MODELLING MASONRY LABOUR PRODUCTIVITY USING MULTIPLE REGRESSION

Anu V. Thomas and J. Sudhakumar

Department of Civil Engineering, National Institute of Technology, Calicut, NITC P. O., Calicut, Kerala, India

Construction labour productivity is influenced by a multitude of factors. Productivity models analyze and estimate the impact of the various factors on productivity. In the present research, multiple regression analysis was used to develop a model to quantify the impact of the influential factors on masonry labour productivity, in the context of a developing country. Previous studies to develop productivity models relied on data collected through questionnaires, wherein the influence of various factors was measured on a qualitative scale. The present study, however, utilized quantitative data directly collected from two case study projects, to develop the model. The regression model identified excessive overtime and material delays as the major factors impacting productivity. The mode of employment of labour was also found to have a significant impact on productivity. Sensitivity analysis was also performed to identify trends of the factors. The significant variables identified by the regression model emphasize the importance of efficient resource planning in achieving high labour productivity.

Keywords: labour productivity, modelling, regression.

INTRODUCTION

Construction labour productivity is a major determinant of success of a construction project. Time and cost overruns of construction projects are widely attributed to poor productivity of construction labour force. Considerable research has hence been dedicated to identifying opportunities for labour productivity improvement. Construction labour productivity is influenced by large number of factors. It is important to identify the relative impact of the various factors on productivity, so that effective plans are framed for productivity improvement.

Productivity models quantify the impact of various factors on construction labour productivity (Sonmez and Rowings 1998). Previous research on developing productivity models have heavily relied on qualitative data collected through questionnaires or historical productivity data. This introduced a lot of subjectivity into the data collection process, with the resultant errors in predicting the effects of the factors on productivity. The present research, however, utilizes actual data directly gathered from the construction sites, to develop the productivity models. Quantitative data, on masonry productivity and influencing factors, was collected on a day-to-day basis from two construction projects and the collected data was used in developing regression models.

1 anuthomastkmce@gmail.com

LITERATURE REVIEW

Though considerable research has been done on identifying the impact of various factors on productivity, many focused on the influence of a single factor on productivity. Multiple regression models have been developed to quantify the impact of change orders, extended overtime, overmanning and shift work on labour productivity (Hanna et al. 1999; Hanna et al. 2005; Hanna et al. 2007; Hanna et al. 2008). Koehn and Brown (1985) developed non-linear equations to quantify the relationships between productivity and temperature and humidity. Thomas and Yiakoumis (1987) employed multiple regression techniques to quantify the impact of relative humidity and temperature on productivity. Moselhi et al. (2005) used neural network models to quantify the impact of change orders on labour productivity and Thomas and Napolitan (1995) quantified the impact of changes on labour productivity using regression analysis. Labour productivity, however, is influenced by multiple factors and it is essential to study the influence of the multiple factors on productivity.

The impact of multiple factors on productivity has been modelled by various researchers. Fayek and Oduba (2005) applied fuzzy expert systems to model pipe rigging and pipe welding operations. Artificial neural networks have also been employed to model the impact of multiple factors on productivity (Moselhi and Khan 2010; Portas and AbouRizk 1997; Song and AbouRizk 2008; Sonmez and Rowings 1998; Zayed and Halpin 2005a). Productivity models to quantify the effect of multiple factors on productivity have also been developed using regression analysis (Sonmez and Rowings 1998; Zayed and Halpin 2005b). Regression analysis is advantageous in developing productivity models, chiefly because it allows for more parsimonious use of the free parameters (Sonmez and Rowings 1998).

Many of the previous studies utilized data collected through questionnaires or historical productivity data wherein the intensity of the influencing factors was measured on a qualitative scale. The models that used real time observations on productivity, however, did not collect data on the problems encountered and the corresponding time losses. The previous productivity models thus fail to quantify the impact of various factors on productivity accurately. The present research is therefore aimed at collecting data on the factors influencing productivity, including the time losses due to various problems encountered in the course of the work, and using the data collected in developing models to quantify the impact of the factors on masonry labour productivity, using regression analysis.

DATA COLLECTION

Data was collected from two high rise building construction project sites, located in the state of Kerala in India. The first case study project is a multi-storey residential building construction. The second case study project is an Information Technology (IT) park complex, located very near to the first building. Both the buildings were reinforced concrete framed structures with masonry infill. The two projects were selected for data collection as they were constructed during the same period, were located at close proximity to one another and employed the same structural framing system.

Daily visit method was employed to collect data from the two project sites. During the daily visit, information about the type of work, the type of labour, the working hours, the overtime hours and the crew size and composition was noted on the data collection forms. There were several crews engaged in masonry at different locations on the
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A site diary was maintained wherein the locations where the work was being carried out during each day were noted. In addition, the locations were marked on the plans and elevations obtained from the project offices. A note of the characteristics of the work area was made in the site diary, which formed the basis of fixing a work complexity rating for the work observed. The output was measured the next day, prior to the start of that day's work. Maintaining the notes of the workstations in the site diary and the plans helped in accurately locating the workstations during the visit for output measurement.

During the visit for output measurement, the site staff was interviewed to understand the problems faced during the previous day's work. The site staff also provided an estimate of the time lost due to each problem encountered, in the course of the work. In addition, hourly relative humidity, rainfall and temperature data for the data collection period was obtained from Indian Meteorological Department (I. M. D.).

CHARACTERISTICS OF DATA COLLECTED

At both the sites masonry work was carried out using laterite, a natural building stone, abundantly available in Kerala. The laterite blocks were laid in stretcher bond. The labour force worked for 6 days a week, on an 8 hour schedule daily.

The contractor on the IT park 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. The masonry work on the residential project site was done entirely by subcontract labour. The payment to the subcontract labour varied with the height of the wall, i.e., subcontract labour received a higher payment for work done above a height of 2.2 m. As such, data was collected separately for work done below and above the height of 2.2 m.

The materials required for the work were transported up to the respective floors via hoists and thereafter the horizontal transportation was carried out using wheelbarrows. The supply of the materials to the masonry crew was the responsibility of the site labourers, whereas mixing of mortar was done by the masonry crew. The scaffolding for the masonry work, if required, was prepared by a separate gang.

A total of 152 observations on laterite masonry was obtained from the project sites. Each observation was the data for the daily work a crew. The daily productivity values varied from a maximum value of 1.09 m²/man-hr to a minimum of 0.12 m²/man-hr. The mean value of daily productivity observed was 0.41 m²/man-hr.

Delays observed

The major cause of the delays on the case study projects was the unavailability of materials at the workplace. A total of 57 out of the 152 data points experienced delay due to materials. The daily time lost due to material unavailability ranged from 30 minutes to 5 hours. The time lost due to material unavailability amounted to a total of 525 man-hours, which is obtained by summing up the product of the duration of delay in each observation and the corresponding crew size.

Other issues observed on the case study projects were rework due to craftsmen errors, which occurred on two instances and three observations when the crew were kept waiting as scaffolding was not ready on time. Rework due to craftsmen errors resulted
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in a total time loss of 18 man-hours, whereas the time lost because scaffolding was not ready amounted to a total of 23.5 man-hours.

Work content

As mentioned earlier, masonry data was collected separately for work carried below and above the height of 2.2 m and a difference in productivity was observed below and above the height of 2.2 m. In addition, differences in productivity were also observed for straight walls and walls involving numerous corners. Thomas and Zavarski (1999) proposed a work content (WC) scale ranging from 1 – 5 in defining baseline productivity. Following these lines, a WC scale ranging from 1 – 3 is adopted for the present study, where WC 1 represents straight walls of height less than 2.2 m, WC 2 represents walls with numerous corners of height less than 2.2 m and WC 3 representing walls of height greater than 2.2 m. The residential building site involved straight walls less than 2.2 m and was rated WC 1, whereas at the IT park site, WC ratings of 2 and 3 were observed. The residential building site did not involve walls of height greater than 2.2 m and hence a separate classification of straight walls greater than 2.2 m was not used in the present research.

REGRESSION MODELS FOR MASONRY PRODUCTIVITY

Stepwise regression procedure available in SPSS software was used for the model development. The various factors which were used as input to the regression model are given in Table 1. The average of the hourly rainfall, temperature and relative humidity data for the working hours served as input to the model. For mode of employment, directly employed labour was the reference category and was coded 0 whereas subcontract labour was coded 1. Work content scale ranging from 1 – 3 was adopted for masonry as discussed earlier, with WC 1 chosen as the reference category and coded 0, the other WC ratings expressed appropriately to represent differences from the reference category. Data transformation of the dependent variable was found necessary to meet the assumptions of regression analysis. Various transformations were tried and it was found that a log10 transformation of the dependent variable gave the best results.

Table 1: Factors used for regression

<table>
<thead>
<tr>
<th>Factors</th>
<th>Type of data</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of skilled to total labour</td>
<td>Continuous</td>
<td>Number</td>
</tr>
<tr>
<td>Total labour</td>
<td>Continuous</td>
<td>Number</td>
</tr>
<tr>
<td>Mode of employment of labour</td>
<td>Categorical</td>
<td>Coded</td>
</tr>
<tr>
<td>Overtime</td>
<td>Continuous</td>
<td>Hours</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Continuous</td>
<td>mm</td>
</tr>
<tr>
<td>Temperature</td>
<td>Continuous</td>
<td>0C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Continuous</td>
<td>%</td>
</tr>
<tr>
<td>Delay - materials</td>
<td>Continuous</td>
<td>Hours</td>
</tr>
<tr>
<td>Time lost - rework</td>
<td>Continuous</td>
<td>Hours</td>
</tr>
<tr>
<td>Tim lost - work not ready</td>
<td>Continuous</td>
<td>Hours</td>
</tr>
<tr>
<td>Work content</td>
<td>Categorical</td>
<td>Coded</td>
</tr>
</tbody>
</table>

Though eleven independent variables were used as input to the regression model, only four variables were significant in the final model. The final model had a R2 value of
0.794 and an adjusted R2 value of 0.787. The corresponding F statistic was 112.312, p value <0.001, ensuring overall fit of the regression model. The coefficients of the regression model along with the associated statistics are shown in Table 2. For the dummy or indicator variables interpretation based on standardized coefficients is not applicable and hence is not presented in the table. The tolerance values and the VIF are measures of multicollinearity. Tolerance values below 0.1 and VIF greater than 10 are indicative of high degree of multicollinearity (Field 2005; Hair et al. 2011). The tolerance value of all the variables was greater than 0.1 and the VIF less than the threshold limit of 10. Hence no multicollinearity was detected among the variables.

The positive coefficient for the mode of employment of labour which was coded as a dummy variable, indicates that the subcontract labour are more productive than the directly employed labour, the value of the coefficient representing the difference in productivity. Talhouni (1990) also has reported the superiority of the performance of the subcontract labour when compared to the directly employed 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. A reduction in productivity with increasing levels of work complexities is also evident from the regression model as both the coefficients WC3_WC1 and WC2_WC1 are negative. The greater the complexity of work, the larger is the reduction in productivity as obvious from the coefficients in Table 2.

The findings of the regression analysis clearly illustrate the influence of excessive overtime and delays due to materials on labour productivity. The standardized coefficients reveal overtime to have a greater influence on productivity than delays due to materials. The effects of overtime on productivity have been widely studied by 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, all of which result in a reduction of productivity (Hanna et al., 2005). Thomas and Raynar (1997) 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. This was true on the IT park site where overtime was allowed indiscriminately, without taking necessary action to ensure adequate supply of materials. Overtime in the past studies was defined as work performed over 8 hours/day and 40 hours/week. The previous research studies investigated 50 hour and 60 hour workweeks, while in Kerala, construction workforce normally worked 6 days a week for 8 hours /day thereby yielding a normal 48 hours week. 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. 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, with two observations having an overtime of 8 and 9 hours. Thus, for the directly employed labour, the weekly work hours were an average of 69 hours/week or more and the resultant detrimental effects on productivity.
Table 2: Coefficients and associated statistics of linear regression model for masonry productivity

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized coefficients</th>
<th>Standardized coefficients</th>
<th>t</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Standard error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.348</td>
<td>0.031</td>
<td>-11.245</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Mode of employment of labour</td>
<td>0.157</td>
<td>0.027</td>
<td>N/A</td>
<td>5.930</td>
</tr>
<tr>
<td>Overtime</td>
<td>-0.024</td>
<td>0.006</td>
<td>-0.231</td>
<td>-4.124</td>
</tr>
<tr>
<td>WC3_WC1</td>
<td>-0.220</td>
<td>0.025</td>
<td>N/A</td>
<td>-8.652</td>
</tr>
<tr>
<td>WC2_WC1</td>
<td>-0.178</td>
<td>0.025</td>
<td>N/A</td>
<td>-7.050</td>
</tr>
<tr>
<td>Delay - materials</td>
<td>-0.024</td>
<td>0.009</td>
<td>-0.111</td>
<td>-2.685</td>
</tr>
</tbody>
</table>

The present study, however, did not recognize a relationship between the weather parameters and labour productivity in the state of Kerala. Masonry, being an interior job, may not be influenced by the weather parameters. Also, the effect of weather on productivity has been previously studied in the context of other countries with differing climates and environment. It is recommended that further studies are conducted, to establish relationships between weather and productivity in the Indian context.

Residual analysis

Examination of the residuals – the difference between the actual and predicted values of the dependent variable – is the principal measure for assessing the validity of regression assumptions and is achieved by plotting the residuals. The value of the Durbin-Watson statistic computed was 1.855 and the value being close to 2, indicated that the assumption of independence of errors has been met. Figure 1 shows the histogram of the residuals for the developed model. The histogram shows that the residuals are normally distributed. Figure 2 presents a plot of the regression standardized residuals against the regression standardized predicted values. The points are approximately randomly distributed in the plot and hence indicate that the assumptions of linearity and homoscedasticity or equality of variances are met. The partial residual plots also did not show major deviations from the assumptions of linearity and homoscedasticity. The residual analysis thus confirmed the developed model to be performing well with respect to the assumptions of regression analysis.
Model validation

The regression model developed was validated by the split sample approach. The data was split into two parts, with 70% of the data randomly chosen for estimating the regression model and the remaining data used for validating the model. To measure the predictive ability of the model, each case in the validation dataset was predicted with the estimated regression model and the mean square prediction error (MSPR) was calculated as follows (Kutner et al., 2004):

\[
MSPR = \frac{\sum_{i=1}^{n^*} (Y_i - \hat{Y}_i)^2}{n^*}
\]

(1)

Where \( Y_i \) is the value of the response variable in the \( i \)th validation case, \( \hat{Y}_i \) is the predicted value for the \( i \)th validation case based on the model-building dataset and \( n^* \) is the number of cases in the validation dataset.
Stepwise procedure was adopted for estimating the model based on the split sample also. The significant variables in the model estimated with the split sample were the same based on the entire dataset, the R2 value for the split sample model being 0.783 (adjusted R2 = 0.772). Each case in the validation dataset was predicted with the estimated regression model and MSPR was calculated as per equation 1. The MSE based on regression fit to the model-building dataset was 0.0117 and the MSPR for the validation dataset was 0.0119, the MSE for the model based on entire dataset being 0.0113. The values of the MSE’s and MSPR are very close and thereby validate the regression model.

**Sensitivity analysis**

The variation in labour productivity due to changes in the values of a factor, while other factors are held constant at their mean value, was studied. Figure 3 presents the variation of labour productivity with increase in overtime hours for subcontract labour at various work content ratings, when other factors were held constant at their mean values. The impact of material unavailability on labour productivity for subcontract labour at various work content ratings is given in Figure 4. Similar plots were also obtained for the directly employed labour. The figures indicate a deterioration of productivity with increase in overtime as well as delays due to material unavailability.

![Figure 3: Impact of overtime on labour productivity of subcontract labour](image)

![Figure 4: Duration of delay due to material unavailability](image)
CONCLUSIONS

Data on productivity, the factors affecting productivity as well as the corresponding time losses were collected from two high rise building construction sites on a day-to-day basis. The collected data was used in developing a regression model, to quantify the impact of the influencing factors on productivity. Stepwise regression procedure used to develop the productivity model has identified overtime, delay due to materials, the mode of employment of labour and the work content as the significant variables for masonry productivity, with overtime being the most important variable influencing masonry productivity. Residual analysis verified the assumptions of regression analysis and the model has been validated by split sample approach. The present research, however, did not identify any relationship between the weather parameters and productivity. The findings of the present study are limited to the data collected from the two construction sites. It is recommended that further studies, involving data collected from more number of construction sites, are carried out to study the impact of weather and various other factors on masonry productivity. The study has revealed poor resource management as a major reason for productivity losses on the construction sites and thus emphasizes the importance of proper resource planning to achieve high labour productivity.

REFERENCES


