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Modeling Construction Productivity by Using Multiple Linear Regression Techniques

Ibrahim Mahamid

Associate prof., Civil Engineering Department, University of Prince Mugrin, Almadinah, KSA
imahamid@ymail.com

Abstract: *This study aims at developing productivity estimating model for basecoarse works of road construction projects using multiple regression techniques. The model was developed based on 63 set of data collected in the West Bank in Palestine. This model type is very useful, especially in its simplicity and ability to be handled by calculator or a simple computer program. It has a good benefit in productivity estimating since the information needed could be extracted easily from scope definition of the projects. The developed MLR model can predict the productivity of basecoarse works for road construction with high degree of accuracy with 94.75% and the coefficients of determination* R^2 *equal to 0.93. This indicates that the relationship between the independent and dependent variables of the developed model is good and the predicted values from a forecast model fit with the real-life data.*

Keywords: Basecoarse; productivity; MLR; Regression; Road construction; Estimating.

Introduction

Labor productivity is simply defined as the amount of goods and services that a laborer produces in a given amount of time (Al-Saleh, 1995). Ever since the beginning of industrialization, the topic of productivity has been of notable interests among researcher, economists, and professionals. These interested parties want to increase the productivity for every amount of money spent. The productivity trends in the construction industry that is considered one of the largest industries in the nation have great impact on national productivity and on the economy (Alinaitwe et al., 2007). Productivity rates are among the most essential data needed in the construction industry. The accuracy of productivity rates is crucial for the determination of direct relationships between these rates and subjects such as estimating, cost control, scheduling, and resource management. The construction projects have experienced great variation in production rate values that affected by series of the influence factors. Researchers have reported that labor costs account for between 30 and 50% of a project's total cost (Al-Saleh, 1995; Harmon et al., 2006; Hanna, 2001), others concluded that variations in productivity of construction workers is one of the most daunting problems faced by construction industries, especially those in developing countries and it is one of the main cost overrun and delay causes in construction projects (Mahamid, 2013; Alinaitwe et al., 2007; Liu et al., 2008). To improve productivity, we must be able to measure it. Drucker (1993) articulates: "If you can't measure it, you can't manage it."

According to Mahamid (2013) labors are key ingredients in construction projects and the decrease in their productivity is very dangerous to an economy. Labor productivity has a significant impact on time, cost, and quality of a construction project. Especially the competitive environment of the construction industry forces construction companies to increase their labor productivity values to keep their positions in the industry (Aynur et al., 2016). Odesola and Idoro (2014) report that construction labor productivity has continued to be investigated because of its importance in national economies.

Public construction projects in Palestine are parts of the country's development initiative. It shared considerable amount of the country's scarce financial resources. Therefore, it is very important to efficiently utilize the main resources of public construction project. To do so, it is necessary to identify and rank factors that might affect the efficient utilization of those resources. This research focuses on one of the most important resources in public construction projects that is labor workforce. Mahamid and Bruland (2012) found that 100% of road construction projects implemented in the west bank during years 2004-2008 suffered from cost deviation. Mahamid (2011) found that poor labor productivity is one of the most critical factors affecting time and cost overrun in road construction projects in Palestine. This indicates that the productivity issue in the Palestinian construction projects is critical and a great attention should be paid to this important issue to measure it, then to manage it.

Research objectives

The objective of this study is to develop a model using multivariable regression for estimating the labor productivity of base works for road construction projects implemented in the West Bank in Palestine.

Previous studies

Construction productivity estimating

Estimation of the productivity is an important task in the management of construction projects. The quality of construction management depends on accurate estimation of the construction productivity (AL-Zwainy et al., 2012). The productivity estimation is based upon the assumption that there are certain relationships between a set of influential factors and productivity in the past events. Therefore, the productivity of the future events can be estimated by determining these relationships and specifying values for the influential factors (AL-Zwainy et al., 2012). Based on labor productivity field data, Thomas et al. (1990) developed a factor model by modeling and analyzing labor productivity that can be used as a predictor of productivity. This factor model presented average daily productivity both on disrupted days and non-disrupted days that can be used for comparing labor productivity. Thomas and Zavrski (1999) also used database as a baseline productivity measurement. In 1999, Thomas and Zavrski developed a conceptual benchmarking model to compare labor productivity in one construction project to that of another. This model was also used to establish benchmarking construction labor productivity in Abdel-Hamid et al. (2004).

Song and AbouRizk (2008) report that the current practice of estimating and scheduling relies on several sources to get productivity values, including an estimators' personal judgments, published productivity data, and historical project data. Moreover, a study conducted by Motwani et al. (1995) showed that more than 20% of contractors rely on estimators' "gut feelings" and opinions for the majority of their estimates. Sonmez and Rowings (1998) define the term "productivity modeling" as an approach of analyzing and estimating the impact of productivity-influencing factors on construction productivity using historical project data. Al-Zwainy (2012) used Back Propagation Feed-forward neural networks for productivity estimation of the finishing works with stone tiles for building project. Based on labor productivity field data, AL-Zwainy et al. (2012) used multivariable linear regression technique to develop construction productivity estimating model for marble finishing works of floors.

In this study, a statistic-based called the multivariable linear regression is to decide to be used. Multivariable linear regression has been widely used in recent research; it attempts to map the relationships between the influential factors and the productivity with the explicit mathematical functions. The mapping functions are initially presumed and later evaluated. They could be linear functions (multivariable linear regression) or non-linear functions (multivariable non-linear regression). This technique could oversimplify the relationships comparing with the neural network technique (Sonmez and Rowings, 1998).

Factors affecting labor productivity in construction projects

Zakeri et al. (1996) conducted a questionnaire survey to identify the main factors affecting construction productivity in Iran. They concluded that the top affecting factors are: lack of materials, weather and physical site conditions, lack of proper tools and equipment, design, drawing and change orders, inspection delays, absenteeism, safety, improper plan of work, repeating work, changing crew size and labor turnover. In UAE, Ailabouni et al. (2007) concluded that the main factors affecting labor productivity in construction projects include: proper work timings giving a balance between work and time for family, leadership skills of supervisors, technical qualifications, whether they are well paid or not and on time, security of job, transparency and accountability of management, payment of overtime, whether materials are available, procedures, policies, work method statements are available, personal skills, competency of supervisors and knowledge of work on an individual level. Jarkas and Bitar (2012) concluded that the most significant ten factors in their effects on labor productivity in construction projects in Kuwait include: clarity of technical specifications, the extent of variation/change orders during execution, coordination level among design disciplines, lack of labor supervision, proportion of work subcontracted, design complexity level, lack of incentive scheme, lack of construction manager's leadership, stringent inspection by the "Engineer", and delay in responding to "Requests For Information" (RFI). Mahamid (2013) conducted a study aims at identifying the factors affecting labor productivity in building construction projects in the West Bank in Palestine from contractors' viewpoint. 31 factors were considered in a questionnaire survey. The results revealed that the top five factors negatively affecting labor productivity in building construction are: rework, lack of cooperation and communication between construction parties, financial status of the owner, lack of labor experience, and lack in materials.

Ng et al. (2004) conducted a questionnaire survey in Hong Kong to identify the demotivating factors influencing the productivity of civil engineering projects from craft workers perspectives. They concluded that overcrowded work areas and rework are the most negatively affecting factors on the productivity of workers in civil engineering projects in Hong Kong. Alinaitwe et al. (2007) conducted a study to identify the factors negatively affecting labor productivity in construction projects in Uganda. The study reported on a questionnaire survey made on project managers of building projects. Respondents were required to rate using their experience how 36 factors affect productivity with respect to time, cost and quality. They found that the top ten factors affecting labor productivity are: incompetent supervisors, lack of skills from the workers, rework, lack of tools/equipment, poor construction methods, poor communication, inaccurate drawings, stoppages because of work being rejected by consultants, insecurity, tools/equipment breakdown, and harsh weather conditions.

Hamad and Al-Kwifi (2015) examined empirically the factors influencing employee job productivity in the Kingdom of Saudi Arabia (KSA). A survey was collected from 200 employees occupying different positions in their respective organizations. Results show that effective performance appraisal is a significant predictor of employee productivity, whereas job satisfaction is not a significant predictor of employee productivity. Nadia et al. (2017) reported that "residential construction involves labor-intensive tasks where workers are frequently confronted with problems that could lead to demotivation. Demotivation is caused not simply by a lack of motivators but the existence of certain situations that cause dissatisfaction and discourage individuals, therefore reducing overall productivity potential". Therefore, they conducted a study is to identify the most critical factors that demotivate manpower in the residential projects in Jordan. They concluded that working overtime and specifications and quality requirements are the leading causes of demotivation.

Based on personal interviews and the literature review, the factors that might affect labor productivity in base works of road construction projects were identified. Seven independent variables were carefully selected and were well defined for each construction project. These independent variables can be classified into two types: objective and subjective variables as shown in Tables 1 and 2, respectively. The quantitative (objective) variables that can be measured, depending on the unit of measurement, such as experience is measured in years, and work teams is measured in number. The qualitative (subjective) variables can be measured depending on the coding system, for example, the equipment conditions can be classified to good and poor and assigns them the value 1 and 2, respectively. Also, the contractor grade which can be classified to grade A, B, and C, it assigns them the values of 1, 2, and 3, respectively. While the weather condition; sunny (1), rainy (2). The terrain conditions can be classified to smooth and hilly and assigns them the value 1 and 2, respectively. Location can be classified to close to materials supplier (1) and far (2).

Table 1: The objective variables

Objective variable	Description	Units
X1	Work team	Number
X2	Experience	Years

Table 2: The subjective variables

Subjective variable	Description	Units
X3	Location	Category
X4	Terrain conditions	Category
X5	equipment conditions	Category
X6	weather	Category
X7	contractor grade	Category

Study Methodology

To designate regression models for estimating base work construction productivity, a three-phases framework is developed. The first phase includes model building, which consists of: (1) collecting quantitative and qualitative data and selecting model's variables; (2) checking the significance of model variables based on statistical criteria; and (3) building regression models. In the second phase, the developed models are validated through comparing their results to the collected validation data points. If these results do not match; then, the model should be improved to produce better results. In the third phase, conclusions and recommendations are formulated based on data analysis and developed model.

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Data Collection

"Questionnaire survey is the most commonly data collection method adopted by the researcher to collect information on factors and production" (Al-Zwainy et al., 2012). The current study collected data through questionnaire, site interviews, site visits, and telephone calls to contractors who are specialists in road construction. Reviewers were asked to provide information about productivity, objective variables, and subjective variables for base works in road construction project that is already completed or is currently in process. As the aim of the research is to develop regression model which required extensive data points, therefore, observations from 63 projects were collected with 8 observations from each project.

Regression Analysis

Regression analysis is an extremely powerful tool that enables the researcher to learn more about the relationships within the data being studied (Mahamid, 2011). Regression models are intended to find the linear combination of independent variables which best correlates with dependent variables. The regression equation is expressed as follows:

$$Y = C + b_1 X_1 + b_2 X_3 + ... + b_n X_n \quad (1)$$

Where,

Y: dependent variable.

C: regression constant

b_1, b_2,…, b_n : regression estimates

X_1,…, X_n : independent variables

In this instance multiple linear regression will be used to determine the statistical relationship between the dependent variable (e.g., actual productivity) and the independent variables (e.g., experience, work teams, …etc).

Development of multivariable linear regression model

The relationship between the selected variables can be tested using different functions. However, Multivariable Linear Regression (MLR) is adopted in the research due to previous mentioned reasons. Excel statistical tools were employed to perform regression analyses and to test the significance of the model. The developed model and the results of the statistical analysis are shown in Table 3 and Table 4 below.

Table 3: Variables coefficients

Variables	*Coefficients*	*Standard Error*
Intercept	268.008	39.812
X 1	501.120	38.675
X 2	7.087	1.207
X 3	-21.760	4.170
X 4	-4.849	1.113
X 5	-18.151	3.449
X 6	-111.020	26.952
X 7	-94.275	23.696

The values above (Table 3) indicate that at least one of the model coefficients is nonzero. The model appears to be useful for predicting the base works productivity. This model included all the potential independent variables that have been identified. The model obtained is:

$$P = 268.00 + 501.120X1 + 7.087X2 -21.760X3 – 4.849X4 – 18.151X4 -111.020X3 – 94.275X7 \quad \text{Model (1)}$$

where:

P: productivity of base works for road construction as output (dependent) variable;

X1, X2, X3, X4, X5, X6, X7: Input (independent) variables as shown in Tables 1 and 2.

The correlation among input variables is tested; the results are shown in Table 4. The results of r (coefficient of correlation) and r^2 (coefficient of determination) show that there is a high correlation between construction productivity and other input variables. This indicates a good relationship between dependent and independent variables.

Table 4: Regression statistics

Regression Statistics	
Multiple R[a]	0.96
R Square	0.93
Adjusted R Square	0.90
Standard Error of the Estimate	31.78

[a]Predictors: (Constant), work team, experience, location, terrain conditions, equipment conditions, weather, contractor grade.

Validation Model

There are several basic ways of validating a regression model. They are:

1) Statistical test on “R” value.
2) Collection of new data to check the model and its predictive ability for comparison of results with the actual productivity of basecoarse works for road construction and the predicted productivity values.

1. Statistical test on “R” value

The following statistical tests were conducted on “R”, (the coefficient of correlation) value for model 1, where R^2= 0.93, N = 63:

1) Probable Error (P.E.) in “R” value

$$P.E. = 0.6745\ [(1-R^2)/N] \qquad (2)$$

$\Rightarrow$ P.E. = 0.6745[(1-0.93)/63] = 0.007494

P.E. = 0.007494 therefore, R = 0.93 ± 0.007494.

According to Ayoub and Mc Cuen (2000); the probable error is regarded as a measure of significance of Karl Person’s coefficient of correlation (R), and if the probable error is small (compared with R), correlation directly exists where R > 0.5. Hence, the correlation of the studied productivity equation is existing.

2) A simple method of testing whether “R” differs significantly from “zero”

Taking null hypothesis that there is no correlation between the two variables, provided “N” is large:

$$3/\sqrt{N}$$

If the value arrived at by this test is greater than the observed or computed value of correlation coefficient (R < $3/\sqrt{N}$) correlation is not significant (Ayoub and Mc Cuen, 2000);

$\Rightarrow 3/\sqrt{N} = 3/\sqrt{63} = 0.37 < 0.93$

Hence, coefficient of correlation can be taken as significant.

2. Collection of new data to check the model and its predictive ability

In this research, the second method is employed also. Ten new observations for each concerning variable were collected as shown in Table 5. These observations which were not included in the model calibration procedures were used as independent verification check. Also, the actual productivity of basecoarse works for road construction and the predicted values, calculated using model 1, are presented in the same table (Table 5).

Table 5 and Figure 1 show that the predicted productivity (by suggested productivity estimation function) predicts an average difference of 1.291% of the actual productivity. and the correlation coefficient between them equals to 0.91 which indicates a good relation between the estimated and actual productivity values.

Table 5: The new collected data to check the model and its predictive ability

X1	X2	X3	X4	X5	X6	X7	Actual productivity (A)	Estimated Productivity (P)	ABS(A-P)/A
1	8	1	1	2	2	2	410	352	0.14061
1	10	1	2	1	2	1	500	474	0.0518
1	8	2	2	1	1	1	480	549	0.144125
1	9	1	2	2	1	3	310	371	0.197871
1	8	2	1	2	2	1	460	425	0.076391
2	7	1	2	2	1	2	860	953	0.107616
2	8	1	2	1	2	2	920	867	0.057859
2	5	2	1	1	1	3	990	845	0.146121
2	12	2	2	1	2	1	870	968	0.11223
1	4	2	1	2	2	3	280	208	0.257286

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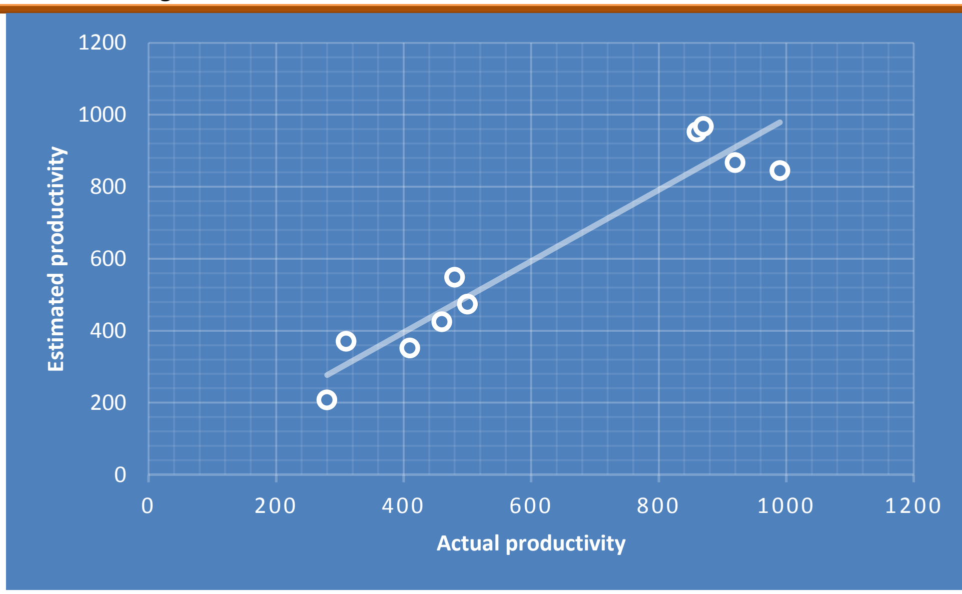

Fig 1: relation between actual productivity vs estimated productivity

Testing accuracy of the developed model

The accuracy for the developed mathematical model is tested using several measures as follow:

1) The mean absolute percentage error (MAPE). The following formula is used to compute the MAPE (Lowe et al., 2006):

$$MAPE = (1/n) * \sum_{i=1}^{n} \left| (A_i - F_i)/ A_i \right| \qquad (3)$$

Where,

A_i is the actual value
F_i is the forecast value
n is number of fitted points

2) Average accuracy percentage (AA%)

$$AA\% = 100\% - MAPE \qquad (4)$$

3) The coefficient of determination (R^2).
4) The coefficient of correlation (R).

Table 6 shows the MAPE and AA resulting from using the MLR model to estimate the basecoarse works productivity of 63 data sets collected from road construction projects implemented in the West Bank in Palestine. The results found to be 5.25% and 94.75%, respectively. The results compare favorably with past researches which have shown that the models with estimate accuracy of value less than ±10% show very good agreement with the actual measurements. (Lowe et al., 2006; Schexnayder et al, 2003; Sodikov, 2005).

Table 6: Results of statistical measures

Measure	MAPE%	AA%	R	R^2
Result	5.25	94.75	0.96	0.93

Conclusion

This study aims at developing productivity estimating model for basecoarse works of road construction projects using multiple regression techniques. The model was developed based on 63 set of data collected in the West Bank in Palestine. This model type is very useful, especially in its simplicity and ability to be handled by calculator or a simple computer program. It has a good benefit in productivity estimating since the information needed could be extracted easily from definition of the projects.

Multivariable Linear Regression used to examine several variables at once and the interrelationships between them. The developed MLR model can predict the productivity of basecoarse works for road construction with high degree of accuracy with 94.75% and the coefficients of determination R^2 equal to 0.93. This indicates that the relationship between the independent and independent variables of the developed model is good and the predicted values from a forecast model fit with the real-life data.

Based on the research results, the following points are suggested to improve construction productivity estimating process in Palestine:

1. Continuous updating on construction productivity by the Government or industry associations (i.e. Palestinian Contractors Union, contractors, suppliers, and Engineers Association) is recommended. The productivity list should be distributed to construction professionals in order they can come up with accurate estimates.
2. Develop a well-organized and computerized database in a manner that enables estimators and researchers to use it easily in their estimates and studies.
3. Revise models periodically based on new up-to-date data.

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