EVALUATION OF LABOUR PRODUCTIVITY IN BRIDGE CONSTRUCTION PROJECTS

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Abstract

Labour is a highly important resource in construction, because it is the one that combines all the other resources namely: materials, plant, equipment, management and finance leading to construction products. The ability of construction firms, unlike that of the other firms to stay solvent largely depends on the labour productivity, since material costs are generally fixed through specification; and profits & overheads are generally controlled by the company management. Improving labour productivity in construction projects remains one of the challenges being faced by the construction managers and contractors.

The objective of this study is to identify various factors influencing the labour productivity in construction projects in road sector especially in bridge construction projects in Sri Lanka and to recommend strategies to improve labour productivity in future projects.

Common factors contributing to labour productivity were identified during the literature survey. A structured questionnaire survey and on site data collection were carried out to recognize significant factors which contribute to labour productivity in Sri Lankan bridge construction projects.

Onsite data collection was done by selecting, earthwork, carpentry work, steel fixing and concreting work of bridge construction projects. Eight significant factors that influence labour productivity have been identified during the study. These include: availability of skilled workers, degree of supervision, materials available at site, conditions of tools and equipment, variations, accuracy of estimate, weather conditions and the location of project.

Key words: Labour Productivity, Factors Contributing, Construction, and Bridge Projects.

1. Introduction

Labour is a highly important resource in construction projects, because it is the one that combines all the other resources namely materials, plant, equipment, management and finance in order to produce various construction projects. Unlike other firms in different spheres of production, the ability of construction firms to stay solvent largely depends on the labour productivity. The construction material costs are generally fixed through specification, profits and overheads are largely controlled by the competition. Therefore one of the major challenges to be faced by the construction managers is improving labour productivity of the construction projects because producing more with less can directly affect profitability as well as long-term survival of the firm.

The main objective of this study is to identify the factors influencing labour productivity in bridge construction projects; to compare actual labour productivity rates with estimated rates and to make recommendations for improving labour productivity in identified items in bridge construction project

1.1 Productivity

Productivity is an effective and efficient utilization of all resources; Labour, plant, materials and management (Prokopenko, 1987). However this generalized definition masks the variety of approaches evident in the literature. Four theories of how productivity may be measured can be detected. One is the productivity as a ratio of output to input of materials, labours, and energy and capital equipment. According to the second theory, a measure of productivity can be obtained by comparing the assets used in production with the value of products constructed by these assets. Productivity also measured as a form of efficiency defined as a relative measure of actual output to potential output so expressed as a percentage. The fourth is the resource utilization theory which was influential to defined productivity in the context of construction as the optimal use of resources to obtain an acceptable goal (Bishop, 1975). The resource utilization theory also enabled the researchers to compare the utilization of resources occurring in different sites and comparing the resources used against a fixed output. Consequently, high productivity was considered as occurring when the utilization of labour, materials, plant and capital were optimized to provide a specific value of construction work.

1.1.1 Models of Productivity Measurements

Thomas et al (1990) identified three models of productivity measurements; they are Economic Models, Project Specific Model and Activity Oriented Model. The economic model defines total factor productivity that is the ratio between total outputs expressed in dollars or rupees and total inputs expressed in same currency. The total input includes labour, materials, equipments, energy and capital. The second is the project specific model that defines productivity as total productivity; that is the ratio between the outputs expressed in a physical unit and the inputs expressed in rupees or dollars. Third is the activity- oriented model defined the productivity relative to project sites. In this study labour productivity is defined as output per work hour and used the activity oriented model. Accordingly the productivity is defined as:

$$\text{Labour Productivity} = \frac{\text{Labour output}}{\text{Man-Day}}$$

2. Methodology

The methodology used for this study consists of:

a. Questionnaire Survey
b. Site Data Collection

Factors that are influencing the labour productivity have been identified during the literature survey especially from the published research work. A questionnaire was designed including the identified factors and it was distributed among the site officers in-charge for bridge construction projects to get their responses.

On site data were collected for selected activities such as concreting, steel fixing, excavation and fixing of formwork in bridge construction projects. Based on data collected actual productivity rates were calculated for each item and compared with the estimated productivity values.

Roscoe (1975) proposed four rules of thumb for determining sample size. In one rule it says for sample experimental research with tight experimental controls successful research is possible with sample as small as 10 to 20 in size. Therefore, it was decided to collect data from 20 bridge construction projects and compare their performance with actually measured and estimated to see whether there is any correlation.

3. Data collection

3.1 Questionnaire Survey

The questionnaire was prepared considering the identified factors affecting labour productivity and was sent to project staff members of selected 20 bridge construction projects (P_1, P_2, P_3….etc). The questionnaire has two parts. Namely Part A and Part B. Part A include 7 factors (F1-F7) and the respondents are requested to indicate their opinion as how they rate the factor's influence (High-H; Moderate-M; & Low-L) to labour productivity. Part B includes 13 factors (F8 –F20) and the respondents were requested to indicate whether the factor's influence to the labour productivity as adverse or not by indicating "Yes" or "No". Summary of the respondent's opinion for Part A and Part B are given in Table 3.1- Summary of the Questionnaire Responses.

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Table 3.1: Summary of the Questionnaire Responses

Factor No	*Overall Project Factors*	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
	Part A / How would you rate the Factors F1-F7																				
F1	*Labour crew performance*	*M*	*M*	*M*			*M*	*M*	*H*	*M*	*H*	*M*	*M*	*H*	*L*		*H*		*M*	*H*	
F2	*Availability of skilled labour*	*L*	*M*	*M*			*L*	*M*	*M*	*L*	*H*	*M*	*M*	*M*	*M*		*M*		*M*	*H*	
F3	*Project Supervision*	*L*	*H*	*H*			*M*	*L*	*M*	*L*	*M*	*M*	*M*	*M*	*L*		*M*		*L*	*H*	
F4	*Design Details*	*H*	*M*	*L*			*M*	*M*	*L*	*M*	*M*	*M*	*M*	*L*	*M*		*M*		*M*	*M*	
F5	*Constructability*	*M*	*M*	*M*			*H*	*M*	*L*	*M*	*M*	*M*	*M*	*H*	*M*		*L*		*M*	*L*	
F6	*Accuracy of the estimates*	*L*	*M*	*M*			*H*	*L*	*M*	*L*	*M*	*M*	*M*	*L*	*M*		*M*		*L*	*L*	
F7	*Construction Difficulty*	*M*	*M*	*L*			*L*	*L*	*H*	*L*	*M*	*M*	*M*	*M*	*M*		*H*		*M*	*H*	
	Part B / Adversely affected or not																				
F8	*Weather Conditions*	*Y*	*Y*	*N*			*Y*	*N*	*Y*	*N*	*N*	*Y*	*Y*	*Y*	*N*		*Y*		*N*	*Y*	
F9	*Access to the area*	*Y*	*Y*	*N*			*Y*	*Y*	*N*	*N*	*N*	*N*	*N*	*Y*	*Y*		*Y*		*N*	*Y*	
F10	*Site conditions*	*N*	*N*	*N*			*Y*	*N*	*Y*	*Y*	*N*	*Y*	*Y*	*Y*	*N*		*Y*		*Y*	*Y*	
F11	*Site congestion*	*Y*	*N*	*N*			*Y*	*N*	*Y*	*Y*	*N*	*N*	*Y*	*Y*	*Y*		*Y*		*Y*	*Y*	
F12	*Sequencing or phasing*	*N*	*N*	*N*			*N*	*N*	*N*	*N*	*Y*	*Y*	*Y*	*N*	*N*		*N*		*N*	*Y*	
F13	*Reassignment of staff or crew*	*N*	*N*	*Y*			*Y*	*N*	*N*	*N*	*N*	*Y*	*Y*	*N*	*N*		*N*		*N*	*N*	
F14	*Owner inspection, quality requirement*	*Y*	*N*	*N*			*N*	*N*	*N*	*N*	*Y*	*N*	*N*	*N*	*N*		*N*		*N*	*N*	
F15	*Material supply*	*Y*	*N*	*N*			*Y*	*Y*	*N*	*Y*	*N*	*Y*	*Y*	*N*	*N*		*N*		*Y*	*Y*	
F16	*Improper or insufficient equipments/tools*	*Y*	*N*	*Y*			*Y*	*N*	*N*	*Y*	*N*	*Y*	*Y*	*N*	*Y*		*N*		*Y*	*Y*	
F17	*Was the project unionized*	*N*	*N*	*N*			*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*		*N*		*N*	*N*	
F18	*Walkouts or strikes*	*N*	*N*	*N*			*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*		*N*		*N*	*N*	
F19	*Change Orders*	*Y*	*Y*	*Y*			*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*N*		*N*		*Y*	*Y*	
F20	*Claim Situation*	*Y*	*N*	*N*			*N*	*Y*	*Y*	*N*	*Y*	*N*	*N*	*Y*	*Y*		*Y*		*N*	*N*	

3.2 Site Data Collection

A data sheet was prepared to collect quantity of work performed and the number of hours actually used for the item of work and accordingly data collected for eight items (A1-A8) from 20 bridge construction projects. The selected eight items are shown in Table 3.2- Description of Selected Construction Activities.

Table 3.2- Description of Selected Construction Activities

Activity No.	*Description of the Activity*
A1	*Excavation in unclassified soil and back filing for abutment and wing walls*
A2	*Class C Concrete of nominal mix 1:3:6 (20) as screed under foundation slabs of abutments and wing walls*
A3	*Class B Concrete of nominal mix 1:3:6 (40) in abutment and wing walls*
A4	*Class A Concrete of Grade 25 (20) in capping beam, ballast walls, curtain wall and bearing pads*
A5	*Smooth finish formwork for abutment and wing walls*
A6	*Smooth finish formwork for abutment capping beams, ballast walls, curtain walls and bearing pads*
A7	*Cold worked deformed high yield steel bars of Grade 460 in abutment capping beams, ballast walls, curtain walls and bearing pads*
A8	*Dry stone lining behind abutments and wing walls (50-200mm)*

Note: All the eight activities are selected from the construction of Abutment and Wing Walls of bridge construction projects.

Labour Productivity related data collected for activity A3-Class B Concrete of Nominal Mix 1:3:6 (40) in Abutments and Wing Walls are tabulated and shown as an example in Table 3.3. Labour Productivity data for the other selected activities (A1, A2, A4, A5, A6, A7 & A8) are also collected during the study and were not shown in this paper. However their average productivity drop have been calculated and are shown in section 3-Analysis of Data. Labour Productivity related data collected for activity A3-Class B Concrete of Nominal Mix 1:3:6 (40) in Abutments and Wing walls are tabulated in Table 3.3.

Table 3.3: Activity A3- Class B Concrete of Nominal Mix 1:3:6 (40) in Abutment and Wind Wall

Project Number	*Quantity Installed (m3)*	*Total Labour Hours*
P1	*251.78*	*2255*
P2	*188.09*	*4463*
P3	*39.75*	*538*
P4	*10.50*	*207*
P5	*56.90*	*1042*
P6	*104.44*	*2011*
P7	*34.48*	*197*
P8	*-*	*Data not available*
P9	*-*	*Data not available*
P10	*112.49*	*2041*
P11	*58.82*	*1748*
P12	*65.39*	*1088*
P13	*16.14*	*216*
P14	*99.85*	*1600*
P15	*206.5*	*309*
P16	*93.59*	*1196*
P17	*45.27*	*1080*
P18	*60.94*	*435*
P19	*264.85*	*4090*
P20	*267.11*	*6979*

4. Analysis of Data

4.1 Questionnaire Survey

Marks were allocated to Part A of the respondent's opinion as 5 for High; 3 for Medium and 1 for Low and the marks obtained are given in Table 4.1. Responses received for the Part B of the Questionnaire Survey is summarized and are given in Table 4.2.

Table 4.1: Summary of Responses of Part A of the Questionnaire Survey

Factor No	*Overall Project Factors*	*P1*	*P2*	*P3*	*P6*	*P7*	*P8*	*P9*	*P10*	*P11*	*P12*	*P13*	*P14*	*P16*	*P18*	*P19*
	How would you rate the Factors F1-F7															
F1	*Labour crew performance*	*3*	*3*	*3*	*3*	*3*	*5*	*3*	*5*	*3*	*3*	*5*	*1*	*5*	*5*	*5*
F2	*Availability of skilled labour*	*1*	*3*	*3*	*1*	*3*	*3*	*1*	*5*	*3*	*3*	*3*	*3*	*3*	*5*	*5*
F3	*Project Supervision*	*1*	*5*	*5*	*3*	*1*	*3*	*1*	*3*	*3*	*3*	*3*	*1*	*3*	*1*	*5*
F4	*Design Details*	*5*	*3*	*1*	*3*	*3*	*1*	*3*	*3*	*3*	*3*	*1*	*3*	*3*	*3*	*3*
F5	*Constructability*	*3*	*3*	*3*	*5*	*3*	*1*	*3*	*3*	*3*	*3*	*5*	*3*	*1*	*3*	*1*
F6	*Accuracy of the estimates*	*1*	*3*	*3*	*5*	*1*	*3*	*1*	*3*	*3*	*3*	*1*	*3*	*3*	*1*	*1*
F7	*Construction difficulties*	*3*	*3*	*1*	*1*	*1*	*5*	*1*	*3*	*3*	*3*	*5*	*3*	*5*	*3*	*5*

Table 4.2: Response Summary of Part B of the Questionnaire Survey

Factor No	*Adversely affected or not*	*Yes*	*No*
F8	*Weather Conditions*	*60 %*	*40 %*
F9	*Access to the Site*	*54 %*	*46 %*
F10	*Site Conditions*	*60 %*	*40 %*
F11	*Site Congestion*	*67 %*	*33 %*
F12	*Sequencing or phasing*	*27 %*	*73 %*
F13	*Reassignment of staff or crew*	*27 %*	*73 %*
F14	*Owner inspection, quality requirement*	*14 %*	*86 %*
F15	*Material supply*	*54 %*	*46 %*
F16	*Improper or insufficient equipments/tools*	*60 %*	*40%*
F17	*Was the project unionized?*	*00 %*	*100%*
F18	*Walkouts or strikes*	*00 %*	*100%*
F19	*Change orders*	*86 %*	*14 %*
F20	*Claim situation*	*46 %*	*54 %*

Using these data, the weighted amount of production rate for each project of all the activities were calculated as below. For example, for the factor F1, consider project P1 of activity A1 .

Quantity installed	=	264.48 m^3
Total work hours	=	3085.5
Productivity index	=	264.48 m3 (= 0.086) 3085.5wh
Sum of the productivity Index of activity A3	=	1.049 m^3 / wh
Weight of productivity P1	=	0.086 / 1.049
	=	0.082
Score given to F1 in the Questionnaire for project P1	=	3
Weighted production rate for the F1 of project P1 of activity A3	=	0.082 × 3 0.246

Similarly weighted production rates were calculated for all 7 factors (F1-F7) for all combinations. Using these weighted production rates "FALL" values are calculated to find out the effect of the factor on Labour Productivity. Formula used to calculate the "FALL" value is given below:

$$\textbf{FALL} = \frac{\sum P_i \quad A_{pi}}{\sum A_{pi}}$$

Where:

P_i = Total weighted amount of production rate of i^{th} project

A_{pi} = Number of activities in i^{th} project (where ***i*** is from 1 to 20)

The FALL value calculated for factors F1 to F7 for all projects are shown in Table 4.3.

Table 4.3: FALL Values of Activity A3

Factor	*Description* *How would you rate the;*	*FALL Value*
F1	*Labour crew performance of the project*	*2.38*
F2	*Availability of skilled labour for the project*	*1.44*
F3	*Supervision for the project*	*1.70*
F4	*Details of the design*	*2.43*
F5	*Constructability of the project*	*1.75*
F6	*Accuracy of the estimate*	*1.05*
F7	*Degree of difficulty for the project*	*1.91*

4.2 Site Data Collection

Actual Productivity of selected eight activities was calculated using the site data gathered and was compared with the estimated values. The estimated values are taken from the rate analysis prepared during estimating. Actual Productivity calculated and the estimated productivity including productivity drop for Activity A1 are shown in Table 4.4.

Table 4.4- Actual and Estimated Productivity of Activity A1

Project No	*Actual Productivity Index (m^3 /wh)*	*Estimated Productivity Index (m^3 / wh)*	*Productivity Decrease (%)*
P1	*0.086*	*0.877*	*90*
P4	*0.528*	*0.877*	*40*
P5	*0.072*	*0.877*	*92*
P6	*0.041*	*0.877*	*95*
P10	*0.036*	*0.877*	*96*
P11	*0.256*	*0.877*	*71*
P12	*0.120*	*0.877*	*86*
P13	*0.099*	*0.877*	*89*
P14	*0.300*	*0.877*	*66*
P17	*0.396*	*0.877*	*55*
P18	*0.111*	*0.877*	*87*

Average productivity drop of Activity A1 is 79%.Similarly Actual Productivity, Estimated Productivity and the averages Productivity Drop for all other 7 activities (A2-A8) were calculated. These values are not shown here but the average Productivity Drop for all activities calculated is given in Table 4.5.

Table 4.5- Average Productivity Drop in Activities A1 to A8

Activity No.	*Description of the Activity*	*Average Productivity Drop*
A1	*Excavation in unclassified soil and back filing for abutment and wing walls*	*79.0%*
A2	*Class C Concrete of nominal mix 1:3:6 (20) as screed under foundation slabs of abutments and wing walls*	*49.0%*
A3	*Class B Concrete of nominal mix 1:3:6 (40) in abutment and wing walls*	*76.0%*
A4	*Class A Concrete of Grade 25 (20) in capping beam, ballast walls, curtain wall and bearing pads*	*78.0%*
A5	*Smooth finish formwork for abutment and wing walls*	*45.0%*
A6	*Smooth finish formwork for abutment capping beams, ballast walls, curtain walls and bearing pads*	*67.0%*
A7	*Smooth finish formwork for abutment capping beams, ballast walls, curtain walls and bearing pads*	*47.0%*
A8	*Dry stone lining behind abutments and wing walls (50-200mm)*	*57.5%*

According to the Response Summary of Table 4.2 Factors F8, F9, F10, F11, F15 and F19 have scored values higher than 50% and it indicates that these factors adversely affect the labour productivity. Similarly all the other factors F12, F13, F14, F17, F18 and F20 have low or no affect on labour productivity as these factors scored less than 50% values in the Response Summary.

FALL values calculated and shown in Table 4.3 for factors F1 to F7 are below the Medium Rating of 3 and the low FALL values indicates that the factor is adversely affect labour productivity. Accordingly it can be concluded that all seven factors F1 to F7 are significantly affect the labour productivity in bridge construction projects.

Productivity calculations are done using the cost records maintained at sites by the supervisors and the technical officers. Therefore it has to be assumed that these are the actual labour productivity rates for those selected activities. Although these results do not provide explanation for the significant drop in productivity but it may be due to internal and external factors influencing the activities. It is clearly that the actual productivity rates are significantly lower than the estimated productivity rates of activities A1 to A8. The highest average productivity drop of 79% is shown for activity A1and the lowest average productivity drop of 45% is shown for activity A5.

5. Conclusion

The main focus of this study was on identifying the factors that are affecting labour productivity in construction projects. Questionnaire survey was conducted at 20 bridge construction sites and questions were included in the questionnaire to test 20 factors related to labour productivity.

From this study it was identified that ten factors which affect labour productivity the most are ; lack of availability of skilled workers, inadequate supervision, Accuracy of the estimates, construction difficulties, Weather conditions, access to site, site congestion, inadequate supplies and Change orders.

According to the Labour Productivity results obtained from the onsite data collection the actual labour productivity of all eight items selected are significantly lower than the estimated labour productivity. Highest labour productivity drop reported was 79% for activity A1 and the lowest reported labour productivity drop reported was 45% for activity A5.

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