WASTE IN INDIAN BUILDING CONSTRUCTION PROJECTS

K. P. Ramaswamy[1] and Satyanarayana N. Kalidindi[2]

ABSTRACT

The Indian construction industry is characterised by challenges such as low productivity, lack of skilled labour, time and cost overruns etc. These are associated with considerable waste present in the construction sites. An important step towards elimination of waste, is to understand and measure the amount of waste actually present in Indian construction sites. Currently there is very little documentation in literature on this issue in the Indian construction industry context.

This paper aims to investigate waste in Indian construction industry, focusing mainly on building projects. Six ongoing projects were taken up for the study and the wastes identified were quantified in terms of project cost by collecting data through direct observations, records and using tools such as work sampling. The results showed that waste due to non value added activities by labour and equipment was much higher compared to material waste generated in the sites. The total cost of waste calculated as percentage of project cost, for the items studied, varied from 5.38% to 14.70% among the projects studied. However, this did not include the cost of quality deviations as this data was not documented in the sites studied.

KEY WORDS

Lean construction, indian construction, productivity, waste, work sampling.

INTRODUCTION

Construction is the second largest economic activity after agriculture in India. It accounts for 11% of India's GDP and has generated employment for about 33 million people in the country. 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 also faced with chronic problems such as time and cost overruns, low productivity, poor safety, inferior working conditions, insufficient quality, lack of skilled manpower etc. These are associated with considerable 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 organisations are yet to address this issue. Towards implementing lean principles, in which a major focus is on elimination of waste, it is important to

---

[1] M.Tech Student, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-600036, India, Phone +91-9940179701, ramaswamy1985@gmail.com

[2] Professor, Building Technology & Construction Management Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-600036, India, Phone +91-44-22574268, satyakn@iitm.ac.in

understand and quantify the amount of waste actually present in Indian construction sites. However, there have been hardly any research findings published in the Indian context on the incidence of waste in the construction industry. In general, project managers tend to conceptualise "waste" as physical construction waste rather than a more generic conception of the term that will include both the incidence of material losses as well as the execution of unnecessary work by resources that generate additional costs but do not add value to the product (Koskela 1992). Formoso et al. (2002) stressed the need to consider a broader view of waste that includes not only material waste, but also waste related to resources such as labour and equipment.

This paper attempts to investigate the incidence of waste in Indian construction industry, focusing mainly on residential and commercial building projects. A methodology has been developed for quantifying waste categories identified such as material scrap waste, excess inventory, rework, waiting, idle, transportation, excess processing, and excess movement. Six ongoing building construction projects were taken up for the study and the wastes identified were quantified in terms of project cost by collecting data through direct observations, records and using tools such as work sampling and quality tracking system. This paper presents some of the preliminary data collected and the analysis.

REVIEW OF LITERATURE

In the 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 means that there are two approaches for improving the processes. One is to improve the efficiency of value-adding activities and the other is to eliminate waste by removing non-value-adding activities. Ohno (1988) presents seven categories of waste that were identified in the Toyota production system: (1) unnecessary movement of people (2) waiting by employees (3) defects in products; (4) overproduction of goods; (5) inventories of goods; (6) unnecessary processing; and (7) unnecessary transport of goods. Considering also the material waste in construction industry, waste should be understood as any inefficiency that results in the use of materials, equipment, labour, or capital in larger quantities than those considered as necessary in the production of a building. Thus 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).

Measuring waste is an effective way to assess the performance of production systems but very few research studies have been conducted to observe all wastes in a construction process. However, studies from various countries in which different aspects of waste have been quantified, give an indication of the order of magnitude of non value adding activities in construction. Research by Koskela (1992) in USA revealed that cost of non-conformance constitutes 12% of project costs. Burati et al. (1992) collected quality deviation data from nine fast-track industrial construction projects. Analyses of the data indicate that deviations on the projects accounted for an average of 12.4% of the total project costs.

The previous studies in other countries regarding the material waste, as quoted by Formoso et al. (2002) are mentioned below. Skoyles (1976) conducted a study of material waste in UK and the amount of waste measured varied from 2-15% in weight in relation to amount of materials defined by design. Bossink and Brouwers (1996) measured material waste in The Netherlands as 1-10% of weight of purchased amount of materials.

Formoso et al. (2002) measured the waste of materials in building projects in Brazil and identified root causes. They did two empirical studies in Brazil in 1992-1993 and 1996-1998. In the first study, the cost of waste was estimated to be 8% of total cost, ranging from 5.1%-11.6% among the sites studied. The second study also showed results of almost same level of magnitude as observed in previous one. They analysed sources of waste and indicated that a large proportion of waste occurs because flow activities, such as material delivery, inventories, and internal transportation and handling, are often neglected by site management.

Polat et al. (2006) presented an economic comparison of on-site and off-site fabrication practices of rebar by means of a simulation model. They defined inventory cost in terms of financial cost, storage cost and handling cost. Garas et al. (2001) addressed the incidence of material waste in the Egyptian Construction Industry by means of a waste diagnostic survey. Timber frameworks with an average waste of 13% and sand with an average 9% showed the highest percentages of waste among all materials studied. While other materials such as reinforcing steel with an average 5%, cement 5%, and concrete 4% were within the acceptable rates.

Quality costs is perhaps a relatively more researched area. A quality performance tracking system (QPTS) has been developed by Davis et al. (1989) to systematically collect and classify costs of quality. A quality performance management system (QPMS) to track quality performance efforts in industrial projects has been presented by Ledbetter (1994). Love and Irani (2002) developed a prototype Project Management Quality Cost System (PROMQACS) to determine quality costs in construction projects.

Considerable work has been carried out in using work sampling technique to predict labour productivity. Thomas et al. (1984) presented theoretical aspects to evaluate the adequacy of work sampling as a surrogate productivity measure. But very little attention has been paid to use the tool to evaluate the inefficiency of labour performance.

QUANTIFICATION OF WASTE

WASTE CLASSIFICATION

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. But very few studies have been conducted to quantify all types of waste in construction. Hence an attempt has been made to quantify significant waste categories identified based on literature review and pilot studies carried out. As a first step for the quantification purpose, waste in construction has been classified as shown in Figure 1. The classification has been arrived at based on the waste definition given by Ohno (1988) and Koskela (1992). Material waste includes scrap waste generated in the sites and waste due to excess inventory being kept in stores. In Quality costs, only cost due to rework in construction was considered for quantification. Inefficiencies in utilisation of labour and equipment were further categorised into non value adding activities such as waiting, idle, transportation, excess processing and excess movement.

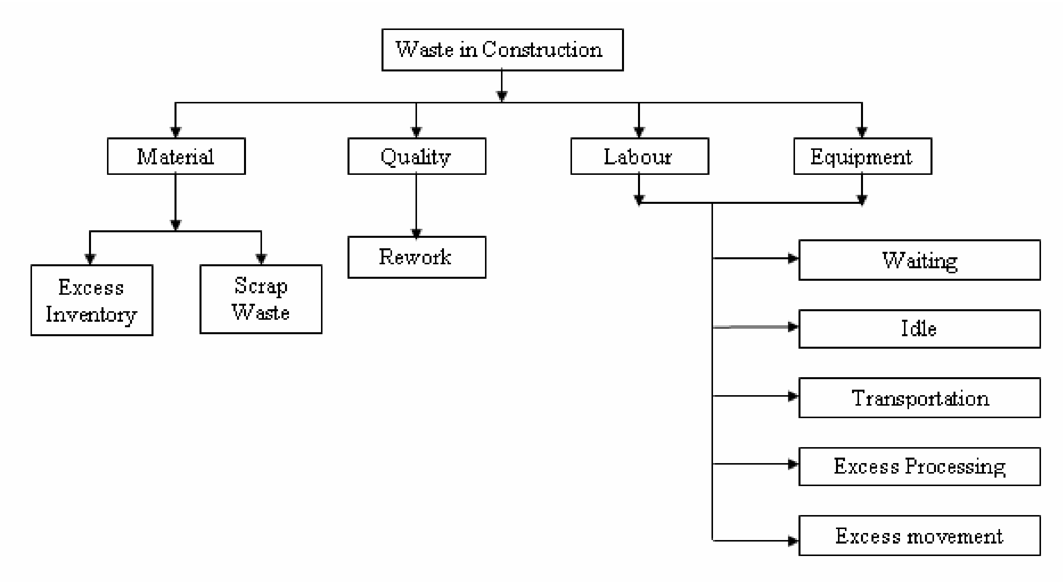

Figure 1: Construction Waste Classification

METHODOLOGY

The methodology used for quantifying different types of waste is shown in Table 1 and is explained in detail in the following sections.

Table 1: Methodology Used for Quantification of Waste

Type of waste	Methodology used for quantification
Material Scrap Waste	Reconciliation data
Excess Inventory	Records maintained in stores
Rework	Quality performance management system
Labour Inefficiency	Work sampling
Equipment Inefficiency	Equipment utilisation sampling

MATERIAL WASTE

Data regarding material scrap waste was obtained from reconciliation data and other documents maintained by planning engineers in the site. Equation (1) gives the material scrap waste as percentage of theoretical quantity of material. Cost of material scrap waste for a particular site was obtained by equation (2).

$$\text{Material scrap waste, } W_i\,(\%) = \frac{(M_{actual} - M_{theoretical})}{M_{theoretical}} \times 100 \qquad (1)$$

$$\text{Cost of material scrap waste} = \sum_{i=1}^{k} \frac{W_i T_i C_i}{100} \qquad (2)$$

where,

C_i	=	Unit price of material i
k	=	Number of materials for which data was collected
M_{actual}	=	Actual quantity of material consumed
$M_{theoretical}$	=	Theoretical quantity of material consumed
T_i	=	Total quantity of material i required for the project
W_i	=	Scrap waste for the material i

Data regarding excess inventory was obtained from data maintained in stores and based on discussion with stores in-charge. Quantity of excess inventory was calculated by equation (3) and it was assumed that 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 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 from equation (4) 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 from equation (5). Storage cost obtained from equation (6) consists of the rental cost of the storage area. Handling cost obtained from equation (7) is the cost of moving the material from the trucks to the storage area.

Quantity of excess inventory, $Q_i = I_i - (t_{pi} D_i) - S_i$ (3)

Cost of Excess Inventory

= Financial cost + Storage cost + Handling cost (4)

$$\text{Financial cost, } A_f = D_y \sum_{i=1}^{k} Q_i C_i N_i [(1 + i_R)^{t_i} - 1] \quad (5)$$

$$\text{Storage cost, } A_s = D_y \sum_{i=1}^{k} R_i A_i \quad (6)$$

$$\text{Handling cost, } A_h = D_y \sum_{i=1}^{k} \frac{Q_i W N_i}{P_h} \quad (7)$$

where,

A_i	=	Area of storage of excess inventory of material i
D_i	=	Average demand for the material i per day
D_y	=	Project duration in years
I_i	=	Average ordered quantity of material i
i_R	=	Interest rate
N_i	=	Number of orders made for material i per year
P_h	=	Daily productivity of crew involved in handling material
Q_i	=	Quantity of excess inventory of material i
R_i	=	Annual rent for the area
S_i	=	Safety stock quantity of material i
t_i	=	Time period for which material i is purchased before than it is required (approximated as Q_i/D_i)
t_{pi}	=	Average time taken to procure material i
W	=	Average daily wage of workers

REWORK IN CONSTRUCTION

A framework for the quantification of cost of rework has been developed in which rework in construction process was further categorised into change, error, omission and damage and an attempt has been made to track rework costs.

LABOUR INEFFICIENCY

Inefficiency of labour was evaluated using work sampling. Random work samplings of significant activities were carried out for a period of 5-7 days by taking videos, at each of the construction sites studied. A total of 12 predefined categories were used for the sampling. All the activities were classified either into Value adding (VA), Non value adding but required (NVAR) or Non value adding (NVA). Videos taken were further analysed to find the percentage time spent by workers in each category. A total of 400 observations were made from the video for each activity by assuming a confidence level of 95%, category proportion of 50% and absolute accuracy of 5% according to equation (8) given below.

$$N_{obs} = \frac{4\,p\,(1 - p)}{s^2} \tag{8}$$

where,

N_{obs} = Minimum number of observations required
p = Percentage occurrence of the activity being measured
s = Degree of accuracy desired

Only significant and critical activities were monitored. Average non value adding time in percentage was then calculated and the cost of inefficiency of labour was obtained from equation (9) given below.

$$\text{Cost of labour inefficiency} = \frac{T_l\, N_l\, D_d\, W}{100} \tag{9}$$

where,

D_d = Project duration in days
N_l = Average number of labourers per day
T_l = Average non value adding time of labourer in %
W = Average daily wage of labourer

EQUIPMENT INEFFICIENCY

Similar to the labour work sampling, equipment utilisation sampling was used to find the inefficiency of equipment. Average non value added time for equipment was calculated based on the data collected for major equipment used in the site. The cost of equipment inefficiency was calculated from equation (10) given below.

$$\text{Cost of equipment inefficiency} = \frac{T_e\, D_m\, (\sum_{j=1}^{q} H_j)}{100} \tag{10}$$

where,

D_m = Project duration in months
H_j = Average internal hire charge of equipment j (Rs/month)
q = Total number of equipment used in the site
T_e = Average non value adding time of equipment in %

FINDINGS

Data was collected from six building projects in India. The details of the projects selected are shown in Table 2. Material wastes for the following materials were investigated: reinforcement, cement, sand, bricks/blocks, coarse aggregates of 20mm and 10mm size. These materials were chosen because of their importance in terms of both cost and potential for generating waste. It may be noted that most multistoried buildings in India are constructed as RCC framed structures with masonry infill or load bearing masonry structures. Further most concrete in India is job mixed. Table 3 shows the material scrap waste as percentage of theoretical quantities of materials. The material scrap waste obtained from equation (2) for the materials studied, as percentage of material cost, varied from 2.58% to 7.87% among the projects. A similar study regarding material waste was conducted in Brazilian context in 1992-1993 by Formoso et al. (2002). They had reported cost of material waste to be 8% of the total cost, ranging from 5.1% to 11.6 % among the sites studied.

Table 2: Details of Projects Studied

Parameter	Project A	Project B	Project C	Project D	Project E	Project F
Total construction cost (INR*, million)	70	80	300	886.5	2100	2189.7
% complete at time of data collection	50	70	60	77	70	20
Average no. of workers per day	150	70	120	900	2000	680
No. of major equipment in site	2	1	3	10	15	15
Type of work	Villas	Apartments	Mall	IT Park	Hotel	IT Park

* 1 USD = Indian Rupee (INR) Rs. 50.57 as on April 1, 2009

Table 3: Material Scrap Waste in Percentage

Material	Project A	Project B	Project C	Project D	Project E	Project F	Average
Cement (t)	4.65	4.07	5.10	0.71	1.27	8.03	3.97
20 mm Aggregate (m^3)	3.10	1.83	3.00	1.20	1.47	na	2.12
10 mm Aggregate (m^3)	5.05	3.95	5.30	1.84	12.33	na	5.69
River Sand (m^3)	3.87	3.52	4.20	3.00	1.37	na	3.19
Blocks (Nos.)	3.28	2.56	4.00	0.93	2.40	na	2.63
Reinforcement (t)	3.90	3.21	4.90	2.95	3.76	7.81	4.42
Cost of scrap waste for above listed materials as % of material cost*	3.79	3.17	4.59	2.58	4.15	7.87	4.36

na – not available
* calculated using equation (2)

Table 4 shows the wastage due to excess inventory as percentage of respective material cost in each site. In some sites, reinforcement is procured only once or twice for the entire project in which case the inventory cost was found to be higher. The reason could be because of the amount of discount they are getting if purchased in a bulk amount rather than purchasing it in small lot sizes or an anticipated increase in cost in future.

Table 4: Waste Due to Excess Inventory as Percentage of Material Cost

Material	Project A	Project B	Project C	Project D	Project E	Project F	Average
Cement	0.33	0.24	0.56	0.34	0.14	0.75	0.32
20 mm Aggregate	4.57	2.47	2.88	0.49	2.51	-	2.58
10 mm Aggregate	4.54	0.85	2.71	1.32	3.19	-	2.52
River Sand	6.43	2.04	2.21	2.67	4.57	-	3.58
Blocks	1.13	1.29	0.97	0.55	1.01	-	0.99
Reinforcement	1.79	1.24	1.24	0.85	1.97	6.78	2.31
Total cost of excess inventory for above listed materials as % of material cost	1.45	1.14	1.17	0.79	2.09	5.15	1.97

An attempt has been made to quantify cost of rework during the construction stage. However, none of the construction sites studied maintained the rework data. Also the data collected based on the non-conformance reports was found to be too low. Hence, rework data could not be quantified properly.

Indian construction industry is labour intensive. With labour wages increasing, it is important to quantify cost of labour inefficiency to take further steps to minimise it. The inefficiency was calculated using work sampling technique. Table 5 shows the results of work sampling and the values are the averages of the percentage time spent by the labour for the activities monitored. Main activities monitored across sites include concreting, plastering, reinforcement work, blockwork etc.

Table 5: Labour Work Sampling Results

Activity	Category	Type	Project A	Project B	Project C	Project D	Project E	Project F
Direct work	Processing	VA	32.50	33.63	26.19	27.06	29.85	26.42
Supportive works	Processing	NVAR	11.92	14.25	11.13	17.19	13.62	14.08
Waiting for materials	Waiting	NVA	12.92	13.75	14.31	11.31	13.07	6.75
Waiting for prerequisite work	Waiting	NVA	1.00	0.00	2.38	0.63	1.00	0.00
Waiting for same crew	Waiting	NVA	0.67	1.00	1.50	1.00	0.00	2.50
Waiting for equipment repair	Waiting	NVA	0.00	0.00	0.00	0.00	1.00	0.00
Travelling with materials	Transportation	NVA	14.00	11.50	16.19	11.19	13.22	15.25
Travelling empty handed	Transportation	NVA	7.92	6.00	5.94	5.75	5.60	9.00
Unnecessary movement	Movement	NVA	5.83	5.25	5.56	5.63	6.40	5.75
Repeating an operation	Excess Processing	NVA	2.08	1.88	2.81	3.94	1.97	3.33
Additional Inspections	Excess Processing	NVA	1.00	1.25	2.06	3.56	2.68	6.75
Idle tradesmen	Idle	NVA	10.17	11.50	11.94	12.75	11.58	10.17

All the activities were classified as Value adding (VA), Non-value adding but required (NVAR) or Non-value adding (NVA). Direct work classified as value adding activity is defined as any work which adds value to the customer. Supportive work is defined as any non-value added work but which is required. Non-value added work includes waiting, transportation, movement, excess processing and idle times (CII 2005). Similar classification was used for equipment sampling and the results are shown in Table 6. Major equipments monitored across projects include excavators, tower cranes, passenger hoists, mobile cranes etc. Table 7 and Table 8 show the summary of cost of labour and equipment inefficiency respectively.

A systematic attempt has been made to quantify some common types of waste in construction and the costs calculated for each waste type is shown in Table 9. The total cost of waste calculated as percentage of project cost varied from 5.38% to 14.70% among the projects studied.

Table 6: Equipment Utilisation Sampling Results

Activity	Category	Type	Project A	Project B	Project C	Project D	Project E	Project F
Direct work	Processing	VA	41.75	26.25	35.25	32.22	32.75	29.00
Temporary works	Processing	NVAR	3.75	0.00	1.00	2.78	4.50	6.33
Supportive works	Processing	NVAR	0.00	0.00	0.00	7.78	5.75	4.33
Waiting for materials	Waiting	NVA	10.00	15.25	13.75	13.33	12.00	9.67
Waiting for prerequisite work	Waiting	NVA	0.00	9.50	4.75	2.78	2.50	2.33
Travelling with materials	Transportation	NVA	6.25	0.00	3.50	0.00	1.50	2.67
Positioning equipment	Transportation	NVA	2.50	0.00	1.50	1.11	3.25	5.00
Unnecessary movement	Movement	NVA	1.50	0.00	1.25	2.22	3.00	3.67
Repeating an operation	Excess Processing	NVA	4.25	2.00	3.25	6.11	9.75	7.00
Additional Inspections	Excess Processing	NVA	4.00	4.25	3.50	4.44	3.50	3.00
Idle without any work	Idle	NVA	21.00	37.50	28.25	25.00	18.50	25.00
Equipment breakdown	Idle	NVA	5.00	5.25	4.00	2.22	3.00	2.00

Table 7: Cost of Labour Inefficiency

Parameter	Project A	Project B	Project C	Project D	Project E	Project F
Average % VA time	32.50	33.63	26.19	27.06	29.85	26.42
Average % NVAR time	11.92	14.25	11.13	17.19	13.62	14.08
Average % NVA time	55.58	52.13	62.69	55.75	56.53	59.50
Average no of labourers per day	150	100	120	900	2000	680
Project duration (months)	24	24	24	17	24	20
Total cost of inefficiency (Rs)	8,504,250	5,316,750	7,672,950	38,383,875	122,104,800	36,414,000
Waste in % of project cost	12.15	6.65	7.67	4.33	13.77	4.11

Table 8: Cost of Equipment Inefficiency

Parameter	Project A	Project B	Project C	Project D	Project E	Project F
Average % VA time	41.75	26.25	35.25	32.22	32.75	29.00
Average % NVAR time	3.75	0.00	1.00	10.56	10.25	10.66
Average % NVA time	54.50	73.75	63.75	57.22	57.00	60.34
Total internal hire charges of all equipments (Rs/month)	65,000	30,000	100,000	1,500,000	4,200,000	3,500,000
Project duration (months)	24	24	24	17	24	20
Total cost of inefficiency (Rs)	850,200	531,000	1,530,000	14,591,100	57,456,000	42,238,000
Waste in % of project cost	1.21	0.66	0.51	1.65	2.74	1.93

Table 9: Waste Summary*

Cost (Rs)	Project A	Project B	Project C	Project D	Project E	Project F
Material Scrap	675,798	580,745	1,320,174	7,869,718	26,100,834	23,634,084
Excess Inventory	259,534	208,347	336,801	2,402,966	13,110,783	15,477,740
Labour Inefficiency	8,504,250	5,316,750	7,672,950	38,383,875	122,104,800	36,414,000
Equipment Inefficiency	850,200	531,000	1,530,000	14,591,100	57,456,000	42,238,000
Total Cost of Waste	10,289,782	6,636,842	10,859,925	63,247,659	218,772,417	117,763,824
Waste in % of Project Cost	14.70	8.30	10.86	7.13	10.42	5.38

* Cost of rework could not be quantified properly and hence not included in the summary

CONCLUSIONS

A framework has been developed to quantify different categories of waste in terms of cost and data was collected from six ongoing building projects. Material scrap waste for selected materials was quantified using reconciliation data. The waste due to excess inventory was quantified from the records maintained in stores. Attempt has been made to quantify cost of rework using framework of quality performance management system. Labour and equipment inefficiency was quantified through work sampling technique. It was found that project engineers and managers, in general, tend to conceptualise waste as material waste only.

The results showed that the material scrap waste as percentage of material cost for the selected items that were studied varied from 2.6% to 7.9%, which was low when compared to the studies done in Egypt and Brazil (Garas at al. 2001, Formoso et al. 2002). The waste due to excess inventory was also found to be low. None of the construction sites studied maintained rework data. Hence, cost of rework could not be quantified properly. It was found that cost of inefficiency of labour and equipment put together was very high when compared to material waste. The average percentage time spent by labour and equipment in non value adding activities was found to be 57% and 61% respectively. This emphasises the need to reduce the share of non value added activities to increase overall project performance. The cost of waste calculated for the items studied as percentage of project cost varied from 5.4% to 14.7% among the projects studied. However, this does not include cost of quality, which has been found to be significant in a number of studies in other countries. From literature (Burati et al. 1992), the deviation cost of quality in advanced economies has been found to be at least 12% of project cost. The industry experts estimate that in India it should be higher because of the lack of skilled labour, technologies etc. Hence considerable amount of waste is present in Indian construction sites and there is a large scope to improve the project performance by implementing lean principles.

Since this was a preliminary study, there is a need to further study a number of projects and in greater detail to understand and quantify waste in Indian construction projects. Further, more importantly, the ways to mitigate these wastes need to be studied.

REFERENCES

Bossink, B. A. G., and Brouwers, H. J. H. (1996). "Construction waste: Quantification and source evaluation." *Journal of Construction Engineering and Management*, ASCE, 122 (1), 55-60.

Burati, J. L., Farrington, J. J., and Ledbetter, W. B. (1992). "Causes of quality deviations in design and construction." *Journal of Construction Engineering and Management,* ASCE, 118 (1), 34–49.

Construction Industry Institute (CII) (2005). "Lean principles in construction." Research Summary 191-1, Austin, TX.

Davis, K., Ledbetter, W. B., and Burati, J. L. (1989). "Measuring design and construction quality costs." *Journal of Construction Engineering and Management*, ASCE, 115, 389–400.

Formoso, C. T., Soibelman, L., De Cesare, C. and Isatto, E. L. (2002). "Material waste in building industry: Main causes and prevention." *Journal of Construction Engineering and Management,* ASCE, 128(4), 316–325.

Garas, G. L., Anis, A. R., and Gammal, A. E. (2001). "Materials waste in the Egyptian construction industry." *Proceeding, 9th Annual Conference of the International Group of Lean Construction.*

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

Ledbetter, W. B. (1994). "Quality performance on successful project." *Journal of Construction Engineering and Management,* ASCE, Vol.120, No. 1, 34-46.

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.

Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989). "Productivity improvement in construction." *McGraw Hill*, New York.

Ohno, T. (1988). *Toyota production system*, Productivity, Cambridge, Mass.

Polat, G., Arditi, D., Ballard, G., and Mungen, U. (2006). "Economics of on-site vs. off-site fabrication of rebar." *Construction Management and Economics*, 24, 1185–1198.

Skoyles, E. F. (1976). ‘‘Material wastage: A misuse of resources.’’ Building Research and Practice, July/April, 232–243.

Thomas, H. R., Guevara, J. M., and Gustenhoven, C. T. (1984). "Improving productivity estimates by work sampling." Journal of Construction Engineering and Management, ASCE, Vol. 110, No. 2, 178-188.