of inventory leading to excessive stocks, shortages etc

Motion: excessive or unnecessary movement of people when carrying out work. This can be due to poor layout of tools, materials, plant etc in the workplace

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Waiting: where resources (people and/or plant) are idle waiting for information, materials, people or access etc
Over-production: producing more than is required and/or ahead of time, which can introduce waste due to out-of-sequence works
Over-processing: doing more than is required to meet design requirements leading to excessive time and/or cost. For example, spending time to produce a level of quality that is higher than required, double handling of items, materials etc
Defects: non-'right first time' quality requiring reworks, introducing extra time and cost
Skills misuse: the waste of not effectively tapping into the expertise and knowledge of people.

3.2 Research Methodology:

This research presents a study of a construction project in which specific lean construction elements will be tested on a middle sized construction organization. Each technique is evaluated in terms of its impact on the performance of the project. Based on the findings of the study, a new "lean assessment tool" is proposed to quantify the results of lean implementations through performance management framework.

The study will test and evaluate six lean construction tools for possible improvements. They are last planner, increased visualization, daily huddle meetings, first run studies, the 5s process, and fail safe for quality. The data collection methods in this research include direct observation, interviews and questions, and documentary analysis, and these three methods are applied to each of the tools. Observational data is to be collected directly from surveys, and huddle meetings, and the construction process. The Lean Construction tools or techniques and the methods that are used in the first run study and the productivity study are generally decided upon by the vice president of the general contractor (GC) and the Research Team (RT).

The following flowchart describes the layout of this project briefly:

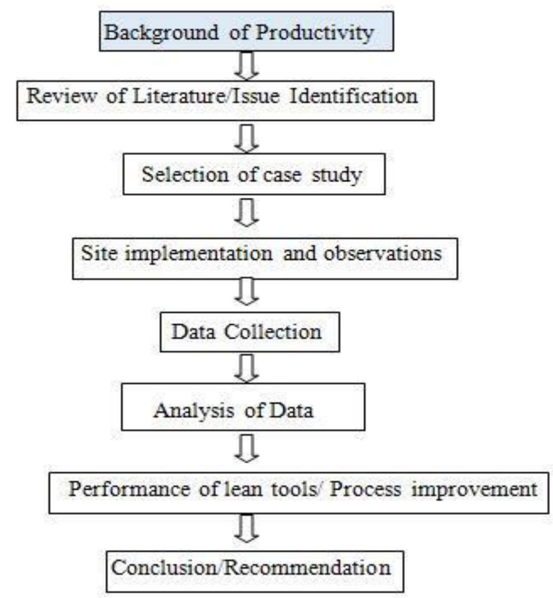

Figure 3.1 Flow Chart Showing Research Structure

3.3 Research Gap:

Although this technique much consolidated in India, various countries around the world are now in the quest of seeking more value with this thinking. However, numbers of structural and cultural barriers are to be seen that are militating against its successful implementation despite of the geographical area. Despite these continuous efforts, studies show that the presence of lean culture in the large construction companies in India is still less than what is professed by literature. More over the study recognizes a significant gap in the LC in other developing countries compared to UK, which evident the immense room to be improved in LC all around the world in general

3.4 Research Strategy

Quantitative and qualitative methods are used in this thesis. Quantitative data has been collected to measure the proportion of non-value added and the value added for time and steps in each process. This was measured by standardization tools, while qualitative data was used in order to understand the reasons of non-value added in the process by using the five why tools and giving solutions and suggestions for reducing the non-value added in construction.

3.5 Data Collection

To achieve the objectives of the current study, the researcher has used several sources. These include:

3.5.1 Primary Sources

Productivity data was obtained from Company. Moreover 30 crafts men who have more than 10 years' experience were interviewed. The results obtained were compared with productivity data reported in SP construction Pune. Minimum, the most likely and the maximum productivity of the resources are shown in (Table 3.1). In addition, the 5 why were used to determine the causes of waste.

Table 3.1 Productivity of resources in company

Main Activity	Activity process	Unit	Unit/hours		
			Minimum	Most Likely	Maximum
Mobilization and excavation	Excavation work	M3	57.69	62.5	68.18
Plain concrete	Form work	M3	0.625	0.875	1
	Cast plain concrete	M3	0.75	0.875	1
	Remove form work	M3	0.58	0.7	0.875
Foundation work	Form work	M3	0.625	0.875	1.125
	Fix neck column	M3	0.648	0.81	1.08
	Cast foundation	M3	5.77	6.5	12
	Remove form- work	M3	2.62	3.25	4.31
Neck column	Form work	M3	0.072	0.083	0.147
	Cast concrete	M	0.083	0.1	0.125

		3			
	Remove form work	M3	0.31	0.375	0.46
Back filling	First layer	M3	17.85	20.8	22.3
	Second layer	M3	25	31.25	41.66
	Final layer	M3	25	31.25	41.66
Ground beam	Form work	M3	0.28	0.4	0.58
	Cast concrete	M3	0.083	0.1	0.125
	Remove form work	M3	0.7	0.93	1.125
Column work	Fix steel column	M3	1.81	2.26	3
	Form work	M3	0.176	0.2	0.35
	Cast concrete	M3	0.4	0.48	0.6
	Remove form work	M3	1.51	1.81	2.26
Ground floor	Preparation work	M2	33.33	36.36	40
	Steel work	M2	14.28	14.81	15.38
	Mechanic work	M2	66.7	80	100
	Cast concert	M2	66.7	80	100
Slab work	Form work	M2	6.55	7.37	8.42
	Hollow cement Block work	M2	9.83	11.8	14.75
	Steel work	M2	6.55	7.37	8.42
	Electric work	M2	6	8	12
	Cast concrete	M2	8	9	10
	Remove form work	M2	4.91	5.9	7.37
	Building under the window	M^2	2.07	2.17	2.38
Building work	Lintel work under window	ML	15.91	19.1	23.87
	Cast lintel under the windows	ML	47.75	63.66	95.5
	Remove form work	ML	23.87	31.83	47.75
	Building behind the Widows	M^2	2.65	2.8	3.18
	Lintel work behind	ML	15.91	19.	23.87

	Window			1	
	Cast lintel up the Windows	ML	47.75	63.66	95.5
	Remove form work	ML	47.75	31.83	93.87
	Building up the Window	M^2	2.07	2.17	2.38

3.5.2 Secondary Sources

The secondary sources include books, references, journals and magazines, and papers related to the research subject.

3.6 Application of Lean Principles in Construction

Standardization was used to reduce the waste in the process by using the data of (Table 3.1). The five why tools were used to identify the causes of waste and reduce the number of steps. The following ten points were used to define the biggest non- value added process in the project by using arena simulation in order to reduce non value added.

1. Select all non-value-added activities in the simulation model (candidates for improvement).
2. Set the task durations of the improvement candidates to zero (one at a time). Although, in many cases, eliminating these activities is not possible or practical, doing so will allow one to determine their significance on the model output.
3. Produce simulation results (run the simulation).
4. Sort the candidates in order of their significance to the simulation model. This will enable the improvement process to focus on those activities that have the greatest impact on model outputs.
5. Look for practical activity reduction solutions for the candidates, starting with the activity that has the greatest potential for improvement.
6. Edit the simulation model to reflect zero-time delivery the biggest non value added activities. Although this may not be possible or practical, it will allow one to determine the effect on the project.
7. Produce simulation results (run the simulation).
8. Look for practical solutions to improve the material delivery processes (if required). If the material delivery process has a significant impact on model outputs, efforts should be made to make practical improvements.
9. Look for practical solutions to improve production activities. Only after the lean concepts (value-added activities and pull-driven flow) have been introduced to the model should the improvement be focused on production activities.
10. Introduce buffers to compensate for increased model variability and for differing production rates of linked operations. The lean production improvement process has generally been shown to introduce significant variability into processes. Buffers should be introduced as a final step to compensate for this effect.

4. RESULT AND DISCUSSION

Lean has been applied on a completed construction project of the construction because there is a lack of projects under construction. The project data are available and the project is of a medium size. The lean tools (standardization) are applied on this project and simulation has been applied to analyse the processes and activities duration.

4.1. Project Description

Table (4.1) shows information about the selected project.

Table 4.1 Details of project

No	SUBJECT	DATA
1	Company name	SP Construction Pune
2	Location	Pune
3	Owner	Shailesh Jagtap
4	Contractor	Shailesh Jagtap
5	Sub-contractor	Vivek Mangude
6	Design consultant	Rahul Kumar
7	Site consultant	Rishita lunawat
9	Project area	3200 m^2
10	Basement floor area	2370 m^2
11	Ground floor area	2508 m^2
12	First floor area	2420 m^2
13	Start day	20/05/2017
14	Finish day	20/06/2019
15	Real project duration	750days
16	Contract duration	365 days
17	Estimated cost of project	16 Cr

4.2 Project Activities

Lean construction has been applied on the following project activities in mobilization, plain concrete, foundation, neck column, isolation, back filling, ground beam works, column for ground floor, ground floor, ground floor slab, first floor column, second floor slab, building for ground floor, and building works for first floor. The execution of the project is divided into three blocks A, B and C.

4.3 Lean Criteria Procedure

The procedure of applying the lean principles is as follows:

- Defining the customer, the customer value, all resource required for construction, and all activities required for construction.
- Identify non value added process (steps, time).
- Removing or reducing the wastes in process by using the standardization and the five why tools to identify the cause of failure.
- Identifying non value added activities by applying the points in figure 4.1 on the construction of Building project.
- Improving the project until reaching perfection.

The above procedures are applied to the project as follows: The value of customer is to construct the project with the same duration and cost and specification of contract.

Only the following eight points in Figure (4.1) from the ten points in section (3.6) were applied to the project because it is a completed construction project.

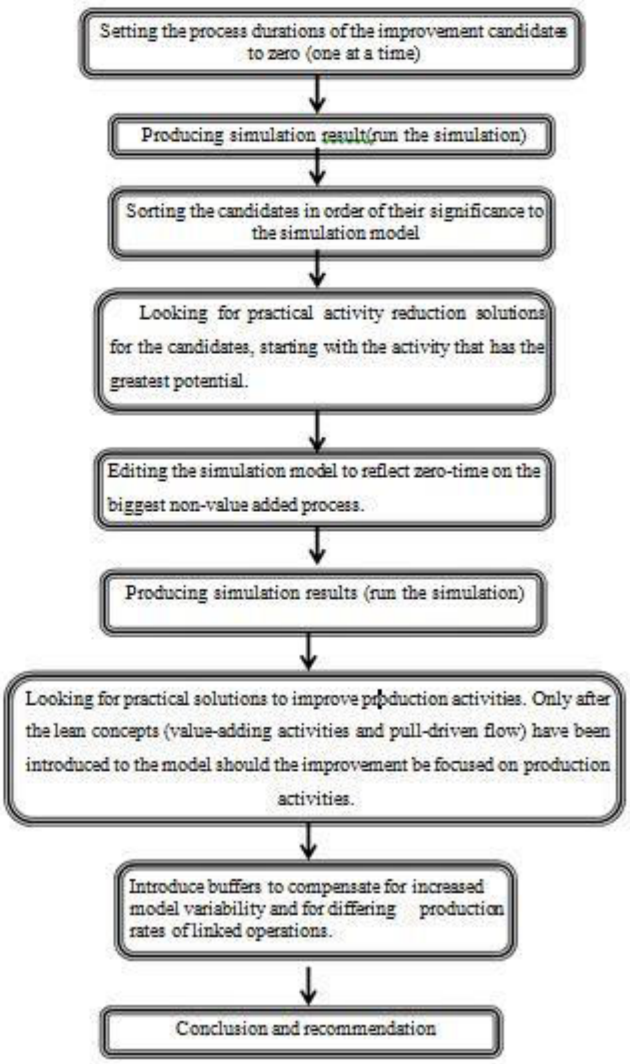

Figure 4.1 Procedure of the application of lean principles

Table 4.2 represents the resources, the duration for the process and the bill of the quantities of project by using Table (3.1). The following resources are available throughout all the project period: Project manager (1), Site engineer (2), Foreman (1), Surveyor (1).

Calculation in the last column was done as follows:

Duration (hour) = Quantity/ (Number of resources x Productivity x 8 hours)

Maximum duration of the excavation process = 6000/ (1x 57x 8)= 13 hours.

Most likely duration of the excavation process = 6000/ (1x 62x 8)= 12 hours.

Minimum duration of the excavation process = 6000/ (1x 68x 8)= 11 hours.
The remaining processes were calculated in the same way.

Table 4.2 Productivity of the project activities

Main Activity	Process	Unit	Quantity	No. resource	Productivity/* hour	Duration 1day= 8h
Mobilization and excavation	Excavation work	M3	6000	1 Excavator	57, 62, 68	11,12, 13 days
Plain concrete	Form work	M2	140	5 workers	0.6, 0.8, 1	3.5, 4.5. 5.5 days
	Cast plain concrete	M2	140	5 workers	0.7, 0.8, 1	4,5,6 hours
	Remove form work	M2	140	5 workers	0.6, 0.7, 0.9	3, 4, 5 days
Foundation	Form work	M3	935	9 workers	0.6, 0.9, 1	11.5, 15, 21 days
	Fix neck column	M3	935	9 workers	6, 8, 10	1.5,2, 2.5 days
	Cast foundation	M3	935	9 workers	6 , 7 , 12	12, 16,18 hours
	Remove form work	M3	935	9 workers	2, 3, 4	3, 4, 5 days
Neck column	Form work	M3	60	8 workers	0.07, 0.08, 0.15	51, 90, 103 hours
	Cast concrete	M3	60	8 workers	0.08, 0.1, 0.12	60, 75, 90 minute
	Remove form work	M3	60	8 workers	0.3, 0.4, 0.5	16, 20, 24 hours

* This column shows the minimum, most likely and maximum productivities according to the bill quantity of the project.

Table 4.2 Productivity of the project activities(Cont.)

Main Activity	Process	Unit	Quantity	No. resource	Productivity /hour	Duration 1day= 8h
		M3	1000	2 excavators	18, 21, 22	2.5, 3,3.5 days
Back filling	Second layer	M3	1000	2 excavators	25, 31, 41	1.5, 2, 2.5 days
	Final layer	M3	1000	2 excavators	25, 31, 41	1.5, 2, 2.5 days
Ground beam	Form work	M3	180	8 workers	0.3, 0.4, 0.6	4.5, 7, 10 days
	Cast concrete	M3	180	8 workers	0.08, 0.1, 0,12	60, 75,90 hours
	Remove form work	M3	180	8 workers	0.7, 0.9, 1	2.5, 3, 4 days
Column work	Fix steel column	M3	145	4 workers	1.8, 2, 3	1.5, 2, 2.5 days
	Form work	M3	145	4 workers	0.1, 0.2, 0.3	102, 180, 206 hours
	Cast concrete	M3	145	4 workers	0.4, 0.5, 0.6	60, 75, 90 minute
	Remove form work	M3	145	4 workers	1.5, 1.8, 2	16, 20, 24 hours
Ground floor	Preparationwork	M2	2000	5 workers	33, 36, 40	10, 11, 12 hours
	Steel work	M2	2000	5 workers	14, 15, 16	26, 27, 28 hours
	Mechanic work	M2	2000	5 workers	60, 80, 100	4, 5 ,6 hours
	Cast concrete	M2	2000	5 workers	60, 80, 100	4, 5 ,6 hours

Table 4.2 Productivity of the project activities(Cont.)

Main Activity	Process	Unit	Quantity	No resource	Productivity/ 1hours	Duration 1day=8h
Slab	Form work	M2	1180	9 workers	6, 7, 8	(3.5, 4, 4.5) days
	Hollow cement block	M2	1180	9 workers	10, 12, 15	(2, 2.5, 3) days

work	Steel work	M2	1180	9 workers	6, 7, 8	(3.5, 4, 4.5) days
	Electric work	M2	1180	4 workers	6, 8, 12	(6, 8, 12) hours
	Cast concrete	M2	1180	9 workers	8, 9, 10	8, 9, 10hour
	Remove form work	M2	1180	9 workers	5, 6, 7	4, 5, 6 days
Building work	Building under the window	M2	5730	5 workers	2, 2.5 ,3	20, 22, 23 days
	Lintel work under window	ML	5730	5 workers	16, 19, 24	2, 2.5, 3 days
	Cast lintel under the windows	ML	5730	5 workers	48, 64, 95	4, 6, 8 hours
	Remove form work	ML	5730	5 workers	24,32, 48	1, 1.5, 2 days
	Building behind the widows	M2	5730	5 workers	2.5, 2.8, 3	15, 17, 18 days
	Lintel work behind window	ML	5730	5 workers	16, 19, 24	2, 2.5, 3 days
	Cast lintel up the windows	ML	5730	5 workers	48, 64, 95	4, 6, 8 hours
	Remove form work	ML	5730	5 workers	24, 32, 48	1, 1.5, 2 days
	Building up the window	M2	5730	5 workers	2, 2.5 ,3	20, 22, 23 days

4.4. Non-Value Added and Value Added Process Identification

Activities can be classified as:

1. Activity that adds value and can be defined as follows:
   - Activity which contributes to the customer's perceived value of the product or service (Convey et al., 1991).
   - Activity that "converts material and/or information towards what is required by the customer" (Koskela et al., 1992).
2. Activity that does not add value and can be defined as follows:
   - Activity which, if eliminated, would not detract from the customer's perceived value of the product or service (Saukkorriipi et al., 2004).
   - Activity which takes time, resources and space but does not add value" Koskela et al., 1992).

In the analysis of the project, the value added and non-value added times and steps of the process can be defined as follows:

- Value added time is the time that increases the value duration of the process without any waste.
- Non-value added time is the time that does not increase the value added of the process without waste.
- Value added steps are the steps that increase the value of the work steps without any kind of waste.
- Non-value added steps are the steps that do not increase the process value without waste.
- Waste is a kind of seven wastes over-production, defects, inventory, transportation, waiting, motion and over-processing

Section 4.4.1 to 4.4.14 show the value and non-value added processes of the project activities. The non-value added takes "0" whereas value added takes number "1" or a fraction according to the number of the steps in a process. For example section (4.4.1) the excavation process took two steps so the value added steps equal 1/2 +1/2 = 1. If the excavation was performed in one step, the value added of step takes "1".

In the fourth quarter, a big improvement in the value steps produced big improvement in the value added time. The number of steps in the isolation activity of the value added steps rose by 50% that also raised the value added time by 18%. These rises happened because cleaning process was done after removing the formwork. It was done during the work of the contractor because of the lack of workers and the cleaning material.

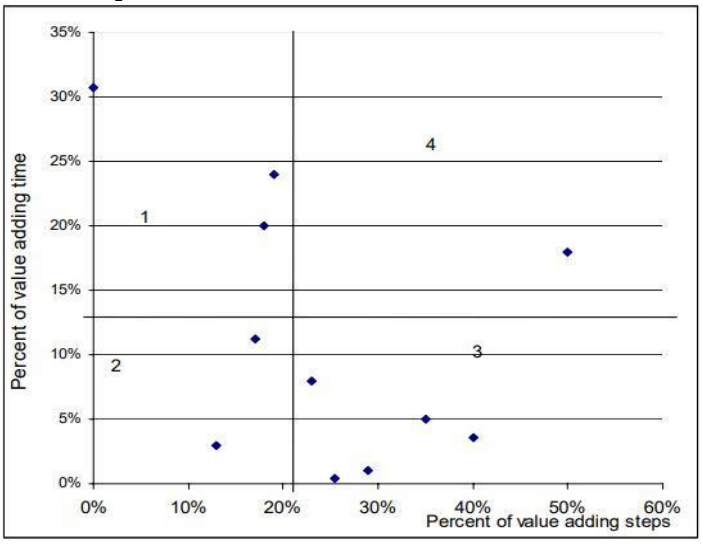

Figure 4.9 Comparing value added steps to value added time

Regarding the causes of delays of activities, using the five why tools showed the following results:

- The failure due to design error was 30.7%.
- The failure due to work error was 24%.
- The failure due to lack of experienced management was 20%.
- The failure due to lack of resources was 18% due to lack of permanent resources
- The failure due to lack of material formwork was 8% because the contractor had to divide the project into many stage because of lack of the formwork. The solution is to save enough formwork. Figure (4.10) shows the percentage of the causes of a failure as in the diagram.

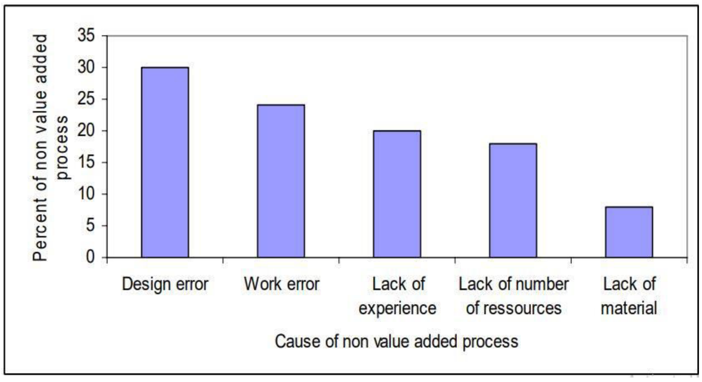

Figure 4.10 Cause of failure

4.7 Finding the Largest Non-Value Added Process

The eight points that were mentioned in the methodology (4.3) were applied using arena simulation in order to find the biggest non value added process. The whole non value added process is shown in Table (4.33) by putting "0" non value added process in turn and calculating the time period in the end of the project (run the simulation Figure (4.11)).

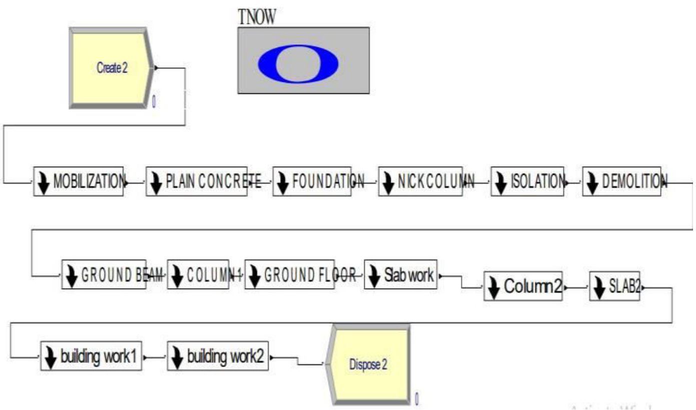

Figure 4.11 Simulation model

Finally, buffers are introduced to balance the processes duration.

Figure (4.12) shows that duration of the foundation formwork process is 129.6 hours. This is far from the other processes (shown as number eight). Ground floor columns formwork process duration are 163.82. First floor columns formwork process duration was 157.51 hours. These are longer than the other processes (shown as number 34, 53). The duration of the building processes took 173.29, 133.2, 173.69, 172.75, 132.67, 172.21 hours. These numbers correspond to 42, 43, 44, 61, 62, 63. These duration are larger than those in the other processes

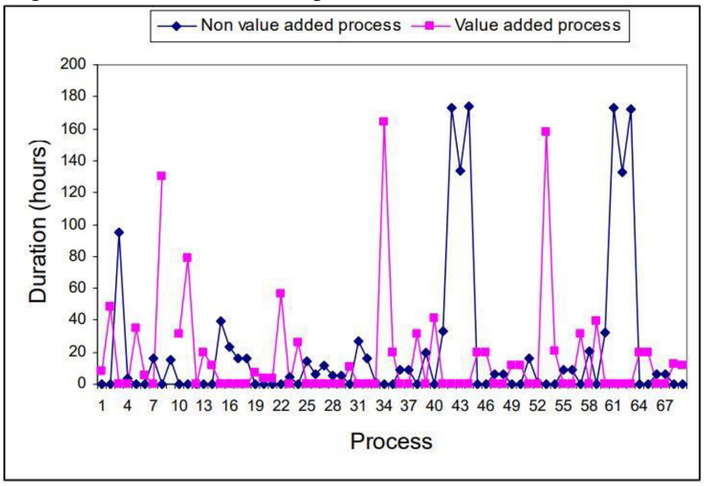

Figure (4.12) Duration variability before introducing buffers and after applying lean tools

Table (4.37) shows the balance improvement into the process by decreasing the duration of processes. Foundation formwork process duration decreased from 129.6 hours to 42.6 hours by increasing the number of resources from 9 to 27 workers shown as number eight in Figure (4.13). The duration of excavation process decreased from 95.29 to 45 hours by using 2 excavators shown as number three. The duration of the ground floor columns formwork decreased from 163.82 hours to 56.49 hours by increasing the number of workers to12 workers shown as number 34. The first floor columns formwork duration decreased from 157.51 hours to 56.49 hours by increasing the number of workers to 12 workers shown as number 53. The ground floor building duration decreased from 173.29, 133.24, 173.96 hours to 65.9, 66.07, 66.37 hours by increasing the number of workers to 13, 10, 13 workers shown as number 42, 43, 44. The first floor building duration decreased from 172.75, 132.67, 172.21 hours to 65.9, 66.07, 66.37 hours by increasing the number of workers to 13, 10, 13 workers shown as number 61, 62, 63.

The result of introducing buffer is that the non-value added time decreased by 55% (from 1906.15 hours to 846.5 hours).

5. CONCLUSIONS

5.1 Conclusion

This study of Lean Construction Practices in the SP Construction shows the influence of applying the lean construction. This study was conducted by identifying criteria of lean construction and applying standardization tools, 5 why tools, 10 point to achieve the lean principle in reducing the activity steps and duration by eliminating the non-value added process in the activity by using the arena simulation. The following consequences have been reached:

1. Value added time increased from 49% to 63% as a result of applying lean tools.
2. The used lean tools decrease the cycle time from 6000 hours to 1503.43 hours (decreased by 75%).

3. The value added can be enhanced to 74% by improving the form work material in foundation (using prefabricated) and column activities (steel form work).
4. The number of steps decreased from 161 to 69 (a reduced by 57%).
5. Non -value added duration of total process was 4892.17 hours (81%) it decreased to 846.5 hours (14% decrease).
6. Lean construction through standardization tools reduces the variability of the process, example the excavation work for one hour (57m3,62m3,68m3).
7. The rate of no value added process related to the design error was 30.7%. This has been considered the biggest value of the no value added in the process since it happens during the stage of design, therefore, we must apply the lean in the design to avoid waste during the construction.
8. The percentage of the no value added in the process due the above mentioned reasons were as follow: Rework 24% lack of experience management 20%, lack of number of resources 18%, lack of material 8%. This requires training workers. Engineers, other managers, supervisors should begin suitable courses in management. It is favourable to work with a permanent technical staff in the company. Efficient resources, sufficient materials should be provided and saved for the project.

5.2 Future Scope

In order to apply lean construction tools and achieve its benefits successfully, the following recommendations should be considered:
1. Using standardization tool in companies.
2. Training the workers in the company in order to reach the needed productivity which has big effects on the improvement of work.
3. Using the 5 why tools to identify the errors and their causes to avoid them and not looking for the mistaken people.
4. Focusing on this study as a first step to use the lean in construction projects.
5. Applying the methodology used in the current study to all companies in the India.
6. Improving the master schedule of the project by standardization tools and measuring the percent plan complete for each process to deal with errors weekly.
7. Process evaluation and project progress should be measured every 4 weeks as mentioned in the last planner tools.
8. The percent plan complete average of lean project must be more than 80%.
9. After proving the potential application, lean studies should focus on obstacles of lean implementation.

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