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# Relationship between Labour Productivity and Design Characteristics in High-rise Buildings

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ABSTRACT

*Formwork installation, rebar fabrication/installation, and concrete casting are often repetitive in high-rise building projects. Previous studies have shown that labor productivity is significantly affected by many reasons. This study aims to consider the relationship between average labor productivity and design characteristics in typical floors of high-rise building projects. Data were collected through questionnaire which was distributed to experts and experienced people in construction projects. A neural network model was developed to estimate labor productivity. The main result is the comparison between predicted and actual labor productivity for typical floors. The Mean Absolute Percentage Errors (MAPE) are less than 3.5%, and R-squared indices are greater than 85% for all three activities mentioned above. These results showed that the model developed in this study is very appropriate when predicting labor productivity in high-rise building projects.*

**Keywords:** *Labor productivity, High-rise building, Design characteristics, Artificial neural network, Vietnam*

## INTRODUCTION

Labor productivity in construction industry has been long studied by many previous researchers. Kometa and Olomolaiye (1997) have conducted a work sampling at seven project sites for formwork and rebar installation activities to identify the real working days as follows: 51% for masonry team, 44% for formwork team, and 56% for rebar team. Their study has also indicated that there are three factors which mostly affect the productivity of labor team including lack of materials, inappropriate equipments, and repetitive activities. In addition, Thomas and Sanvido (2000) have considered the quantitative effect of fabrication on productivity in three cases: installation of canopy and door, erection of outside wall panel, and steel pile driving. The result was labour productivity increased respectively 16.6%, 28.4% and 56.8%. Furthermore, David and Hanna (2005) further studied the absence of workers in an electrical construction site. They have claimed that when the rate of absence is from 6% to 10%, the productivity will decrease approximately 24.4%, and when rate of absence is from 0% to 5%, there is no productivity loss. On the other hand, construction productivity has been increased approximately between 5% and 20% due to floor repetitions or successive activities as studied or reported by the United Nations 1965, Thomas *et al.* 1986, Everett and Farghal 1994, Couto and Teixeira 2005, Jarkas 2010, Stefan and Kim 2010, and Long and Hung 2012.

Unfortunately, Oglesby *et al.* (1989) stated that there is probably no standard method to measure the labour productivity due to the complexity of operations and relations in a construction site, and the labour productivity is different in each type of building structures. A few researchers have attempted to consider factors affecting labour productivity and to propose some methods for improving productivity by reducing the influence of these factors, but probably still having no consideration to factors related to building characteristics, e.g., a building designed with flat slab structure is often easy to construct than beam slab structure, or a column designed with circle shape is often easy to construct than square shape. Thomas and Yiakoumis (1987) have indicated that design factors have also effect on construction productivity involving constructability, quality of documents, specification requirements, and quality control requirements. Therefore, further research is needed to understand more what design characteristic factors affect labour productivity in high-rise construction practice. In the past, there were few models which has been used to measure or predict the labour productivity. This study uses the activity-oriented models which were developed by Thomas *et al.* (1986) because productivities are the subject of the measurement at the activity level. Thus, productivity is measured as the ratio between man-hours and performed quantity.

Based on above discussion, this study aims to explore the relationship between labour productivity and design characteristics in high-rise construction. Three main structural activities, namely formwork installation, rebar fabrication/installation, and concrete casting, were studied to investigate their average productivities in typical floors. Other floors were not considered due to their complexity and irregularity. The viewport of analysis only bases on contractor's opinions. The results directly serve the improvement in planning and managing the human resources and worker teams on site for contractors.

## DESIGN CHARACTERISTICS

In the construction industry, the factors influencing the productivity have been the subject of inquiry by many researchers. In order to improve productivity, conducting a study of the factors affecting it, whether positively or negatively, is necessary. Borcherding and Alarcon (1991) have categorised the major components of productivity loss as waiting or idle, travelling, working slowly, doing ineffective work, and doing rework. In addition, Hanna *et al.* (1999a, 1999b) have found that the change orders have negatively impacted on labor efficiency for mechanical construction. Furthermore, Ibbs *et al.* (2007) have claimed that the factors affecting labor productivity such as schedule acceleration, changes in work, management characteristics, project characteristics, labor and morale, and project location/external conditions. Enshassi *et al.* (2007) has listed and ranked factors affecting labour productivity into 45 factors in 10 groups from previous studies.

Several approaches have been adopted in relation to the classification of factors affecting construction productivity. Thomas and Yiakoumis (1987) have concluded that factors affecting productivity are categorised into the board classifications of: (1) manpower-labor; (2) design features-work content; (3) environmental-site conditions; (3) management practices-control; (4) construction methods; and (5) project organisational structure. Kane et al (cited in Herbsman *et al.*, 1990) classified the factors into two main groups: technological factors and administrative factors. Heizer and Render (1990) also classified factors influencing site productivity into three groups: labor characteristic factors; project work conditions factors; and non-productive activities. However, Olomolaiye *et al.* (1996) stated that factors affecting construction productivity are rarely constant, and may vary from country to country, from project to project, and even within the same project, depending on circumstances. They further classified these factors into two categories: external factors and internal factors.

Based on the classification and conclusion by Thomas and Yiakoumis (1987), Oglesby *et al.* (1989), Zhao and Chua (2003), and Ibbs *et al.* (2007), this study aims to consider the relationship between labor productivity and design features-work content in typical floors of high-rise buildings. The four factors have been identified as follows: (1) Higher number of typical floors; (2) Higher height of typical floor; (3) type of slab structure of typical floors; and (4) type of support structure of typical floors. The description of these factors is shown in Table 1.

Table 1: Design Characteristics of High-rise Buildings

| Code | Characteristics | Description |
|---|---|---|
| $X_1$ | Higher number of typical floors | It is defined from the first typical floor to the last typical floor of a high-rise building. |
| $X_2$ | Higher floor height | It is defined from structural level of a floor to the next upper or lower floor (within typical floors only). |
| $X_3$ | Type of slab structure of typical floors | It is a kind of slab structure of high-rise building including beam slab, flat slab without caps, flat slab plus caps, pre-stressed concrete slab, and others (or combined type). |
| $X_4$ | Type of support structure of typical floors | It is a kind of support structure of high-rise building including column, shear wall, core wall, and others (or combined type). |

## ARTIFICIAL NEURAL NETWORK MODEL

The configuration of the model adopted in this study is four layer back propagation artificial neural network (ANN). The input layer has four neurons representing the four structural design features of high-rise building as mentioned in Table 1. The output layer has three neurons representing the labor productivity of formwork installation ($Y_1$), rebar fabrication/installation ($Y_2$), and concrete casting ($Y_3$). In order to develop the hidden layer, Ripley (1996) stated that the model with two hidden layers can approximate any mapping with highest accuracy. Furthermore, Liu (1998) proposed that the number of neurons in each hidden layer can be estimated in range from $(2\sqrt{n} + m)$ to $(2n + 1)$. Where, n is the number of input neurons and m is the number of output neurons. Thus, the model has two hidden layers with nine neurons in each layer as shown in Figure 1.

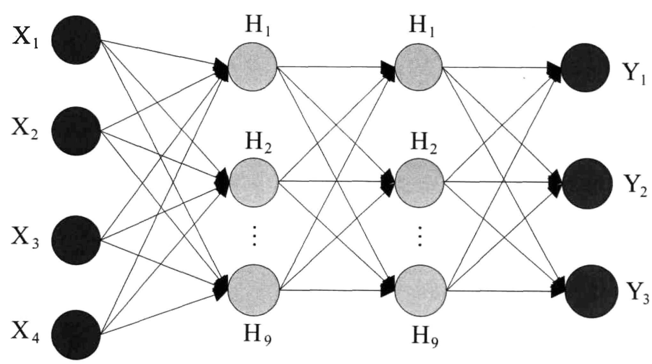



Figure 1: The Configuration of Artificial Neural Network Model

SPSS version 18.0 has been used to develop ANN model. 70% of the total number of data has been used for training neural network whereas 30% has been used for testing. Number of epochs used is 1000 at which network shows maximum convergence. Learning algorithm used is gradient decent with momentum back propagation with log tangent transfer function. Learning rate and momentum factor used in the model are 0.4 and 0.9. For the purpose of assessing the prediction performance obtained by the model, the R2 index used to measure the prediction accuracy is the coefficient of multiple determinations.

The impact of the structural design features on productivity performance may be determined via an elasticity test of the input factors. This was done by perturbing each of the input neurons in the output due to the change in the independent variables was taken to reflect the influence of the variable on the output. The elasticity of the productivity with respect to the $k$-th variable, $E_k$, is expressed as follows:

$$E_k = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\Delta P}{\Delta W_k}\right)_i \times 100\% \qquad (1)$$

where: $\Delta P$ is the change in productivity due to a corresponding with change in the $k$-th design feature factor, $\Delta W_k$, subscript $i$ denoting the ratio obtained for the $i$-th data set; and $n$ is the number of data sets considered.

## DATA COLLECTION AND ANALYSIS METHOD

Productivity data were collected in floor-to-floor from thirty high-rise projects in Ho Chi Minh, Vietnam through questionnaire. Several required documents include weekly reports, site diaries, and monthly claims. The potential construction personnel are project managers and site mangers. Three activities were aimed to collect data including formwork installation, rebar fabrication/ installation, and concrete casting. The collected information directly related to the definition of input and output variables in ANN's configuration. Other useful information may be recorded if needed. The design characteristic factors were observed simultaneously during measurement of labour productivity at the construction sites. The non-probability sampling was applied in this study because of its certain limitations.

First, the types of effect of design characteristics on labour productivity are assessed by respondents. It may be positive influence or negative influence. Then, find mean value to see the most influence type. Next, use an ANN model to predict the labour productivity in typical floors. Finally, based on the results, this study compares the predicted value with actual value, and defines the significant factor which has the most influence on labour productivity through elasticity test.

## ANALYSIS AND FINDINGS

### Type of Effect

The respondents were requested to assess the effect of design characteristics on labour productivity. It is considered as the hypotheses of the study. The results are shown in Table 2. Higher number of typical floors ($X_1$) has positive influence on labour productivity due to floor repetitions. It means that the labour productivity of upper typical floor often has an increase comparing with lower typical floor. Higher height of a typical floor ($X_2$) often has negative influence on labour productivity because the working conditions for a high column decrease, e.g., the higher the column is, the more difficult the workers feel when casting concrete and installing formwork for this column. Type of slab structure ($X_3$) has negative influence on labour productivity because of level of difficulty of structure, e.g., the slab designed with many beams is more difficult to install formwork than flat slab. Type of support structure ($X_4$) has also negative influence on labour productivity because of level of difficulty of structure, e.g., the column designed with the circle shape is often easier to install formwork than the square shape. The mean value was analysed to see the proportion of agreement for each factor. Most respondents agree with the hypotheses of the study. Only height of a typical floor is a fifty-fifty chance of agreement.

Table 2: Proportion of Agreement for Design Characteristics

| Code | Characteristics | Proportion of agreement | Type of effect |
|---|---|---|---|
| $X_1$ | Higher number of typical floors | 100% | Positive |
| $X_2$ | Higher floor height | 50% | Negative |
| $X_3$ | Type of slab structure of typical floors | 91% | Negative |
| $X_4$ | Type of support structure of typical floors | 83% | Negative |

### Labor Productivity Prediction

This study has standardised each input variable before putting it in ANN model. Variable $X_1$ was treated by calculating percentage in comparison with total number of floors of building. There was no need to standardise variable $X_2$. For variable $X_3$ and $X_4$, the five-point Likert scale was assigned with a value being 1 to 5 for each choices, therefore, they are considered nominal variables. The average labor productivity of typical floors was calculated from floor-to-floor labor productivity, therefore, the output variables are actual man-hours spent for square meters of formwork installed ($Y_1$), metric tons of rebar fabricated/ installed ($Y_2$), and cubic meters of concrete casted ($Y_3$). The results of prediction by ANN are shown in Table 3.

Table 3: Results of Labour Productivity Prediction by ANN

| Project | Input variable | | | | Actual value | | | Predicted value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ (%) | $X_2$ (m) | $X_3$ | $X_4$ | $Y_1$ (hrs/ $m^2$) | $Y_2$ (hrs/ ton) | $Y_3$ (hrs/ $m^3$) | $Y_1$ (hrs/ $m^2$) | $Y_2$ (hrs/ ton) | $Y_3$ (hrs/ $m^3$) |
| 1 | 75.9 | 3.300 | 4 | 3 | 1.41 | 41.39 | 1.16 | 1.37 | 39.89 | 1.20 |
| 2 | 66.7 | 3.250 | 1 | 5 | 1.47 | 36.54 | 1.21 | 1.43 | 36.74 | 1.18 |
| 3 | 80.0 | 3.350 | 1 | 1 | 1.49 | 30.77 | 1.19 | 1.54 | 31.83 | 1.24 |
| 4 | 70.8 | 3.150 | 1 | 1 | 1.47 | 39.16 | 1.23 | 1.45 | 41.84 | 1.24 |
| 5 | 83.3 | 3.400 | 1 | 3 | 1.40 | 40.26 | 1.46 | 1.43 | 40.05 | 1.43 |
| 6 | 84.2 | 3.400 | 1 | 5 | 1.64 | 28.96 | 1.41 | 1.62 | 29.28 | 1.38 |
| 7 | 83.3 | 3.150 | 2 | 2 | 1.48 | 37.12 | 1.28 | 1.46 | 39.08 | 1.23 |
| 8 | 84.8 | 3.200 | 1 | 5 | 1.19 | 37.64 | 1.07 | 1.24 | 38.82 | 1.11 |
| 9 | 83.3 | 3.150 | 1 | 2 | 1.46 | 41.04 | 1.24 | 1.50 | 39.29 | 1.27 |
| 10 | 73.7 | 3.300 | 1 | 2 | 1.55 | 33.43 | 1.29 | 1.53 | 35.41 | 1.24 |
| 11 | 84.2 | 3.300 | 1 | 5 | 1.42 | 37.86 | 1.29 | 1.39 | 36.56 | 1.24 |
| 12 | 73.5 | 3.200 | 1 | 2 | 1.35 | 42.24 | 1.25 | 1.37 | 42.27 | 1.20 |
| 13 | 80.0 | 3.300 | 1 | 5 | 1.45 | 39.23 | 1.32 | 1.42 | 37.56 | 1.27 |
| 14 | 84.0 | 3.050 | 4 | 5 | 1.56 | 33.17 | 1.21 | 1.51 | 32.67 | 1.25 |
| 15 | 88.9 | 3.200 | 5 | 5 | 1.43 | 32.79 | 1.41 | 1.45 | 34.56 | 1.39 |
| 16 | 86.8 | 3.200 | 5 | 5 | 1.39 | 37.00 | 1.31 | 1.45 | 35.15 | 1.36 |
| 17 | 69.4 | 3.200 | 1 | 5 | 1.32 | 35.77 | 1.20 | 1.38 | 37.71 | 1.15 |
| 18 | 80.6 | 3.150 | 5 | 5 | 1.44 | 31.35 | 1.26 | 1.48 | 32.20 | 1.23 |
| 19 | 82.8 | 3.300 | 1 | 5 | 1.36 | 35.32 | 1.20 | 1.40 | 36.91 | 1.25 |
| 20 | 89.7 | 3.200 | 3 | 5 | 1.27 | 37.57 | 1.23 | 1.31 | 39.32 | 1.26 |
| 21 | 85.0 | 3.150 | 1 | 2 | 1.48 | 36.95 | 1.34 | 1.52 | 38.78 | 1.29 |
| 22 | 81.3 | 3.250 | 2 | 2 | 1.43 | 31.41 | 1.08 | 1.44 | 33.26 | 1.13 |
| 23 | 77.3 | 3.300 | 1 | 5 | 1.39 | 36.03 | 1.23 | 1.43 | 37.77 | 1.27 |
| 24 | 89.3 | 3.150 | 3 | 5 | 1.41 | 39.37 | 1.38 | 1.44 | 37.72 | 1.35 |

*Cont..*

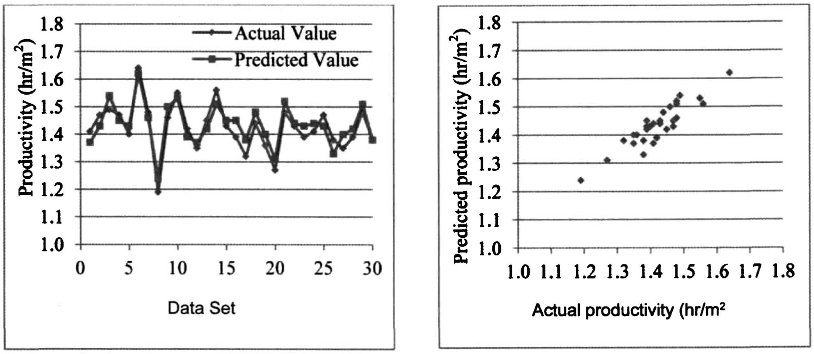
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 81.8 | 3.200 | 2 | 2 | 1.47 | 38.49 | 1.14 | 1.43 | 37.31 | 1.17 |
| 26 | 77.3 | 3.250 | 1 | 3 | 1.38 | 41.48 | 1.16 | 1.33 | 42.28 | 1.19 |
| 27 | 86.7 | 3.200 | 4 | 1 | 1.35 | 32.54 | 1.12 | 1.40 | 32.78 | 1.16 |
| 28 | 86.7 | 3.150 | 3 | 2 | 1.39 | 38.57 | 1.25 | 1.42 | 36.75 | 1.20 |
| 29 | 88.9 | 3.250 | 1 | 2 | 1.48 | 34.14 | 1.29 | 1.51 | 33.58 | 1.33 |
| 30 | 84.6 | 3.300 | 1 | 5 | 1.38 | 38.18 | 1.26 | 1.38 | 36.47 | 1.23 |

In order to assess the degree of accuracy of predicted model, the mean absolute percentage error (MAPE) and R-squared index will be used. The results of calculation in Table 4 show that the MAPE are quite small as follows: 2.05% for formwork, 3.36% for rebar and 2.78% for concrete; and the R-squared indices are 86.34% for formwork, 85.21% for rebar and 85.10% for concrete. These results indicate that the ANN model, which was developed by this study, is appropriate.

The comparison of measured and predicted productivity for all thirty data sets of formwork installation activity is shown in Figure 2a, and the correlation depicted as a scatter plot shown in Figure 2b. Similarly, Figure 3a and Figure 3b for rebar fabrication/installation activity, and Figure 4a and Figure 4b for concrete casting activity. They show a relatively good fit. This could be further improved if the significant design characteristics could be identified and the model is developed with respect to these.

Table 4: Accuracy of ANN Predicted Model

| **Activity** | **MAPE (%)** | **R-squared** |
|---|---|---|
| Formwork | 2.05 | 86.34 |
| Rebar | 3.36 | 85.21 |
| Concrete | 2.78 | 85.10 |



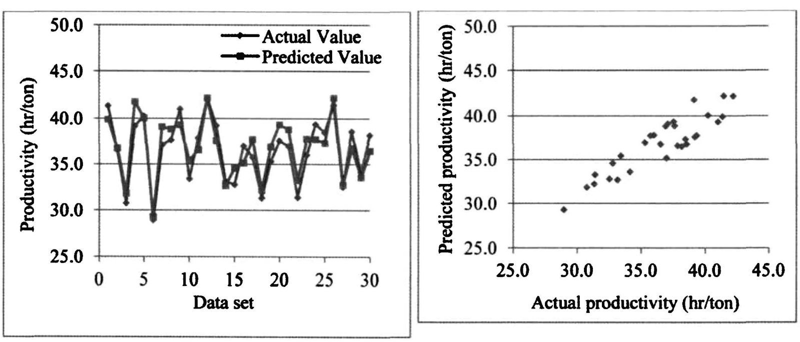

(a) Line plot for formwork

(b) Scatter plot for formwork

Figure 2: Comparison between Predicted and Actual Productivity

## Identifying Significant Factor

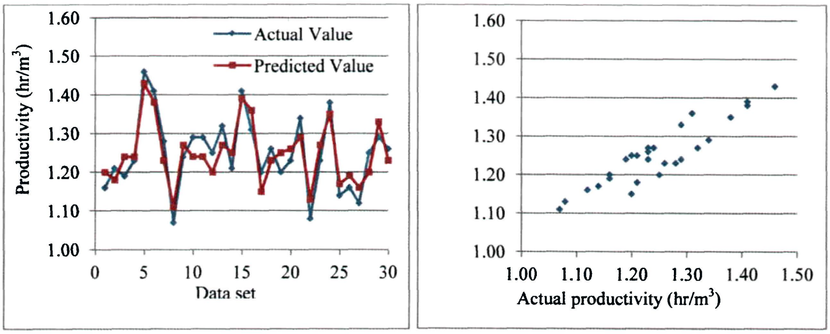
Venkataraman *et al.* (1995) suggested that elasticity test could be done by perturbing each input factor, one at a time, by 5% change (Equation (1)). But, in this study, there are two kinds of variables including scale and nominal. Each time, the model is restrained and the reaction computed for the remaining input variables. This is done because of the highly non-linear relationships existing in the ANN model (Zhao and Chua 2003). The results of analysis are shown in Table 5. For example, a 5% increase in the number of typical floors results in nearly 0.7% change in the productivity of formwork installation.




(a) Line plot for rebar

(b) Scatter plot for rebar

Figure 3: Comparison between Predicted and Actual Productivity




(a) Line plot for concrete

(b) Scatter plot for concrete

Figure 4: Comparison between Predicted and Actual Productivity

Table 5: Results of Elasticity Test for Design Characteristics

| Code | Characteristics ($W_k$) | Elasticity ($E_k$) | | |
|---|---|---|---|---|
| | | Formwork | Rebar | Concrete |
| $X_1$ | Higher number of typical floors | -0.07 | -0.63 | 2.42 |
| $X_2$ | Higher floor height | 0.16 | 1.82 | 0.02 |
| $X_3$ | Type of slab structure of typical floors | 1.34 | -0.54 | 0.80 |
| $X_4$ | Type of support structure of typical floors | 1.40 | -1.69 | 1.40 |

The results indicate that number of typical floors ($X_1$) has the most significant relationship for concrete activity with 2.42%. A reason that can be explained for this finding is that concrete casting activity is often done by a tower crane or concrete pump truck, therefore, labour productivity of upper floor will be reduced compared with lower floor. Height of a typical floor ($X_2$) belongs to rebar activity with 1.82%. A reason is possibly that rebar installation activity often meets difficulties in a typical floor if the height of this floor is too large. Type of slab structure ($X_3$) belongs to formwork activity with 1.34%. One explanation for this finding is possibly that labour productivity depends on the level of difficulty of structure. It means that if slab elements are designed with complicated structure type, the productivity of formwork installation for this slab element is obviously lower than the others. Eventually, type of support structure ($X_4$) belongs to rebar activity with 1.40%. The reason to explain this finding is similar to that of $X_3$.

## CONCLUSION

This study has employed the ANN model to predict the labour productivity that is influenced by design characteristics for three activities including rebar fabrication/installation, formwork installation and concrete casting. The main results could be highlighted that the ANN model is quite appropriate because the deviations between predicted and actual values are small. In detail, the MAPE are less than 3.5%, and the R-squared indices are greater than 85% for all three activities. To find the most significant factor, the elasticity test was adopted by perturbing each of the input factors by 5% change in one time. The results showed that number of typical floors is the most significant factor for labor productivity of concrete activity. Similarly, height of a typical floor and type of support structure belong to rebar activity, and type of slab structure belongs to formwork activity.

With the above results, this study would like to recommend that the designers and contractors should know the relationship between labor productivity and design characteristics due to floor repetitions when performing a high-rise building project.

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