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An Analysis of Lean Construction Practices in Tamil Nadu Construction Industry

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***Abstract* - The construction industry plays a significant role in economic growth, both directly through its activities, and indirectly through the provision of buildings and infrastructures for the smooth functioning of businesses. However, the construction industry is highly challenged as a 3D's industry – dirty, dangerous and demanding. Lean Construction is a new production philosophy which would bring in revolutionary changes in the construction industry. It is a way to design production systems to minimize waste of materials, money, time and effort in order to generate the maximum possible amount of value. Lean significantly contributes to the efficiency of the construction industry. Lean philosophy is all about designing and operating the right resources at the right time with right systems. Two very important construction tools are added under lean construction are the production control and structuring of the work. Thus, the construction in "Lean Construction" refers to the entire industry which includes owners, architects, designers, engineers, contractors, sub-contractors and suppliers. In current technological trend, lean construction has gained its importance significantly. An analysis of lean construction practices in Tamil Nadu construction industry has been made by certain methodologies. A questionnaire survey is used to collect information and data from the construction companies about the practice of lean construction techniques in the major districts of Tamil Nadu. It also includes the drawbacks, problems faced during implementation and wastes generated during operational process. Methodologies have been formulated to rank all the above criteria and arrive at the required conclusions. Collected data has been analyzed in two categories, one by manual consisting of three approaches and the other by software. Solutions & Suggestions for the major problems have been proposed to minimize the ranked wastes from the analyzed data and overcome the barriers in implementing lean construction techniques.**

Keywords—Lean Constructiont; Wastes; Barriers; Management; Techniques.

I. INTRODUCTION

The construction industry plays a significant role in economic growth, both directly through its activities, and indirectly through the provision of buildings and infrastructures for the smooth functioning of businesses. However, the construction industry is highly challenged as a 3D's industry – dirty, dangerous and demanding. The construction industry lags 10 years behind the manufacturing industry because of the several reasons. The primary reason being its fragmented approach rather than an integrated approach. The second important reason is that the construction industry is far more complex than the manufacturing and thus the technical innovations are required to be more developed to be significantly implemented. Lean construction is a new production philosophy which would bring in revolutionary changes in the construction industry. To survive in today's competitive market, it has become imperative for construction companies to improve the quality of their work, increase work effectiveness, reduce waste and costs, and increase profit. This is particularly more pressing under the current financial crisis and economic recession. Consequently, the combination of project speed, high quality, and low cost has become a key engineering and managerial effort in facing the growing competition in the construction business. Most construction managers agree that the industry is susceptible to multiple wastes, overruns, delays, errors, and inefficiency. As a result, construction projects seldom finish on time, within budget, and at a quality level accepted by the customer. Thus, several project management approaches have emerged to improve construction performance including lean construction, lean project management, and value-engineering. Lean principles have slowly made inroads into the construction industry because of its approach to waste elimination and providing value with less effort and time.

A. Lean Construction

Lean construction, as defined by the Lean Construction Institute (LCI), is a production management-based project delivery system emphasizing the reliable and speedy delivery of value. It is a new way to design and build capital facilities. Lean has already caused a major change in manufacturing industry and when applied to the construction industry, lean changes the way of working throughout the delivery process. Lean construction has successfully resulted into maximizing the value and minimizing the waste in the construction process. Lean production focuses on eliminating waste and maximizing productivity through the pull system, employee involvement, continuous improvement, etc. Much has been discussed about the waste elimination and productivity improvement that can be achieved by applying the lean concept. However, as the consideration of the environment is becoming an increasingly important part of the construction culture, there is a need to investigate the applicability of the lean concept to achieve environmental sustainability, which is often used interchangeably with the term "green".

Lean philosophy is all about designing and operating the right resources at the right time with right systems. The most essential and important objective of lean philosophy is to identify, eliminate waste and achieving the customer needs in all respects. Two very important construction tools are added under lean construction are the production control and structuring of the work. Lean significantly contributes to the

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efficiency of the construction industry. It helps the industry to reveal and support customer purposes. The application of lean in the construction process has resulted into structuring of the work throughout the process and the improvement of performance of the project. Lean construction assures to deliver reliable work between specialists in design, supply and assembly, thus delivering Value to the customers and reducing the waste. The efficiency in Lean approach is improved by redesigning the process Lean construction is different from current construction management because it aims at increased performance at the project level, it possess and focuses on a clear set of objectives for the delivery process, its designed the process and the product simultaneously and, it looks towards the efficient productivity throughout the life cycle of the project.

B. Historical Background

Since the 1950s, lean production or Toyota production system principles have evolved and were successfully implemented by Toyota Motor Company. Toyota production system had two pillar concepts: (1) Just in Time flow (JIT) and (2) Autonomation (smart automation). The term ‘‘lean’’ was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production. Starting from efforts to reduce machine setup time and influenced by TQM, a simple set of objectives was developed for the design of the production system. Lean production aims to design and make things differentiated from mass and craft forms of production by the objectives and technique, and to optimize performance of the production system against a standard of perfection to meet unique customer requirements. Since 1992, Koskela has reported the adaptation of lean production concepts in the construction industry and presented a production management paradigm where production was conceptualized in three complementary ways, namely as Transformation, Flow, and Value generation (TFV) theory of production. This tripartite view of production has led to the birth of lean construction as a discipline that subsumes the transformation-dominated contemporary construction management. The first goal of lean construction must be to fully understand the physics of production, the effects of dependence and variation along supply and assembly chains. In lean construction as in much of manufacturing, (1) Planning: defining criteria for success and producing strategies for achieving and (2) Control: causing events to conform to plan, and triggering learning and re-planning are two sides of a coin that keeps revolving throughout a project.

C. Lean Principles

The lean principles are establishing good terms within the team comprising of owners, architects, contractors, subcontractors and suppliers, emphasizing on the process design, and thus combining project design, stopping production rather than spoiling the construction process, enhancing participation of all the team members in a project, thus decentralizing decision making.

D. Lean Management Vs Traditional Management

The Lean construction is different from the typical construction in many aspects. In the typical construction, the conversion activity takes place, that is, every input is converted into output through a process. The typical construction focuses on the finishing the things thus achieving the efficiency but lacks in the value. The typical construction aims to achieve efficiency by implementing new technology whereas the lean approach focuses on eliminating or reduction of non-value adding activities and increasing the efficiency of the process through continuous improvement. The efficiency in Lean approach is improved by redesigning the process Lean construction is different from current construction management because it aims at increased performance at the project level, it possess and focuses on a clear set of objectives for the delivery process, its designed the process and the product simultaneously and, it looks towards the efficient productivity throughout the life cycle of the project. Managing construction under lean is different from typical contemporary practice because it has a clear set of objectives for the delivery process, is aimed at maximizing performance for the customer at the project level, designs concurrently product and process and applies production control throughout the life of the project.

E. Lean Concepts & Techniques

The last planner is the person or group of people responsible for production unit control, which means completion of individual tasks at the operational level. Last planner necessitates work flow control, ascertaining the stream of supply, design, and installation throughout production units. This can only be done by using look-ahead schedule, which determines the progression and rate of work. It carves up the master schedule into many packages, specifying the techniques of check capacity, execution, and establishes a stockpile of standing by work. The scope of look-ahead schedule ranges from 2 to 6 weeks and should be put in order by team work. The Lean Project Delivery System is a set of interdependent functions, rules of decision making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate, and is a conceptual framework developed by Ballard to guide the implementation of lean construction on project-based production systems. LPDS was depicted as a model with five main phases, where each phase is comprised of three modules. The interdependence between the phases was represented by sharing one module between two subsequent phases. Production control and lean work structuring were both shown to extend throughout the five main phases. The Lean Project Delivery System is a set of interdependent functions, rules of decision making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate, and is a conceptual framework developed by Ballard to guide the implementation of lean construction on project-based production systems. LPDS was depicted as a model with five main phases, where each phase is

comprised of three modules. The interdependence between the phases was represented by sharing one module between two subsequent phases. Production control and lean work structuring were both shown to extend throughout the five main phases. Daily huddle meetings provides a platform for the team members to share their views and to share what has been achieved, at the same time, discus problems they are

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facing during the production process; An informal meeting of all project foremen was replaced with the weekly work plan meeting, which focused on the completion of assignments during the following week. The discussions during the meetings addressed overlapping activities and identified potential problems on the job site. Actions agreed to at the meetings were recorded in minutes and were reviewed the following week. Project personnel met at the beginning of each workday for 5 to 10 minutes to review the work to be done that day. Scheduling, safety, and housekeeping were the most common issues to arise during these meetings Based on job surveys, at least 67% of the workers found value in the meetings. More than 42% of the workers provided some feedback during the meetings. Most of them stated that they are more likely to talk directly to their foremen during that time of the day. The strategy of Kanban is grounded on key components, i.e., market place, supplier kanbans, collection vehicle, satellite stores, and inventory management system. Market places are site warehouse that allocate different materials and small tools to the workers. Similarly, satellite stores are situated on site, where they get products from market places. Collection vehicle collects materials from preferred suppliers to the operational site. Kanban use plastic bins as a signal to pull materials from suppliers to site, using the concept of Just In Time. Request forms are normally used as kanban signals between market place and satellite stores. The system of kanban starts normally with open doors, so that the site can pull materials from the supplier up to certain perimeters. Subsequently, the material requested from suppliers arrives at market, and products are later on picked from the stores, which are usually managed by recorder points. Concurrent engineering can be described as parallel execution of various tasks by multidisciplinary teams with the goal of obtaining most favorable products concerning functionality, quality, and productivity. Many enhancements can be accomplished by using concurrent engineering. Scheduling could be recovered by network analysis. Concurrent engineering is focusing on the team efforts; communication and information sharing are the keys for discovering new ideas. While partnering with subcontractors and suppliers can also be good changes regarding concurrent engineering, the success of lean production is depending on the involvement of all participants in the early stages of the design. Visual inspection shows the uneven nature of the construction and leads to the application of visual tools for material, work and information flow, etc. Identification of materials can accelerate repetitive processes and diminishes the risk of selecting wrong product. Progress charts and schedules can implement the dedication to the completion of tasks. Information and technology can also improve the communication between decision maker and executer, and can accelerate the process as well. The first level of housekeeping consisted of separating material by reference and placing materials and tools close to the work areas with consideration of safety and crane movements. Next, materials were piled in a regular pattern and tools were placed in gang-boxes. Each subcontractor took responsibility for specific work areas on the job site. The next level included the preparation of a material layout design. The layout contained key information of each work activity on the job site. The visual workplace helped locate incoming material, reduce crane movements, and reduce walking distance for the crews. The next step consisted of keeping a clean job site. Workers were encouraged to clean workplaces once an activity had been completed. A housekeeping crew was set to check and clean hidden areas on the job site. The final level of housekeeping sought to maintain all previous practices throughout the project. At the end of the project, this level was not fully achieved, in part because project personnel did not view housekeeping as a continuous effort. They had to be reminded frequently of housekeeping practices. An overall quality assessment was completed at the beginning of the project. Most quality issues could be addressed by standard practices, and it seemed there was little room for improvement. During the execution of the project, however, some critical items appeared. Safety is tracked with safety action plans, i.e., lists of main risk items prepared by each crew. Potential hazards were studied and explored during the job. Most hazards, such as eye injuries, falls and trips, and hearing loss, have standard countermeasures; however, in practice, workers have to be reminded of safety practices. Two assignments were selected with input from the foreman, superintendent, and project manager: installing bumper walls and construction joints. Bumper wall installation was chosen because it is a high-cost activity, and construction joint installation was selected because of its high variability. Assignments were documented with video shooting and productivity studies. One flaw in the documentation was that most of the input came from the foreman instead of from the crew. The crew was focused exclusively on the completion of the task. The description of the activities could have been more detailed with input from the crew. The work performed was checked in a formal meeting attended by the project manager, the foreman, and the crew. The research team led the meetings, looking for potential improvements and learning opportunities. Most of the participants tried to give their best suggestions as to what could be improved for the next repetition of the assignment. Ideas suggested during the meetings were tested by the same crew, with support from the project manager and the foreman. Six Sigma is a business-driven, multi-faceted approach to process improvement, reduced costs, and increased profits. With a fundamental principle to improve customer satisfaction by reducing defects, its ultimate performance target is virtually defect-free processes and products. The Six Sigma methodology, consisting of the steps “Define - Measure - Analyze - Improve - Control,” is the roadmap to achieving this goal. Within this improvement framework, it is the responsibility of the improvement team to identify the process, the definition of defect, and the corresponding measurements. This degree of flexibility enables the Six Sigma method, along with its toolkit, to easily integrate with existing models of software process implementation.

F. Wastes generated in Construction Industry

Reduction and removal of waste is an important part of lean and green construction. Using the material resources efficiently can lead to sustainable waste management. Waste is hardly ever recognised by the project managers which is the major cause of loss of efficiency and productivity

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(Koskela 1992). It identifies the seven forms of waste which are over production, conveyance, inventory, processing, waiting, correction and motion. We can reduce the level of waste production in the construction industry by designing such a way that minimum waste is generated, by increasing the efficiency of the production process, by using the just-in-time tool to prevent the wastage of unused material, by recycling materials wherever possible and by educating the staff about waste reduction and material recycling. Formoso et al. classified construction wastes into two types: unavoidable (or natural) waste in which case the cost of prevention of the waste is higher than the production cost; and avoidable waste, in this case the cost of waste is higher than the cost of prevention. Construction wastes can be categorized according to its source or stage in which the root causes of the waste occur. It is classified construction waste causes into six sources: design, procurement, materials handling, operation, residual and others. Garas et al. grouped construction wastes into two: time wastes which include waiting periods, stoppages, clarifications, variation in information, rework, ineffective work, interaction between various specialists, delays in plan activities and abnormal wear of equipment. The other type is material waste which comprises over ordering, overproduction, wrong handling, wrong storage, manufacturing defects and thefts or vandalism.

II. NEED FOR 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.

III. OBJECTIVES OF THE RESEARCH

The objectives and scope of the research are: (1) To analyze the extent of lean development in Tamil Nadu (TN) construction industry. (2) To analyze the current lean practices at all the levels of construction projects in TN construction companies. (3) To investigate all the barriers in implementing Lean Construction techniques. (4) To rank the construction wastes generated in TN construction industry. (5) To propose better solutions to overcome the barriers in implementing lean construction techniques. (6) To recommend the solutions and suggestions for the major problems to minimize the top 10 prioritized wastes in TN construction industry. (7) To develop a practical framework for adopting lean construction techniques and measuring lean performance.

IV. RESEARCH METHODOLOGY

The main tool for the collection of data includes questionnaire survey. The target population for the data collection includes project managers of TN construction companies. The methodology starts with review of existing literature, followed by study the possibilities of all wastes in construction industry. Then, it is followed by the design of questionnaire for questionnaire survey. Then, it is continued to conduct questionnaire survey for data collection. The collected data is then analyzed using manual as well as software approach. The manual approach includes weighted average method, inter-priority basis ranking and relative importance index method. The software analysis is done using SPSS (Statistical Package of Social Sciences). Then, it is followed by proposing solutions and suggestions to overcome the barriers in implementing lean construction. And the project is extended to recommend solutions and suggestions to minimize the ranked wastes.

V. STRUCTURE OF QUESTIONNAIRE

The questionnaire has been structured based on the six main divisions. This includes barriers in implementing lean construction, techniques used in lean construction, wastes generated in construction industry, stages at which wastes are produced, statistical analysis of various parameters for the assessment of company’s growth, measurement of lean conformance. The questionnaire has also uploaded to Google drive in the form of Google docs so that the survey details can be collected online also. The survey has been conducted both in direct (Personal Interview) as well as through online. This online form has seven sections. This includes General introduction about Lean Construction, details of respondent, barriers in implementing Lean Construction and Techniques used in Lean Construction, techniques used in Lean Construction, Ranking – Wastes Generated in Construction Industry, stages at which wastes are generated, statistical analysis of various parameters for the assessment of company’s growth, measuring Lean Conformance.

VI. DATA COLLECTION

The direct personal interview method and online filling using Google forms are used for filling the questionnaire and collecting the data in which the respondents make a brief clarification for the ideas which are included in the questionnaire. The construction firms have been selected based on certain criteria. As the study includes entire Tamil Nadu, it is necessary to conduct a survey in major cities, districts of Tamil Nadu. The survey has been conducted at all the levels and types of construction projects. The various levels of projects are huge level, medium level and low level which are considered based on total construction cost and size of the project. The various types of projects includes the construction of: Residential Buildings, Flats, Apartments & Villas, Commercial Buildings such as hotels, restaurants, shops, etc.., Commercial Buildings such as marriage halls, theatre halls, shopping malls, etc.., Educational Institutions such as schools, universities, colleges, etc.., Government Projects, Roads & Bridges, Rotaries, etc.., Runways, taxiways, airport terminal buildings etc.., Urban Infrastructure, Power structures, Irrigation Harbor, industries like steel plants, textile plants, etc.., Tall structures, Oil refineries, pipelines, domes, etc.., Railway Works, Religious Structures, boilers, cooling towers, offshore structures, etc.., The major cities and districts are selected based on the composite index ranking of the district. Generally, Composite index is defined as grouping of equities, indexes or other factors combined in a standardized way, providing a useful statistical measure of overall market or sector performance over time. Composite Index is the average of the 13 indices such as percentage of population 0-6 years, birth order three

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and above, birth below age 20, complete immunization coverage, dropout from full immunization, female Literacy Rate, households Using Safe Drinking Water, households with toilet facility, percentage of electrified households, women receiving 2 TT Injections, women receiving 3 or More ANC Visits, under 5 mortality rate, contraceptive prevalence rate. Ranking is based upon a 2006 International Institute for Population Sciences, Mumbai report titled "Ranking and Mapping of Districts - Based on Socio - Economic and Demographic Indicators" using the 13 Indicators. Literacy, population growth and demographic transition will affects the evolution of construction industry. That is why, the composite index of the district is taken into consideration while selecting the major districts to conduct a survey. The top 25 districts has been selected for conducting a survey. Top 25 districts has been selected from the composite index of the districts. And the selected districts are as follows along with its composite index and its composite index ranking:

TABLE I. Selected Districts & its Composite Index

S.No	Name of the District	Composite Index	Rank
1	Chennai	0.86750	1
2	Kaniyakumari	0.81977	3
3	Coimbatore	0.79946	4
4	Kancheepuram	0.79856	5
5	Erode	0.79705	6
6	Nilgris	0.78501	7
7	Madurai	0.77851	8
8	Tiruvallur	0.77749	9
9	Thanjavur	0.77334	10
10	Tirunelveli	0.76828	11
11	Trichy	0.75728	12
12	Thiruvarur	0.75270	13
13	Karur	0.75253	14
14	Namakkal	0.75202	15
15	Tuticorin	0.75111	16
16	Theni	0.75040	17
17	Virudhunagar	0.74846	18
18	Sivagangai	0.74664	19
19	Nagapattinam	0.74328	20
20	Dindigul	0.74081	21
21	Cuddalore	0.73888	22
22	Vellore	0.72538	23
23	Salem	0.72383	24
24	Tirupur	0.72253	25
25	Krishnagiri	0.70919	26
-	Union Territory – Pondicherry	0.82433	1

The survey is conducted in the construction firms of various districts at the various levels of construction projects such as huge, medium and low level projects in the above specified two methods. One by direct personal interview and site survey and the other through online by Google forms. The survey is also conducted in construction firms who has undergone various types of project as mentioned above. The following table shows the survey type and the number of surveyed companies through each type. The survey has been done by means of direct personal interview, courier or mail and through online. It is very clear that 21 companies have been surveyed by direct personal interview, 8 through courier and 74 through online (Google Forms).

TABLE II. Number of Surveyed Companies based on its Type

S.No	Survey Type	Number of Surveyed Companies	Total Number of Companies in which Questionnaire has been given
1	Direct Personal Interview	21	21
2	Though Courier	8	15
3	Online Survey (through Google Forms)	74	180
Total		103	216

The total number of construction firms are 103 in which questionnaire survey has been conducted. It is very clear that the total number of surveyed construction firms are 103 in which 54 companies are lean and the rest are non-lean companies. The details of questionnaire survey conducted in construction companies based on various levels of projects such as huge, medium and low level projects with respect to each district are: 25 surveyed companies have undergone huge level projects, 71 surveyed companies have undergone medium level projects and 7 companies have undergone low level projects. The different levels of project are classified based on total construction budget cost and size of the project.

VII. DATA ANALYSIS

The questionnaires are distributed to the construction firms and the data are collected by means of direct interview method and online filling using Google forms from the respondents. Then the collected data are analyzed by means of manual method as well as using software method. The manual analysis has been done by 3 manual approaches such as priority ranking method, relative importance index (RII) method, weighted average method. The software analysis is also done using SPSS (Statistical Packages of Social Sciences) software. Out of 6 sections of the questionnaire, 5 sections has been analyzed by one manual approach called as group priority ranking method. The waste ranking section is analyzed using 3 manual approaches and 1 using software.

A. Priority Ranking Method

This method is also called as group priority ranking method and it is used for analyze 5 sections of the questionnaire. The first section of barriers in implementing lean construction techniques has been analyzed by this method. The lean score, non-lean score and overall (lean & non-lean) score, huge level projects score, medium level projects score, low level projects score, total score and mean has been calculated. The total score and mean is tabulated for all the four sections as follows:

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TABLE III. Total Score & Mean Value for Barriers in implementing Lean Construction Techniques

S. No	Barriers in implementing Lean Construction techniques	Total Score	Mean
1	Lack of Exposure on the need for lean construction	237	39.5
2	Uncertainty in the Supply Chain	204	34
3	The Tendency to apply traditional management	258	43
4	Culture & Human attitudinal issues (Mindset Issues)	222	37
5	Lack of Commitment from top management	168	28
6	Non-Participative Management Style Workforce	183	30.5
7	Attitude and ability to work in group	174	29
8	Lack of client and supplier involvement	171	28.5
9	Difficulties in understanding the concept of Lean Construction	177	29.5
10	Fragmentation and Subcontracting	117	19.5
11	Lack of proper training	198	33
12	Tendency to avoid formal planning	186	31

TABLE IV. Total Score & Mean Value of Techniques used in Lean Construction

S.No	Techniques used in Lean Construction	Total Score	Mean
1	Last Planner Planning System (LPS)	168	28
2	Lean Project Delivery System (LPDS)	126	21
3	Daily Huddle Meetings	228	38
4	Kanban System	213	35.5
5	Concurrent Engineering	249	41.5
6	Increased Visualization	204	34
7	Kaizen Total Quality Improvement (5S)	114	19
8	Safety & Quality Checks	264	44
9	First Run Studies – PDCA Cycle	186	31
10	Six Sigma Principle – DMAIC/DMADV	102	17
11	Pre-Fabrication	111	18.5

TABLE V. Total Score & Mean Value of Stages at which Wastes are Generated

S.No	Stages at which wastes are generated	Total Score	Mean
1	Contract Bidding Stage	21	3.5
2	Design Stage	63	10.5
3	Materials Procuring & Handling Stage	246	41
4	Operational Stage	282	47
5	Residual (Debris)	99	16.8
6	Theft / Vandalism	126	21

TABLE VI. Total Score & Mean Value of Wastes generated in Construction Industry

S.No	Wastes generated in Construction	Total Score	Mean
1	Waste due to Improper Planning of Construction	1512	252
2	Waste due to Worker's Mistakes	2310	385
3	Waste due to delay in material supply	2128	354.67
4	Waste due to irregular Cash Flow	2082	347
5	Waiting due to crews interference	1470	245
6	Waiting due to Inspection	1284	214
7	Waste due to Stock Problem	1140	190
8	Waste while waiting for instruction	1110	185
9	Waste in waiting due to equipment's installation	1104	184
10	Waste due to theft or Vandalism (theft)	1434	239
11	Waste produced due to over-ordering & over production	1116	185
12	Waste due to wrong handling and wrong storage	1284	214
13	Waste occurred due to manufacturing defects	1164	194
14	Waste due to ordering of materials that do not meet the project requirements defined on design documents	1194	199
15	Waste due to re-work	2220	370
16	Waste due to in-effective work (errors)	2250	375
17	Waste due to interaction between various Specialists	1302	217

B. Weighted Average Method

Weighted average is defined as an average calculated by taking into account not only the frequencies of the values a variable but also some other factor such as their variance. The weighted average of the observed data is the result of dividing the sum of the products of observed value, the number of times it occurs, and this other factor by the total number of observations. In order to define the relative importance of the main factors and the weight of each sub factors the following weighted average formula is used

$$Average\ Weight = \frac{Sum\ of\ Weight\ of\ Wastes\ in\ each\ group}{Total\ No\ of\ Wastes\ X\ No\ of\ Respondents}$$

The wastes in construction industry is analyzed by this method. For analyzing the data, sum of weight of each waste is calculated. Total number of factor is considered as total number of listed wastes and it is 18. The total number of respondents are 103.

C. Relative Importance Index (RII)

The wastes in construction industry has also been analyzed by Relative Importance Index method. The index is calculated by the following formula:

$$Relative\ Importance\ Index = \frac{\sum W}{A\ X\ N}$$

Where,

W is the weightage given to the factors by respondents, Weightage is given as 2, 4, 6, 8 and 10 for Never Occur, Very Rarely Occurs, Rarely Occurs, Frequently Occurs and very Frequently Occurs, A is the highest weight in the scale and it is given as 10 and N is the total number of respondents = 103.

D. SPSS Analysis

SPSS Statistics is a software package used for statistical analysis. It is a software for managing data and calculating a wide variety of statistics. The software name originally stood for Statistical Package for the Social Sciences (SPSS). The graphical user interface has two views which can be toggled by clicking on one of the two tabs in the bottom left of the SPSS Statistics window. The 'Data View' shows a spreadsheet view of the cases (rows) and variables (columns). Unlike spreadsheets, the data cells can only contain numbers or text, and formulas cannot be stored in these cells. The 'Variable View' displays the metadata dictionary where each row represents a variable and shows the variable name, variable label, value label(s), print width, measurement type, and a variety of other characteristics. The analysis has been done by descriptive statistics in the SPSS software. In this analysis, mean, median, mode and standard deviation is

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calculated. The wastes generated in construction industry has also been analyzed by means of software using Friedman Ranking method. The Friedman mean rank has been calculated in the software.

VIII. RESULTS AND DISCUSSIONS

From the above analyzed data, the following results are obtained:

1. The analysis showed that about 82.5 % of the surveyed companies have a clear idea about lean construction.
2. It is found that about 52.42 % of the surveyed companies have incorporated the lean construction techniques in the projects and about 47.57 % of the surveyed companies have not incorporated it.
3. The barriers in implementing lean construction is ranked from the collected as:

TABLE VII. List of Barriers in Implementing Lean Construction based on its Rank

S.No	Barriers in implementing Lean Construction	Rank
1	The tendency to apply traditional management	1
2	Lack of exposure on the need for lean construction	2
3	Culture & Human attitudinal issues (Mindset issues)	3
4	Uncertainty in the supply chain	4
5	Lack of Proper Training	5
6	Tendency to avoid formal planning	6
7	Non-Participative management style for workforce	7
8	Difficulties in understanding the concept of lean construction	8
9	Attitude and ability to work in group	9
10	Lack of client and supplier involvement	10
11	Lack of commitment from top management	11
12	Fragmentation and subcontracting	12

4. It is also found that the number of barriers can be eliminated to implement lean construction is 4 (on an average).
5. It is found that the safety & quality checks and concurrent engineering has been prioritized in the top level. Almost, many surveyed non-lean companies are using lean techniques either directly or indirectly.
6. The wastes in construction industry are analyzed both in manual as well as software. Both the results are compared, there is no much deviation in the priority ranking. The ranking of the wastes in construction industry is as follows:\

TABLE VIII. List of Wastes generated in Construction Industry based on its Rank

S.No	Wastes generated in Construction Industry	Rank
1	Waste due to Worker's Mistakes	1
2	Waste due to in-effective work (errors)	2
3	Waste due to re-work	3
4	Waste due to delay in material supply	4
5	Waste due to irregular Cash Flow	5
6	Waste due to Improper Planning of Construction	6
7	Waiting due to crews interference	7
8	Waste due to theft or Vandalism (theft)	8
9	Waste due to interaction between various Specialists	9
10	Waiting due to Inspection	10
11	Waste due to wrong handling and wrong storage	11
12	Waste due to ordering of materials that do not meet the project requirements defined on design documents	12
13	Waste occurred due to manufacturing defects	13
14	Waste due to Stock Problem	14
15	Waste produced due to over-ordering & over production	15
16	Waste while waiting for instruction	16
17	Waste in waiting due to equipment's installation	17

7. It is found that the wastes are generated mostly in the operational stage and it is followed by material procuring & material handling stage.
8. It is found that the wastes cannot be eliminated but it can be minimized to the certain levels. 100% of the surveyed companies have answered that they are minimizing the wastes to the certain levels. The average percentage of minimizing the waste is 32 %.
9. It is also found that almost all the surveyed companies have a 5 – 50 % of increment in their firm's performances with respect to production rate and quality performance of the project, duration of completion of the project, cost performance of the project, labour workforce of the project, labour support and safety measures of the project.
10. In the section of lean conformance measurement, it has been found from the analysis that 20% of surveyed lean companies are using the 100 percent of lean techniques in their projects, about 10% of surveyed lean companies are using less than 50 percent of lean techniques in their projects, about 20% of surveyed companies are using 50 percent lean techniques in their projects, about 50% of surveyed companies are using 75 percent of lean techniques.

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IX. SOLUTIONS, SUGGESTIONS & RECOMMENDATIONS

A. *Solutions to overcome the barriers in implementing Lean Construction.*

1. Lack of exposure on the need to adopt lean construction can be overcome by communicating the benefits of Lean construction through seminars and conferences to the construction practitioners. Also the government should enact policies which appreciate the effort by firms which adopt Lean principles.

2. Recommendation is to take company-wide initiative to apply Lean principles and it is not enough to send a few managers or personnel for workshops and seminars. This way of working should eventually percolate to the lower levels.

3. The sub-contractors and suppliers should also be made to attend the lean workshops and take initiatives to implement Lean management principles.

4. Barriers in uncertainty in the supply chain can be overcome by choosing proper suppliers who not quote less price, but deliver good quality and who also have a proven track record.

5. By working closely with suppliers and subcontractors, problematic issues can be minimized by participative style of managing projects and establishing strategic alliances with them.

6. There is a tendency to apply traditional management principles. People generally do not want to disturb processes which have been going on since a long time, but now with so much construction boom, it is high time the construction industry gives cognizance to the fact that waste produced by industry is high and needs to be minimized. This can be achieved by training all managers and workers in the firm on the benefits of Lean construction.

7. Workshops on the comparisons on Lean and traditional methods of construction, and how Lean is better should be conducted. Suitable metrics should be developed so that practitioners apply Lean management principles.

8. Managers should promote lean construction, as it can bring considerable revenue savings for the firm. Managers should change with times and new technology. This can be done by bringing about a change in organization culture by making the adoption of lean principles mandatory, by enacting new policies for waste minimization, and by partnering with suppliers and subcontractors to ensure that they follow Lean construction methods.

9. Participative style of management has many benefits. So it is recommended that the managers include the foremen, supervisors, and construction crew in day-to-day planning, as they are more involved with the ground realities.

10. The lean concept of Daily huddle meetings where every day before work starts, everyone gathers to learn about work allocation and discusses various issues will be beneficial. Increased visualization adopted by lean construction will also increase participation, as the progress of the work can be visually represented on a board for all employees to see, so that they know when they are lagging behind.

B. *Solutions to minimize the Ranked Wastes*

From the manual and software analysis, it has been found that the wastes generated has a great impact on construction cost, quality and time. Thus, the following solutions are recommended to minimize the wastes.

1. Split work packages to smaller units/tasks with reduced variability and less simultaneous work (small work chunks) to reduce cycle time.
2. Set up the layout of the work site to achieve a seamless work-flow and clean up and organize the work site daily using 5S (Sort, Straighten, Standardize, Shine and Sustain) techniques.
3. Reduce changeover from one task to another and prevent machine and equipment failures.
4. Balance work resources (add/remove resources) based on work flow, rely on smaller teams, and adjust relations and logic of work tasks accordingly.
5. Arrange for the availability of resources (material, labor, equipment, etc.) for all work packages, use less internal logistics, remove obstacles, implement multitasking and cross training. The objective is to be fully ready before the release of each task in the work package (i.e., no delays, no shortages, no errors, etc.).
6. Use buffers (cost, time, capacity, space, etc.) to absorb work flow variability. For example, feeding buffers can be used to synchronize for the rights start and finish of tasks in order to avoid delays (gaps) and overproduction (delivering work that is not needed at a particular time).
7. Adopt a quality-at-the source policy so that no bad work is passed down-stream (i.e., stop the work, if needed). Integrating the Six Sigma into the lean construction framework enables such policy where the focus is on improving the Sigma rating by reducing the defects.
8. Pull/release tasks from one station/worker to another when required and all resources are ready, preceding tasks are completed, and simultaneous tasks are synchronized.

X. CONCLUSIONS

Lean significantly contributes to the efficiency of the construction industry. The application of lean in the

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construction process has resulted into structuring of the work throughout the process and the improvement of performance of the project. Lean construction assures to deliver reliable work between specialists in design, supply and assembly, thus delivering Value to the customers and reducing the waste. The project tries to bring out the need for the implementation of lean philosophy in the construction industry. The project has also found out all the barriers in implementing Lean Construction and ranked according to the respondents' weightage. It has also found out all the wastes generated in construction industry and it is ranked according to the respondents' preference. It has been concluded by insisting that the Lean philosophies offer the conceptual basis, and lean construction methods and tools have great possibilities for sustainable construction. It is thus mandatory for the acceptance on lean tools to bring out the developmental change in the field of construction to achieve the substantial flow of work. Thus, solutions and suggestions are recommended to overcome the barriers in implementing lean construction and the project is extended to give solutions to minimize the wastes generated in construction industry. Thus, it satisfies the objectives of the project.

XI. FUTURE SCOPE OF THE RESEARCH

Directions for future research include addressing the identified causes of wastes and tracking their root causes to existing business practices in scoping, planning, and decision making as well as to the labor issues such as training, language barriers, and cultural aspects. Future research could also focus on providing guidelines for construction managers for addressing quality concerns, enhancing and testing the assessed techniques including the addition of a safety indicator, and quantifying the costs and gains of adopting the lean construction framework.

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