The International Journal Of Engineering And Science (IJES)
||Volume||2 ||Issue|| 5 ||Pages|| 57-65||2013||
ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805

Labour Productivity Variability Among Labour Force – A Case Study

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--ABSTRACT--
Observations on daily productivity of subcontract labour and directly employed labour engaged in masonry works on a project were made to determine the variability in productivity among the labour force and the causes of the inefficiencies. Productivity plots and statistical tests revealed the productivity of the subcontract labour to be significantly higher than the productivity of the directly employed labour. The subcontract labour achieved on an average 33% higher productivity than the directly employed labour. Benchmarking measures of performance ratio, waste index and coefficient of productivity variability were also applied to illustrate the productivity differences between the two types of labour. The study results confirm the applicability of benchmark measures for comparing crew performance. Investigating the reasons for productivity differences between the two groups revealed that the directly employed labour experienced greater number of disruptions and were constantly on an overtime schedule which has contributed to their poorer performance. A regression equation was also developed to quantify the impact of the disruptions and overtime on labour productivity. The productivity problems observed on the project arise as a result of managerial inefficiencies, and emphasize the need for the management to improve to achieve productivity enhancement.

Keywords: *Benchmarking, Construction labour productivity, Regression, Variability*

Date Of Submission: 01 May 2013 Date Of Publication: 20,May.2013

I. INTRODUCTION

Improving productivity of the construction workforce is crucial to the success of any construction firm as labour costs comprise 30 to 50% of the overall project cost [1-2]. Losses in construction labour productivity have often been attributed to poor management of construction projects and construction professionals and academicians have voiced the need of management to improve to achieve productivity improvement [3-4].

Variability in productivity among labour force was studied, on a construction project in Kerala in India, with the objective of identifying the managerial inefficiencies causing productivity losses. The case study project is located in a city in the state of Kerala in India and is a nine-storey Information Technology (IT) park complex. The contractor on the case study project employed two types of labour force for masonry works on the construction site – labour directly employed by the contractor and subcontract labour. While the directly employed labour had fixed wages and was allowed overtime work, the subcontract labour was paid based on their output, i.e., the no. of masonry units placed during the day. Productivity variation observed between the directly employed labour and subcontract labour is the focus of the present study. The application of benchmarking to identify productivity differences among the labour force is demonstrated in the present study. In addition, impact of the inefficient management practices causing productivity losses have been quantified using various statistical techniques.

II. LABOUR PRODUCTIVITY

Labour productivity has been defined in literature as the ratio of the output quantities to the input work hours, or as ratio of the work hours to the quantities (also called the unit rate). For the purpose of this study, the former definition is adopted and labour productivity is expressed as follows:

$$Labour\ productivity = \frac{Output\ quantity(m^2)}{Work\ hours(whr)} \quad (1)$$

III. BENCHMARKING

Benchmarking is defined as a systematic and continuous measurement process; a process of comparing the output of one organization to the output of another organization anywhere in the world to acquire information which will help the organization to take action to improve its performance [5-6]. Benchmarking can be internal or external. Whatever be the type of benchmarking, the aim behind the process is the same – comparison and improvement.To establish productivity benchmarks, baseline productivity measures have to be developed. Baseline productivity is the best performance a contractor can achieve, on a particular project. It is determined with respect to 10 % of the total workdays that have the highest daily output or production, the number of days in the baseline set being not less than five [7]. Thomas and Zavarski [7] also proposed disruption index (DI) and project management index (PMI) as performance measures of individual projects.

Disruptions are defined as the occurrence of events that are known or are reported in literature to adversely affect labour productivity [8]. DI was defined as the ratio of the number of disrupted workdays to the total number of workdays. The value of DI ranges from 0 to 1 and is measure of the extent to which the project experienced abnormal workdays, with a higher value of DI indicating the project experienced more abnormal workdays [7].

The project waste index (PWI) or the project management index (PMI) is a dimensionless measure of the amount of labour waste associated with an activity/project. A lower value of PWI indicates better performance of the project. PWI is calculated as follows [9]:

$$PWI = \frac{Cumulative\ \ productivity - Baseline\ \ productivity}{Expected\ \ baseline\ \ productivity} \qquad (2)$$

where cumulative productivity is defined as the overall effort required to install the work. It is expressed as follows:

$$Cumulative\ \ productivity = \frac{Total\ quantities\ (m^2)}{Total\, workhours\ (whr)} \qquad (3)$$

The expected baseline productivity has to be determined from an extensive study of multi-project databases. Departure of the calculated baseline productivity from the expected value indicates poor performance of activity/project [10].

Abdel-Razek et al. [5], Enshassi et al. [11] and Idiake and Bala [6] have applied benchmarking to masonry activities in construction projects in Egypt, Gaza Strip and Nigeria respectively, using baseline productivity, disruption index (DI), performance ratio (PR) and project management index (PMI) as performance measures. Performance ratio was defined as ratio of the actual cumulative productivity to the expected baseline productivity, the expected baseline productivity being calculated as the average values of baselines of all projects. The other performance measures were defined after the studies by Thomas [7-9]. However, for computing baseline productivity, daily productivity values were used as opposed to daily production or output suggested by Thomas and Zavarski [7]. Performance ratio is expressed as follows:

$$PR = \frac{Cumulative\ \ productivity}{Expected\ \ baseline\ \ productivity} \qquad (4)$$

In the procedure laid out by Thomas [10], for conducting a labour productivity benchmarking study, three key performance indicators were proposed – productivity variability, baseline productivity and project waste index (PWI). Variability in productivity is a determinant of performance of a construction project. Poorly performing projects exhibit higher variability in productivity when compared to projects that perform well [5, 7-10]. Thomas et al. [9] emphasized the necessity to reduce variability in labour productivity to improve performance of construction projects. The plots of the daily productivity values give a visual representation of the variability in productivity. In addition, Thomas et al. [7] calculated variability in daily productivity using the following equation:

$$Variation\ (V_j) = \frac{\sum \sqrt{(ur_{ij} - baseline\ \ productivity_j)}^{2}}{n} \qquad (5)$$

where ur_{ij} = daily productivity (unit rate) for workday *i* on project *j* and n = number of workdays on project *j*.

The variation V_j for different projects cannot be compared directly unless the baseline productivity values are the same [5, 9]. Therefore, coefficient of variation is calculated for each project as follows [9].

$$Coefficient\ of\ variation\ (CV_j) = \frac{V_j \times 100}{Baseline\ \ productivity_j} \qquad (6)$$

Labour productivity benchmarking using Thomas and Zavarski [7] model has been widely applied in the construction industry for comparing productivity among various projects. This study applies this model to understand the variability in productivity among different types of labour engaged in masonry work on the construction project.

IV. DATA COLLECTION

Daily data on masonry works was collected from the construction site during November – December 2012. The building is a reinforced concrete framed structure with masonry infill. The masonry work was of laterite, as laterite is a readily available natural stone in Kerala.The project site was visited daily to collect information on the size of the crew and daily work hours. The quantities of work completed for each day were measured before the start of the next day's work. The field staff was interviewed daily to get an insight into the disruptions experienced during the course of work. The field staff also provided an estimate of the time lost due to the various disruptions. The labour force worked for 6 days a week, on an 8 hour schedule daily. The height of the masonry wall ranged from 5.2 m in the basement floors to 4 m in the top floors. Since the payment to the subcontract labour varied with the height of the wall, i.e., subcontract labour got a higher payment for work done above lintel level (2.2 m), data was collected separately for work done above and below the lintel level.Masonry work was carried on the different floors simultaneously by engaging different crews yielding a total of 105 daily observations. Table 1 depicts the details of the observations made on the different types of labour at different levels. Table 2 shows an abstract of the data collected for the masonry work of subcontract labour below lintel level.

Table 1. Details of the observations

Labour type	No. of observations		Total
	Below lintel	Above lintel	
Directly employed labour	30	34	64
Subcontract labour	20	21	41

Table 2. Data for masonry work of subcontract labour below lintel level

Observation no.	Work hours (whr)	Daily quantities (m^2)	Daily productivity (m^2/whr)	Baseline days
1	17	6.53	0.384	
2	32	13.59	0.425	
3	36	14.21	0.395	
4	36	14.83	0.412	
5	36	15.3	0.425	
6	36	17.00	0.472	
7	36	15.84	0.440	
8	72	26.81	0.372	
9	36	19.48	0.541	*
10	32	8.13	0.254	
11	36	10.62	0.295	
12	36	17.48	0.486	*
13	36	17.03	0.473	*
14	36	14.05	0.390	
15	36	12.80	0.356	
16	54	21.34	0.395	

17	54	26.44	0.490	*
18	36	15.36	0.427	
19	18	6.20	0.344	
20	14	7.40	0.529	*

V. DATA ANALYSIS

5.1 Baseline productivity

The number of days in the baseline subset was determined as 10% of the observations, as proposed by Thomas and Zavarski [7], with a minimum 5 days in the baseline subset. The days with the highest productivity values were considered to define the baseline set and average of these values yielded the baseline productivity. The baseline productivity was computed separately for the work above lintel and below lintel for each type of labour. Figs.1 and 2 show the daily productivity for the directly employed and the subcontract labour along with the baseline productivity. Visual examinations of the figures clearly indicate variation in productivity for both types of labour. Table 3 shows the baseline productivity and cumulative productivity values for the different types of labour. The cumulative productivity was calculated according to equation (3). The figures and the table clearly depict the superiority of the performance of the subcontract labour when compared to the performance of the subcontract labour, whether it may be for work above lintel or below lintel.

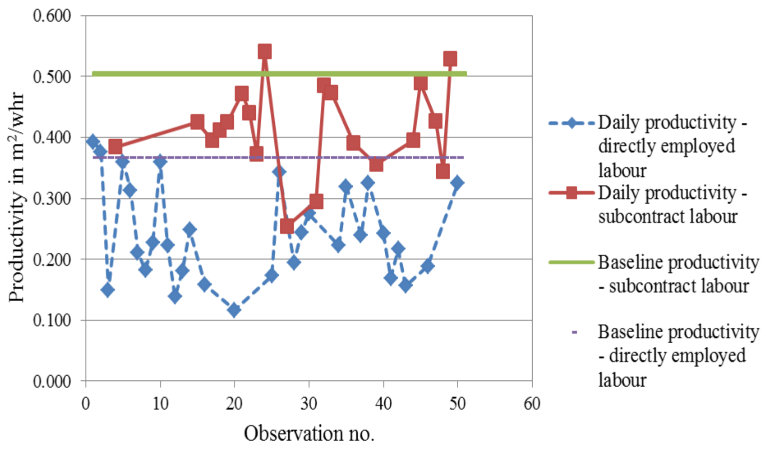

Fig 1: Daily productivity - below lintel

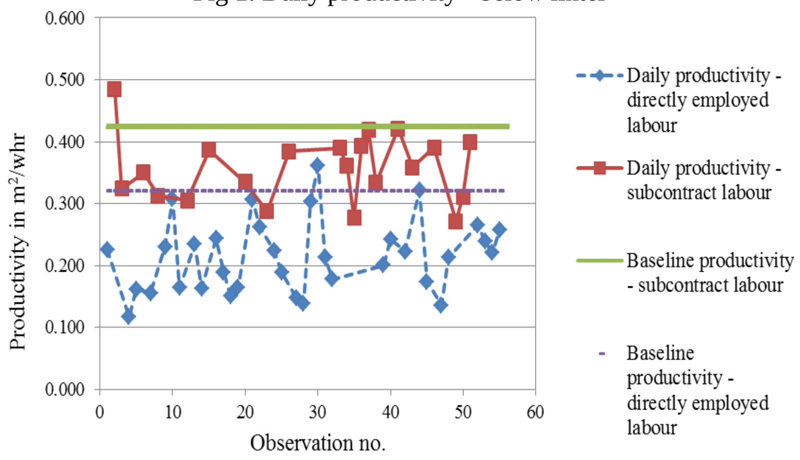

Fig 2: Daily productivity - above lintel

An independent samples t test was conducted to compare the productivity of the directly employed and the subcontract labour. The results of the t test also indicated a significant difference in the productivity of the directly employed and the subcontract labour for work done below lintel (t= - 0.784, p<0.001) as well as above lintel (t= - 0.895, p<0.001). A comparison of the average productivity of the subcontract and the directly employed labour revealed that the subcontract labour achieved on an average 33 % higher productivity than the directly employed labour. This calculation was based on the average productivity observed on the days without disruptions for both types of labour. Talhouni [12] also has reported the superiority of the performance of the subcontract labour. His studies on masonry work on seven Scottish construction sites revealed the performance of the subcontract labour being on an average 38% higher than that of the directly employed labour.

Table 3. Cumulative productivity and baseline productivity

Labour type	Location	Cumulative productivity (m^2/whr)	Baseline productivity (m^2/whr)
Directly employed labour	Below lintel	0.222	0.366
	Above lintel	0.205	0.320
Subcontract labour	Below lintel	0.414	0.504
	Above lintel	0.353	0.423

5.2 Performance measures

To demonstrate the application of performance measures to compare the performances of the directly employed and the subcontract labour, performance ratio, waste index and coefficient of productivity variation were computed. Thomas [10] recommends that the expected baseline productivity be calculated from large number of productivity databases of multiple projects. Since productivity records and standard values for productivity do not exist in the construction industry in Kerala, the expected baseline productivity, for purpose of demonstrating the application of the performance measures, was calculated by averaging the productivity values of the directly employed and the subcontract labour for work above lintel and below lintel separately.

The performance ratios, the waste indices and coefficients of productivity variation were calculated as per equations (2), (4), (5) and (6) and the values presented in table 4. The above equations for PR and PWI have been derived using unit rates and hence the productivity values were first expressed as unit rates before computing the parameters. A lower value of PR indicates better performance, and hence from table 4 it can be inferred that the performance of the subcontract labour was better than the performance of the directly employed labour for work done below as well as above lintel. Lower values of the waste indices and coefficient of productivity variation also demonstrate the superior performance of the subcontract labour on comparison with the performance of the directly employed labour.

Table 4. Performance measures

Labour type	Location	Performance ratio	Waste index	Coefficient of productivity variation
Directly employed labour	Below lintel	1.959	0.771	34.55
	Above lintel	2.122	0.763	33.48
Subcontract labour	Below lintel	1.004	0.179	18.79
	Above lintel	1.178	0.195	17.06

VI. CAUSES OF INEFFICIENCIES FOR THE DIRECTLY EMPLOYED LABOUR

The figures as well as the performance measures indicate the subcontract labour to be performing better than the directly employed labour for the same activity on the same project. Given these results, it becomes necessary to understand the reasons for the poor performance of the directly employed labour. An investigation on the masonry activities in the case study project revealed that the activities were accelerated to meet time schedules. Schedule acceleration was carried out by employing more number of crews and allowing overtime work indiscriminately to the directly employed labour. Work was carried out simultaneously by different crews on different floors with a single site engineer in charge of all the masonry works on all floors. The site engineer had to plan the work, arrange for materials, instruct the workforce and supervise the work. The site had a single hoist which was used to transport the materials to the top floors. The same hoist was used to transport materials for all activities with the result that time was lost in waiting for the hoist to be free to transport materials for masonry work. The site engineer took extra care to ensure material availability to the subcontract labour, as the subcontract labour being paid based on their output pressurized the site engineer for materials whenever materials fell short. The directly employed labour however being paid daily wages did not bother even if materials were not available. Discussions on the disruptions experienced and overtime of the labour force are presented below.

6.1 Disruptions

The majority of the disruptions observed on the case study project were due to unavailability of materials. There were few instances of rework due to craftsmen errors. In addition, design complexity was also observed on few occasions. Table 5 depicts the disruption frequency by type as a percentage of the total number of observations, for each category of labour.

Table 5. Disruption frequency by type

Type of labour	Disruption frequencies (%)			Total disruptions (%)
	Material	Design	Rework	
Directly employed labour	55	3	3	61
Subcontract labour	39	0	2	41

Fig. 3 presents the frequency distribution of the time lost due to disruptions for both types of labour. The directly employed labour not only experienced larger number of disruptions but also the time lost due to the disruptions was higher when compared to the subcontract labour. The directly employed labour lost 86.75whr, whereas the subcontract labour lost only 21.75whr due to disruptions.

Comparison of average daily productivity on days with and without disruptions revealed a productivity loss of 19% for the directly employed labour, whereas for the subcontract labour only little productivity loss was observed. An independent samples t test was used to compare the daily productivity of the directly employed labour and subcontract labour for days with and without disruptions. Significant difference in productivity was observed for the directly employed labour, both for work above and below lintel ($p<0.05$), whereas the difference in productivity for the subcontract labour was not significant. The subcontract labour experienced lesser number of disruptions as well as lower time losses due to disruptions when compared to the directly employed labour. Also, since the payment to the subcontract labour was based on their output, the subcontract labour toiled to achieve the target output irrespective of disruptions, thereby maintaining productivity even when they experienced disruptions. Talhouni [12] had observed on an average 26% loss of productivity due to disruptions. The calculation for productivity in the study was based on production hours alone. Another study by Thomas and Raynar [8] on electrical and piping crafts revealed a loss of efficiency of 27% due to disruptions. In the present study the observations without disruptions were not free from the effects of overtime thereby making an accurate estimation of productivity loss due to disruptions impossible. The study, however, confirms the relationship between low productivity and presence of disruptions, as observed in previous studies.

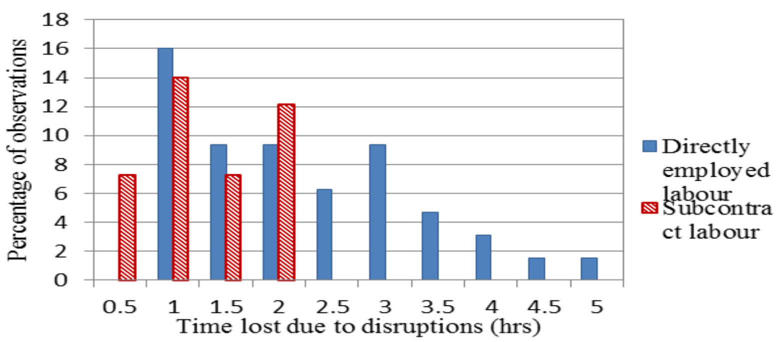

Fig. 3: Time lost due to disruptions

6.2 Overtime

The workforce employed on the construction site worked overtime throughout the period observed and this is another factor that has contributed to the deterioration of productivity on the project. Fig. 4 shows the frequency distribution of the overtime hours for the directly employed and subcontract labour. For the subcontract labour overtime rarely lasted more than one hour, whereas for the directly employed labour daily overtime was on average 3.7 hours (hrs), with two observations having an overtime of 8 and 9 hrs. Overtime was observed on 85% of the observations on daily productivity of the subcontract labour and 94% of the observations of the directly employed labour.

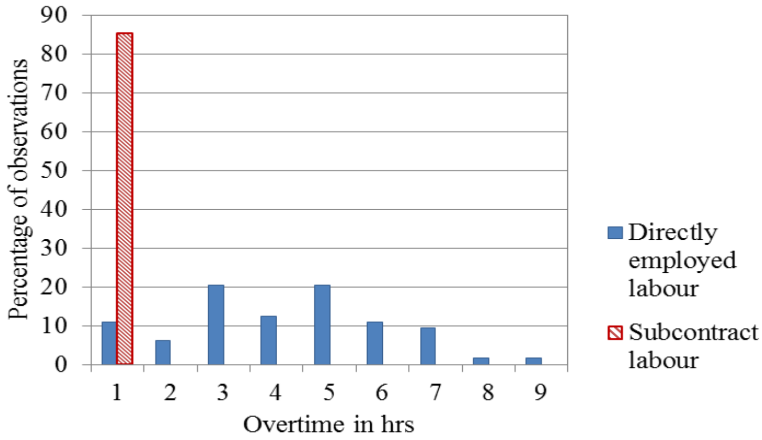

Fig. 4: Daily overtime

The effects of overtime on productivity have been widely studied by various researchers and loss in productivity due to overtime schedules documented. An overtime schedule can result in various problems such as fatigue, higher accident rate, lowered morale of the workforce and in addition a higher cost per unit [13]. All the problems result in a reduction of labour productivity. Thomas and Raynar [8] observed an average of 10% to 15% loss of productivity when working on an overtime schedule. They remarked that overtime schedules lasting 3 – 4 weeks can be used with little loss of efficiency, but longer schedules will lead to productivity losses from fatigue. It was concluded that scheduled overtime was a resource problem with productivity losses arising from inability to provide materials at an accelerated rate. Overtime in the past studies has been defined as work performed over 8 hrs/day and 40hrs/week. The previous research studies investigated 50 hrs and 60 hrs workweeks, while in Kerala, construction workforce normally worked 6 days a week for 8 hrs/day thereby yielding a normal 48 hrs week. For the directly employed labour, the weekly work hours may go up to an average of 69 hrs/week or more and the resultant detrimental effects on productivity.

VII. REGRESSION ANALYSIS

Multiple regression analysis was performed to quantify the impact of the various factors on labour productivity. Stepwise estimation procedure was employed and the results of the regression analysis are presented in tables 6 and 7. Labour type and location being non–metric variables and were coded as dummy variables to perform regression analysis, with the directly employed labour and below lintel work coded as the reference categories. The ratio of the skilled to the unskilled workers was used as a predictor variable as it was found that including the ratio improved the model. The adjusted R^2 value of the regression was 0.675 and analysis of variance was statistically significant ($p<0.001$), demonstrating good model fit. The hypothesis testing for the predictor variables was significant ($p<0.05$) confirming that the predictor variables are not equal to zero. Tests for the residuals indicated linearity, normality and homoscedasticity, thus satisfying the assumptions of regression analysis. The regression model for productivity can be expressed as:

Daily productivity = 0.204 + 0.113 × labour type – 0.011 × overtime (hrs) +0.098 × ratio of skilled to unskilled labour – 0.029 × location – 0.011 × time lost due to disruptions (hrs)

Table 6.Test for significance of regression

Source of variation	Sum of Squares	Degrees of freedom	Mean Square	F	p value
Regression	0.772	5	0.154	44.284	< 0.001
Residual	0.345	99	0.003		
Total	1.118	104			

The regression model also indicates the negative impact of overtime and disruptions on productivity, with overtime having more impact on productivity. An improvement of productivity with subcontract labour can also be observed from the regression model. The crew composition in the present study varied with the number of unskilled workers being greater than or equal to the number of skilled workers in most of the instances. The predictor variable of ratio of skilled to unskilled labour indicate increase in productivity with increase in the ratio, but the result is valid only within range of the ratio from 0.67 to 1.33, as no values lower or higher than this was encountered in the observations. Loss in productivity for work done above lintel is also evident from the regression equation. Thus, the regression results confirm the findings of the preliminary data analysis.

Table 7. Regression model

Variables	Unstandardized Coefficients		Standardized Coefficients	p value	R^2	Adjusted R^2
	B	Std. Error	Beta			
Constant	0.204	0.037		<0.001	0.691	0.675
Labour type	0.113	0.015	0.534	<0.001		
Overtime	-0.011	0.003	-0.255	0.001		
Ratio of skilled to unskilled labour	0.098	0.033	0.175	0.003		
Location	-0.029	0.012	-0.141	0.015		
Total time lost	-0.011	0.005	-0.131	0.035		

VIII. CONCLUSION

Variability in productivity among different types of labour was studied on a construction project in the state of Kerala in India. Significant difference in productivity was observed between the subcontract labour and the directly employed labour with the subcontract labour performing better than the directly employed labour on the project. Investigation on the reasons for the loss of productivity revealed that the directly employed labour experienced higher percentages of overtime and time losses due to disruptions, when compared to the subcontract labour. Moreover, since the wages for the subcontract labour was linked to their output, the subcontract labour strived to achieve the target output irrespective of any disruptions faced. Talhouni [12] has also made similar observations when the productivity of the two groups of workforce was studied.

The study has illustrated the application of benchmarking techniques to understand productivity variability among the different types of labour employed on the same activity. The calculated performance measures and the statistical tests also confirm the superiority of performance of the subcontract labour. Though the present study compared productivity of the subcontract labour and the directly employed labour only, the results of the study confirm the applicability of benchmark measures to compare the performance of different crews working on the same activity on a project.

A regression model was developed to quantify the impact of various factors on construction labour productivity. A reduction in productivity with overtime and disruptions was also evident from the model. Thus all analysis reveals the negative impact of disruptions and overtime on productivity and corroborates the findings of previous studies.

A review of the issues causing productivity losses clearly depicts improper management of the construction project. Poor material planning and distribution was the reason for majority of disruptions experienced on the case study project. Allowing overtime indiscriminately without concern of the productivity of the workforce was another managerial error that has resulted in significant productivity losses. Supervisory issues also existed on the project, and all the effects combined have resulted in severe impact on productivity. The study results thus confirm that majority of the construction labour productivity losses arise as a result of managerial inefficiencies.

Though labour productivity is measured and monitored on construction projects across the world, majority of the Indian construction firms have not initiated productivity measurement on their construction sites, and hence very often productivity losses go unnoticed. It is of paramount importance that labour productivity is measured and productivity records are maintained and compared within and across projects so as to maintain and improve construction labour productivity. In the present competitive business scenario, productivity measurement and benchmarking is essential for the success of any construction firm which in turn will improve the performance of the construction industry as a whole.

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