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A Study on Improving the Indian Economy by Lean Construction Practices

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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. Lean Construction is also about gaining the control through coordination between stakeholders and the team members to improve the performance, delivery and value for everyone involved in the project. 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 Construction, Methodologies.**

1. Introduction

A. Background

Construction is the second largest economic activity after agriculture in India, and it makes significant contribution to the national economy. Construction activity being labour intensive has generated employment for about 33 million people in the country (Singh 2008). There are mainly three segments in the construction industry like real estate construction which includes residential and commercial construction; infrastructure building which includes roads, railways, power etc., and industrial construction that consists of oil and gas refineries, pipelines, textiles etc.

Indian construction industry saw a large scale boom in the past two decades till the recent global economic crisis. Most construction companies were forced to slow down some of their ongoing projects because of the economic meltdown. One of the major challenges facing this sector is the lack of skilled and quality human resources and the limited ability of capital equipment suppliers to meet the demand. As a result, most projects ends up in time and cost overruns. Skillful project management and innovative solutions are necessary to prevent these bottlenecks. A total of $50 billion is estimated to be spent on construction every year in India.

B. Need for the study

The large infrastructure development initiatives undertaken during the last two decades have provided an opportunity for the construction industry to undertake a number of large projects. In its path of advancement, the industry is faced with problems such as time and cost overruns, low productivity, poor safety, inferior working conditions, insufficient quality etc. These are associated with considerable amount of waste present in the construction sites. While a few large construction companies have started to look into waste reduction and process improvement issues through concepts like lean construction, most organizations are yet to address this issue. As a prerequisite to implementing lean principles, in which a major focus is on elimination of waste, it is important to understand and quantify the amount of waste actually present in Indian construction sites. In general, project managers define the term "waste" rather as physical construction waste than the real concept of waste. Waste includes both the incidence of material losses and the execution of unnecessary work that generates additional costs but does not add value to the product (Koskela 1992). It includes the categories such as waiting time, unnecessary transportation, non-value added processing, excess inventory, rework etc. However, such waste has not been clearly identified by project managers. Hence, it is necessary to have a better understanding of the concept of waste and to identify the significant waste variables and their causes. Also a proper methodology has to be developed to quantify different categories of waste in terms of cost. Thus this project attempts to identify, categorise and quantify waste based on the principles of a new production philosophy called lean construction.

2. Literature review

A. Concept of waste in construction

In new production philosophy, "waste" has been given a broader concept and definition as compared to its usual narrow meaning. According to the new production philosophy, waste should be understood as any inefficiency that results in the use of equipment, materials, labour, or capital in larger quantities than those considered as necessary in the production of a building. Waste includes both the incidence of material losses and the execution of unnecessary works, which generate additional costs but do not add value to the product (Koskela 1992). Therefore, waste should be defined as any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client. Then, any improvement effort should be focused on identifying waste in the construction process, analysing the causes that produce waste, and acting on these causes to reduce or eliminate them.

In this lean production paradigm, the concept of waste is directly associated with the use of resources that do not add value to the final product. This is very much different from the conventional conversion view of production processes where no significant attempts were made to separate the activities into value adding or non-value adding activities. The conventional view sees all activities combined as a whole and therefore waste is being monitored and evaluated as a whole conglomerated additional cost to the production and mainly it only captured costs for the material wastes. The new production philosophy intend to look into and detail out the dimension of waste by identifying non-value adding activities and introduce new measures to wastes such as additional costs or opportunity costs especially due to time waste and value loss which very much invisible in conversion model.

This means that there are two approaches for improving processes for new production philosophy compared to conventional conversion view. One is to improve the efficiency of both value adding and non-value adding work, and the other is to eliminate waste by removing non-value adding activities. Therefore, waste should be defined as any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client.

B. Waste classification

Alarcon (1994) stated that waste in construction and manufacturing include delay times, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper choice of management, methods or equipment and poor constructability.

Formoso (1999) commented that there is an acceptable level of waste, which can only be reduced through a significant change in the level of technological development. Based on the ratio of prevention investment cost over the cost of waste itself, they have classified wastes into two general groups:

1. Unavoidable waste (or natural waste), in which the investment necessary to its reduction is higher than the economy produced. The percentage of unavoidable waste in each process depends on the company and on the particular site, since it is related to the level of technological development.
2. Avoidable waste, in which the cost of waste is significantly higher than the cost to prevent it.

Shingo (1981) proposed the following waste classification whereby waste was classified by its nature, based on the Ohno's framework of Toyota Production System such as

1) Waste due to overproduction, 2) Waste due to wait periods, 3) Waste due to transport, 4) Waste due to system itself, 5) Waste due to stock, 6) Waste due to operation, and 7) Waste due to defects.

Formoso (1999) went on to propose their main classification of waste based on the analysis of some Brazilian building sites they had carried out as shown below.

1. Overproduction: related to the production of a quantity greater than required or earlier than necessary. This may cause waste of materials, man-hours or equipment usage. It usually produces inventories of unfinished products or even their total loss, in the case of materials that can deteriorate. An example of this sort of waste is that the overrun of mortar that can't be used on time.
2. Substitution: is financial waste caused by the substitution of a cloth by a costlier one (with associate degree needless higher performance); the execution of easy tasks by associate degree over-qualified worker; or the employment of extremely refined instrumentality wherever a way easier one would be enough.
3. Waiting time: associated with the idle time caused by lack of synchronisation and levelling of fabric flows, and pace of labor by completely different teams or equipments. One example is that the idle time caused by the dearth of fabric or by lack of labor place on the market for a gang.
4. Transportation: involved with the inner movement of materials on website. Excessive handling, the employment of inadequate instrumentality or unhealthy conditions of pathways will cause this sort of waste. it's sometimes associated with poor layout, and also the lack of designing of fabric flows. Its main consequences are: waste of man hours, waste of energy, waste of house on website, and also the risk of fabric waste throughout transportation.
5. Processing: associated with the character of the process (conversion) activity, that may solely be avoided by dynamical the development technology. for example, a share of mortar is sometimes wasted once a ceiling is being plastered.
6. Inventories: associated with excessive or needless

inventories that result in material waste (by deterioration, losses thanks to inadequate stock conditions on website, robbery, vandalism), and financial losses thanks to the capital that's affianced. it would be a results of lack of resource coming up with or uncertainty on the estimation of quantities.

7. Movement: involved with needless or inefficient movements created by staff throughout their job. This may well be caused by inadequate instrumentality, ineffective work strategies, or poor arrangement of the operating place.

8. Production of defective products: it happens once the ultimate or intermediate product doesn't match the standard specifications. this might result in makeover or to the incorporation of needless materials to the building (indirect waste), like the excessive thickness of daubing. It is often caused by a large vary of reasons: poor style and specification, lack of designing and management, poor qualification of the team work, lack of integration between style and production etc.

9. Others: waste of any nature completely different from the previous ones, like felony, vandalism, inclement weather, accidents etc.

C. Identification of waste

One side difficult lean construction advocates is that the systematic identification and quantification of waste, development of lean operations, and improvement verification. though identification of waste may be a requirement for implementing lean, not abundant analysis has been worn out this space thus far. Alwi et al. (2002a) investigated the incidence of waste inside contractors corporations in country, specializing in nonresidential building and infrastructure comes. information was collected through questionnaires. The findings recommend that six factors were found to be the key variables of waste together with repair on finishing works, expecting materials, delays to schedule, slow tradesmen, waste of raw materials on web site and lack of supervising. Whereas style changes, slowness in creating selections, lack of adept labour, inappropriate construction strategies, poor coordination among project participants, delay of fabric delivery to web site and poor designing and planning were known because the key variables inflicting waste. Similar study was conducted by the Alwi et al. (2002b) in Australian housing industry conjointly. The paper recommends that to minimize the negative impact of waste, contractors ought to maintain elaborated records of all events that occur on-site in reference to the incidence of waste.

3. Methodology

A. Introduction

Critical waste variables and waste cause variables can be identified by conducting a questionnaire survey. The respondents include project managers, construction managers, planning managers, planning engineers and site engineers. We have to ask to rate the frequency of generation of waste, level of effect of waste categories on construction and the importance of waste cause variables on a five-point scale from 1 to 5. The data collected & analysed using the concept of relative importance index. Based on literature review and questionnaire survey conducted, waste in construction was classified into material scrap waste, excess inventory, rework, inefficiency of labour and equipments. Inefficiency of labour and equipments were further classified into non-value adding activities such as waiting, idle, transportation excess processing and excess movement.

B. Identification of waste

From literature review, 56 variables that related to waste activities were identified. The variables were then separated into waste variables and waste cause variables. Waste variables are those variables that contributed to a reduction in the value of construction productivity and waste cause variables could be defined as factors producing waste.

C. Waste categorization

Waste variables were grouped into five categories–Rework, Waiting, Material, Human Resource, and Operations. Waste cause variables were grouped into six categories–People, Project Management, Design and Documentation, Material Management, Execution, and External.

D. Questionnaire survey

The questionnaire is given in appendix and it consists of three sections. The details of the respondents, projects and company profile were gathered in the first section. The second section contained questions regarding the frequency of waste and the level of effect/impact of waste on construction projects.

E. Data analysis

Data analysis were done on the basis of the data collected from the site.

F. Improvement measures

From literature and analysis based on questionnaire and quantification, possible improvement measures were done. Also further interviews were conducted with construction industry experts to get their opinion regarding the improvement measures for minimizing waste in construction sites.

4. Waste identification

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Waste variables were grouped into five categories–Rework, Waiting, Material, Human Resource, and Operations. Waste cause variables were grouped into six categories–People, Project Management, Design and Documentation, Material Management, Execution, and External.

A. Structure of questionnaire

The questionnaire is given in appendix and it consists of three sections. The details of the respondents, projects and company profile were gathered in the first section. The second section contained questions regarding the frequency of waste and the level of effect/impact of waste on construction projects. Respondents were asked to rate the frequency of generation of waste as (1) never; (2) rarely; (3) occasionally; (4) often; and (5) always. Also the level of effect/impact of waste categories on construction was rated from 1 (no significant effect) to 5 as (high detrimental effect) for each waste variable. The third section dealt with the causes of waste. The level of effect/impact of waste cause variables on construction were to be rated on a scale from 1 (no significant effect) to 5 (highly detrimental effect).

The collected data was analysed using the concept of Relative Importance Index (RII). Importance index was calculated for frequency and effect of variables, using equation given below.

$$RII = \frac{(5M_1 + 4M_2 + 3M_3 + 2M_4 + 1M_5}{5(M1 + M2 + M3 + M4 + M5)}$$

where,

M1 = number of respondents who rated 5
M2 = number of respondents who rated 4
M3 = number of respondents who rated 3
M4 = number of respondents who rated 2
M5 = number of respondents who rated 1

Frequency index calculated for waste variables represents the frequency of occurrence of waste in construction sites. Impact index calculated for waste variables represents the impact of waste variables on construction performance. Similarly impact index calculated for waste cause variables indicates the significance of waste cause variables on producing waste in construction sites. Frequency index and impact index were calculated by equation. Weighted index for each waste variable was calculated by equation multiplying the frequency index by the impact index. Waste variables were arranged in descending order of their weighted index values to determine the rank. In case of waste cause variables, the rank was determined by arranging the variables in the descending order of the impact index calculated by equation. Ranking of variables were then used to identify the critical variables.

Weighted Index for waste variable = (Frequency Index) x (Impact Index)

Critical waste and waste cause variables identified from questionnaire survey represents only the perception of respondents regarding the waste in construction industry. Also it has been identified from literature review that very few studies have been conducted to quantify all types of waste in construction. Implementation of Lean Construction concepts in construction sites can be effective if one knows the extent of waste present in each category so that appropriate importance can be given and improvements be made to reduce the impact due to it. Hence an attempt has been made to quantify significant waste categories identified based on literature review and questionnaire survey. As a first step for the quantification purpose, waste in construction has been classified into materials, quality, inefficiency due to labour and equipment.

Material prices represent quite four-hundredth of the overall construction price and therefore, a vital issue for the success of a construction project. Material waste includes scrap waste generated in sites and also the waste attributable to excess inventory being unbroken in stores. Scrap waste is generated in sites attributable to numerous reasons like poor accomplishment, rework, loss of materials etc. Scrap waste is that the amount of fabric wasted compared to amount of fabric issued and is generally expressed as share of theoretical or measured amount.

Excess Inventory for material is that the inventory amount in far more than necessities for on time delivery. Causes of excess inventory may be protection against things which will fail, unreliable forecasts, poor programming, poor market forecast, unreliable shipments by suppliers, communication issues with suppliers and customers, management choices etc. Excess inventory may end up in raised labour price, price of interest on assets, raised area price, raised maintenance price, material aging, risk of fabric degeneration etc. In general, it's common follow to stay lots of material inventories during a construction website, as a result of it's too troublesome and difficult to form a tiny low order for construction materials every and each time on demand. These surplus inventories will meet sudden demands, and conjointly might have economical benefits by avoiding increase of raw materials. However, they even have negative aspects; (1) increase monetary prices, thus referred to as inventory holding prices and infrequently (2) decrease construction productivity attributable to excessive storage areas, surplus quantity of labor in method (WIP), and different inefficiencies.

price of quality consists of price of quality management efforts and deviation prices (rework). From waste purpose of read, deviation prices or retread prices square measure a lot of important. therefore, during this study, solely price attributable to retread in construction was thought of for quantification. retread has become a pandemic feature of each construction method, that invariably ends up in time and value overruns in comes and it may be outlined as doing one thing a minimum of one time beyond regulation attributable to non-conformance to necessities. basically retread may end up from errors, omissions, failures, injury and alter orders.

Inefficiencies in utilization of labour and equipments were any subcategorized into non-value adding activities like waiting, idle, transportation, excess process and excess movement (CII 2005). Waiting time embrace classes like looking forward to material, tools and examination, looking forward to instrumentation repair, looking forward to necessity work or another crew, looking forward to same crew members etc. Idle time needs to be distinguished from waiting time. Idle time may be explained because the time that labour and equipments square measure unbroken idle while not doing any activity as a result of the work has not been assigned. Waste attributable to transportation includes classes like labourers transporting materials and tools, labourers movement empty two-handed, equipments moving with materials, positioning of apparatus etc. Waste attributable to excess process is usually associated with the character of process activity. repetition associate degree operation that isn't required, extra inspections and directions etc. falls below this class.

Excess movement can be defined as any unnecessary or inefficient movement made by labourers or equipments during the job. This might be caused by poor working place conditions, inappropriate construction methods etc.

5. Data analysis

A. *Material scrap waste*

Data regarding material scrap waste was obtained from reconciliation data and other documents maintained by planning engineers in the site. The format used for the data collection is given in Last. The data collected includes theoretical quantity of materials, total receipt of materials, existing inventory in site, total quantity of materials required for the project etc. Data was collected only for top 5-6 materials used in the site. The difference between total receipt of material and existing inventory in the site gives the actual quantity of material used till date and then the scrap wastage as percentage of theoretical quantity of material was calculated according to the equation given below. Wastage calculated was then compared with the nominal value. Nominal value is the wastage assumed by construction companies in their cost estimates. Cost of material scrap waste for a particular site was obtained by equation.

$$\text{Material scrap waste, } Wi\ (\%) = \frac{(Mactual - Mtheoretical)}{Mtheoretical} \times 100$$

$$\text{Cost of material scrap waste} = \sum_{I=1}^{K} \frac{Wi\ Ti\ Ci}{100}$$

Where,
Ci = Unit price of material i
k = Number of materials for which data was collected
M_{actual} = Actual quantity of material consumed

Table 1
Details of project studied

Parameter	Project A	Project B	Project C	Project D
Location	Chennai	Chennai	Chennai	Chennai
Total construction cost (Rs. million)	160	350	171.5	125
Type of contract	Lumpsum	Lumpsum	Lumpsum	Lumpsum
Planned duration(months)	16	24	15	24
Time overrun	56 months	12 months	5 months	4months
Average no of workers per day	70	150	120	80
Type of work	Bridge	Bridge	Bridge	Bridge

Mtheoretical = Theoretical quantity of material consumed
Ti = Total quantity of material i required for the project
Wi = Scrap waste for the material i

Table 2
Material scrap waste in percentage

Material	Project A	Project B	Project C	Project D
Cement(T)	2.3	3.5	4.6	3.5
20mm aggregate(m^3)	3.2	3.4	4.1	2.7
10mm aggregate(m^3)	5.4	3.2	4.3	1.2
River sand(m^3)	3.8	4.5	3.4	4.7
Reinforcement(t)	1.7	1.9	2.1	1.5
Cost of scrap waste*	3.7	3.2	2.4	3.7

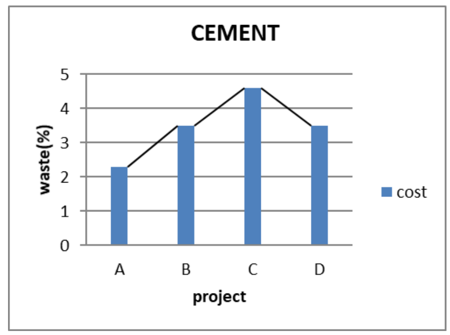

Fig. 1. Material scrap waste (cement)

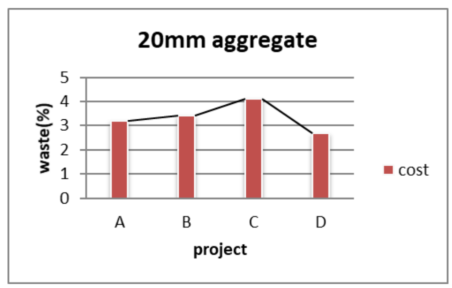

Fig. 2. Material scrap waste (20mm aggregate)

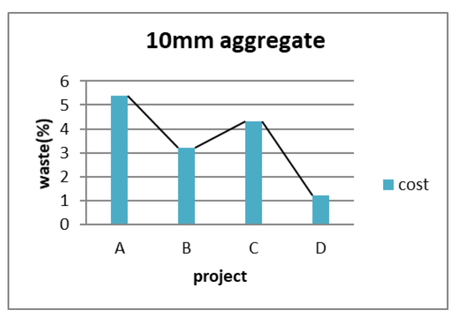

Fig. 3. Material scrap waste (10mm aggregate)

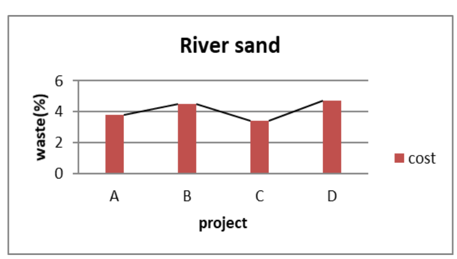

Fig. 4. Material scrap waste (River sand)

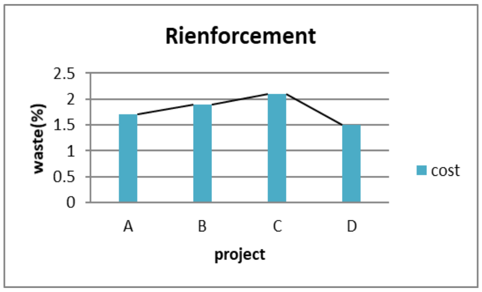

Fig. 5. Material scrap waste (reinforcement)

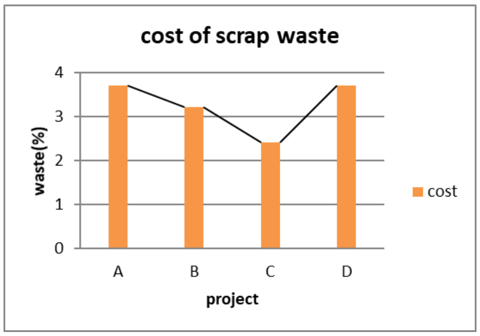

Fig. 6. Material scrap waste (cost of scrap waste)

B. Excess inventory

Data regarding excess inventory was obtained from data maintained in stores and discussion with stores in-charge. Quantity of excess inventory was calculated by equation given below and it was assumed that the demand for material is almost constant throughout the project duration. Safety stock is a term which was included in the calculation of excess inventory to take care of the factors such as variability in the lead time of materials and the variability in the usage or demand of materials. In order to simplify the calculations, approximate value for the same was obtained based on the judgment and experience of stores in-charge and planning managers. Cost due to excess inventory was obtained by equation as the sum of financial cost, storage cost and handling cost. When a material is purchased before it is needed, the inventory is carried in storage with a financing cost and was obtained by equation. This cost depends on the length of time; the material is kept on inventory and the value of money. Storage cost obtained by equation consists of the rental cost of the storage area. In this study, storage cost was taken as zero as there is no rent paid for the storage area in the site. Handling cost obtained by equation is the cost of moving the material from the trucks to the storage area. The main factors influencing handling cost are daily productivity of workers who are involved in transporting materials from trucks to storage area and the excess inventory quantity of materials.

Quantity of excess inventory, Qi = Ii – (tpiDi) – Si

Cost of Excess Inventory

= Financial cost + Storage cost + Handling cost

Financial cost, Af $= \mathrm{Dy} \sum_{i=1}^{k} \mathrm{Qi\ Ci\ Ni}\,[(1 + \mathrm{ir}) - 1]$

Storage cost, As $= \mathrm{Dy} \sum_{i=1}^{k} \mathrm{Ri\ Ai}$

Handling cost, Ah $= \mathrm{Dy} \sum_{i=1}^{k} \frac{\mathrm{QiWNi}}{ph}$

where,

Ai = Area of storage of excess inventory of material i
Di = Average demand for the material i per day
Dy = Project duration in years
Ii = Average ordered quantity of material i
iR = Interest rate
Ni = Number of orders made for material i per year
Ph = Daily productivity of crew involved in handling material
Qi = Quantity of excess inventory of material
Ri = Annual rent for the area
Si = Safety stock quantity of material
ti = Time period for which material i is purchased before than it is required (approximated as Qi/Di)
tpi = Average time taken to procure material i
W = Average daily wage of workers

Table 3
Waste due to excess inventory in percentage

Material	Project A	Project B	Project C	Project D
Cement(T)	.33	.45	.67	.56
20mm aggregate(m^3)	3.6	4.4	4.7	1.7
10mm aggregate(m^3)	4.3	2.8	5.1	3.6
River sand(m^3)	.78	3.5	2.7	2.4
Reinforcement(t)	1.6	1.4	.89	2.1
Cost of scrap waste*	1.3	2.15	1.73	2.7

*calculated using equation above

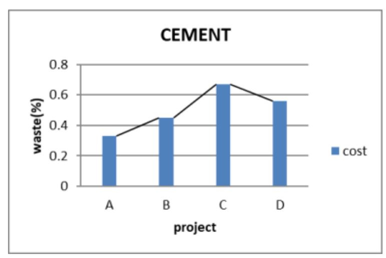

Fig. 7. Excess inventory waste (cement)

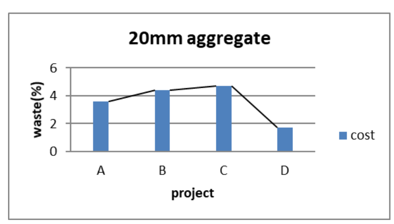

Fig. 8. Excess inventory waste (20mm aggregate)

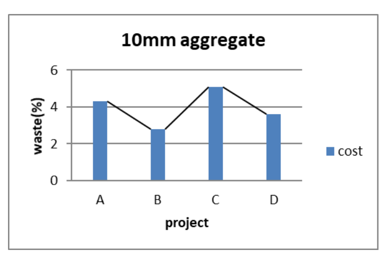

Fig. 9. Excess inventory waste (10mm aggregate)

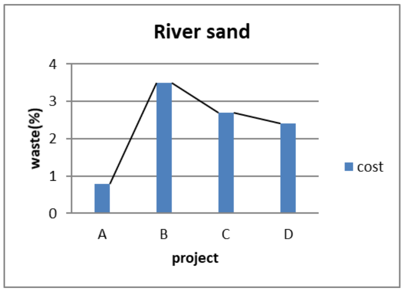

Fig. 10. Excess inventory waste (river sand)

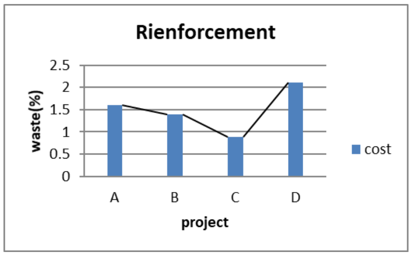

Fig. 11. Excess inventory waste (reinforcement)

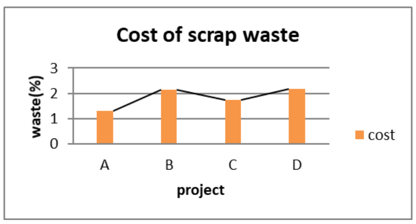

Fig. 12. Excess inventory waste (cost of scrap waste)

C. Rework

A framework for the quantification of cost of rework has been developed similar to the Quality Performance Management System (QPMS) developed by Ledbetter (1994). QPMS defines the cost of quality as "the cost associated with quality management activities (prevention and appraisal) plus the cost associated with deviations." Deviations resulting in doing things over, termed rework, reduce a project's profitability, and is generally recognized as a waste. On the other hand, unnecessary quality management costs also reduce a project's profitability; a fact often overlooked and is not generally recognized as a waste. QPMS is a simple tool involving labour costs only. It is a self-measurement system based on project personnel keeping track of their time spent in three main endeavors: (1) normal work, (2) quality management work (prevention and appraisal), and (3) rework (deviation correction). To reduce rework to its absolute minimum, the root cause(s) of rework must be determined. When tracking rework, three pieces of minimum information are needed:

1. The root cause of the rework.
2. The instigating discipline: Sometimes rework in one discipline creates rework in another discipline. To properly identify the full impact of all rework, costs should be assigned to the instigating discipline, regardless of who else has to perform the rework.
3. The phase in which the rework was detected.

Table 4
Rework classification system

Type	Description used
Owner change	Change authorised by owner-client after some work has been performed
Design change	Change made by designer in design of product or process; Change may occur during design, construction, or startup; Often, change results in improved value and operability of product or process, or is result of “out-of sequence” work
Vendor change	Change made by vendor to purchased product or to interface with project; change may occur during design, construction, or startup; often, change results in improved value and operability of product or process
Constructor change	Change made by constructor on product or process; change may occur during design, construction, or startup; often change results in improved constructability, value, or operability of product or process, or is result of "out-of sequence" work
Unknown change	The source of the change cannot be determined as there is not enough information available
Designer error	Error or omission made by designer of product or process
Vendor error	Error or omission made by vendor furnishing product for project
Constructor error	Error or omission made by constructor on product or process involved on project
Damage	Damage may be caused by a subcontractor or inclement weather

In this study, the methodology used by Ledbetter (1994), Davis et al. (1989) and Love and Irani (2003) has been modified and an attempt has been made to track rework costs. Rework in construction process was further categorised into change, error, omission, and damage. The template used for the data collection is given in Appendix. The classification system used to track rework cost in construction is explained in the Table 4. The data collected includes description of event, category and type of rework occurred, non-productive time in days, the cost of rework incurred (obtained from non-conformance reports maintained in the sites) etc. Various questions asked are as follows:

1. What was the problem? (Date and event description)
2. Which task?
3. What subcontract trade?
4. Who caused it? (Comments on event)
5. How was it classified? (What type)
6. How did it affect time?
7. How did it affect cost?

Table 5
Cost of Rework in Construction

Project	Total nonproductive time (days)	Cost of Rework incurredat time of data collection (Rs)	Rework cost as % of construction cost at time of data collection	Comments
A	54	10240000	0.064	Poor workmanship
B	63	49350000	0.141	Poor workmanship
C	41	14063000	0.082	Poor workmanship
D	34	11375000	0.091	Poor workmanship

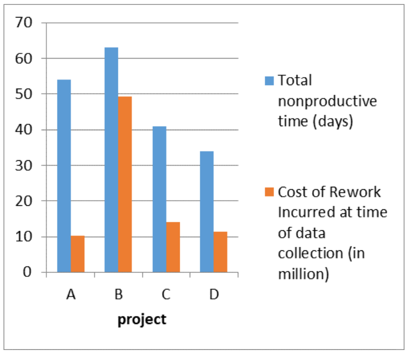

Fig. 13. Cost of Rework in Construction

However, none of the construction sites studied maintained proper rework data. The data collected based on the non-conformance reports was found to be too low. It can be due to two reasons. Either Indian sites are very efficient or costs of rework are not recorded properly. At the same time, the deviation cost of quality has been found to be significant in a number of studies in other countries. From literature, the deviation cost of quality (rework) in advanced economies like US has been found to be at least 12% of project cost (Burati et. al. 1992). Also, from the questionnaire survey, it was identified that most of the construction companies are not aware of the significance of impact of rework on the overall project performance, as evident from low value of weighted index and impact index for repair variables. The level of documentation maintained in the sites was also found to be not satisfactory.

Based on the site visits conducted, it was concluded that there is no proper system available in sites to track the quality costs. Hence, the results indicated in the Table 5.5 do not reflect the actual costs incurred in the sites and form only the "tip of an iceberg". There is an urgent need to track the costs of quality properly in order to quantify the cost of rework in construction accurately. A template to quantify rework costs has been prepared and is given in the appendix.

6. Conclusion and recommendations

There are a lot of non-value adding activities or wastes in construction practices and many among those were left unnoticed or unattended. Previous studies have shown that there were significant amounts of values loss due to construction process flow wastes and tremendous productivity improvements can be achieved by simply targeting at reducing or eliminating those wastes and/ or improve the process flow.

This work was conducted on the basis to study the waste concepts and the level of "leanness" in local construction practices based on philosophies and principles drawn by Lean Construction. A quantitative survey was carried out through structured questionnaires over a randomly selected group of managerial personnel in construction activities.

Poor planning and scheduling, lack of skilled labour, design changes, inappropriate construction methods, and unclear specifications were identified as the top five critical waste cause variables.

Workers resting during construction, waste of raw materials on site, idle workers, waiting for materials, and travelling empty handed were identified as the top five critical waste variables.

A. *Quantification of waste*

The following conclusions were drawn after quantifying waste based on the data collected from six building projects

1. The wastage of cement as scrap waste to percentage of total amount of cement varied from 2.3% to 4.6% among the projects studied.
2. The wastage of 20mm aggregate as scrap waste to percentage of total amount of 20mm aggregate varied from 2.7% to 4.1% among the projects studied.
3. The wastage of 10mm aggregate as scrap waste to percentage of total amount of 10mm aggregate varied from 1.2% to 5.4% among the projects studied.
4. The wastage of river sand as scrap waste to percentage of total amount of river sand varied from 3.4% to 4.7% among the projects studied.
5. The wastage of reinforcement as scrap waste to percentage of total amount of reinforcement varied from 1.5% to 2.1% among the projects studied.
6. The wastage of cement as excess inventory to percentage of total amount of cement varied from 0.33% to 0.67% among the projects studied.
7. The wastage of 20mm aggregate as excess inventory to percentage of total amount of 20mm aggregate varied from1.7% to 4.7% among the projects studied.
8. The wastage of 10mm aggregate as excess inventory to percentage of total amount of 10mm aggregate varied from 2.8% to 5.1% among the projects studied.
9. The wastage of river sand as excess inventory to percentage of total amount of river sand varied from 0.78% to 3.5% among the projects studied.
10. The wastage of reinforcement as excess inventory to percentage of total amount of reinforcement varied from 1.4% to 2.1% among the projects studied
11. Rework cost as % of construction cost at time of data collection varied from 0.064% to 0.141% among the projects studied

In conclusion, the outcomes of the research suggested that there still have rooms for construction process improvements with the application of lean construction and proper waste concepts instilled to all level of construction personnel and processes.

B. *Scope for further research*

More case studies with the help of construction companies should be developed to show lean construction implementation benefits in Indian construction industry.

Some of the lean construction tools like Last Planner System, Increased visualization, Daily Huddle Meetings, and First Run Studies should be implemented in some of the sites and its potential benefit in Indian construction industry needs to be explored in detail.

References

[1] Ballard, G. (2001). "Cycle time reduction in home building." *Proc., 9th Annual Conf., Int. Group for Lean Construction*, National Univ. of Singapore, Singapore

[2] Ballard, G. (2000). "The last planner system of production control." Ph.D. thesis, Univ. of Birmingham at Birmingham, U.K.

[3] Alarcon, L. F. (1994). "Tools for the identification and reduction of waste in construction projects." *Lean construction*, Alarcon, (Ed.), A.A. Balkema, otterdam, The Netherlands, 374–387.

[4] Alarcon, L. F., and Serpell, A. (1996). "Performance measuring, benchmarking and modeling of project performance." *5th International Conference of the International Group for Lean* Construction, University of Birmingham, UK.

[5] Alarcon, L. F., Diethelm, S., Rojo, O., and Calderon, R. (2005). "Assessing the impacts of implementing lean construction." *Proceedings of the 13th annual conference of the International Group for Lean Construction*, Sydney, 387-393.

[6] Alwi, S., Hampson, K., and Mohamed, S. (2002a). "Waste in the Indonesian construction projects." *Proc., The 1st International Conference of CIB W107 -Creating a sustainable Construction Industry in Developing Countries*, South Africa, 305-315.

[7] Howell, G. (1999). "What is lean construction–1999." *Proceeding, 7th Conference of the International Group for Lean Construction*, University of California at Berkeley, California.

[8] Howell, G., and Ballard, G. (1998). "Implementing lean construction: understanding and action." *Proceeding, 6th Conference of the International Group of Lean Construction*, Guaruja, Sao Paulo, Brazil.

[9] Koskela, L. (1992). "Application of the new production philosophy to construction." *Tech. Report No. 72*, CIFE, Stanford Univ., California.

[10] Koskela, L. (2000). "An exploration towards a production theory and its applicationto construction." *Technical Research Centre of Finland, VTT Publications 408*, Finland.

[11] Koskela, L., and Howell, G. (2002). "The underlying theory of project management is obsolete." *Proceedings of the PMI Research Conference*, 293-302.

[12] Love, P. E. D., and Irani, Z. (2003). "A project management quality cost information system for the construction industry." *Journal of Information and Management*, 40, 649-661.

[13] Mohan, S. B., and Iyer, S. (2005). "Effectiveness of lean principles in construction." *Proc., Int. Group for Lean Construction 13th Annual Conf. (IGLC-13)*, IGLC, sydney, Australia, 421-429.

[14] Salem, O., Solomon, J., Genaidy, A., and Minkarah, I. (2006). "Lean construction: From theory to implementation." *Journal of Management in Engineering, ASCE*,22(4), 168-175

[15] Shingo, S., 1985, "Zero quality control: Source inspection and the pokayoke system," Productivity, Cambridge, Ma., 57–69.