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OPTIMIZING LABOR PRODUCTIVITY IN EGYPT USING REGRESSION PREDICTION MODELS

Amr, F. Hegazy[1], Mona, M. Abouhamad[1,2], and, Hesham, M., Osman[1]
[1] Faculty of Engineering, Cairo University, Egypt
[2] m.abuhamd@gmail.com

ABSTRACT: The construction industry is one of the major and growing industries in Egypt, contributing 7% to the country's national GDP. Labor productivity is considered a critical issue in the construction industry in Egypt due to the lack of unified productivity figures representing the industry. This leads to overly estimated productivity measures at the tendering phase which causes the inevitable time and cost overruns. This research uses activity sampling technique to collect productivity data for conventional and manhour intensive construction activities. Linear and non-linear regression models are used to model the data and conclude the independent variables affecting productivity. Weather, %overtime, number of labors/m^2, and, slab height are considered the main model variables. The two regression models are compared to conclude the most suitable model. Moreover, sensitivity analysis is undertaken to deduce the factors with the highest and lowest impact on the productivity. Data validation showed high correlation between actual and predicted productivity with an average error of 0.6%. The actual productivity value is compared against productivity measures from leading national firms used for tendering purposes and against an international standard (RS-Means). The comparison revealed a slight difference between national productivity measures ranging from 16% to 6%. However, the international standard productivity measure was found 47% higher than the actual productivity. Modeling intensive manhours activities will lead to optimized resource utilization and practical schedule estimates. This conclusion highlights the need for national productivity measures to be used as benchmarks for productivity estimates in the Egyptian industry. The methodology used is generic, and while the research findings are regional, the applicability of the methodology is broad for different regions.

1. INTRODUCTION

The construction industry is one of the biggest and most growing industries in Egypt contributing 7% to the country's GDP. Around 8% of the total employment in Egypt works in the construction industry; ranked as the largest local construction workforce in the Middle East reaching up to 1.2 million. However, several challenges threaten the construction industry such as delays, over-budgeting and poor quality. The most significant challenge is the labor productivity estimation, which is used as a basis for planning and allocation of the resources, affecting all the project main objectives of being on time, within budget, and, adhering to the quality required. On the other side, achieving high productivity measures means constructors are subjected to increased profitability, improved competitiveness, and higher paid wages (Rojas 2008). Productivity is a commonly used term but often poorly defined where it is often misunderstood due to its linkage with profitability and performance (Pekuri, Haapasalo, & Herrala, 2011). This is because productivity is defined as an ambiguous term that depends on the researcher’s point of view and the context it is used in (Pekuri et al. 2011). In construction, productivity is calculated at various levels of detail for different reasons (Song and AbouRizk, 2008). Project managers and construction professionals identified the productivity as the ratio between earned work volume and the actual work hours, or work hours used (Hanna et al., 2005). Site management teams are more effectively to allocate their resources, provide better support, increase labors motivation and enhance labors commitment which will lead to productivity improvements, this can be achieved through better understanding of the factors influencing labor productivity. Therefore, it is important to record and understand what the labors need and what affects their performance in order to achieve productivity improvements (Dai et al. 2009a; Oglesby et al. 1989).

The purpose of this research is to model the construction productivity of commercial and administrative projects to determine the factors leading to productivity variability through applying prediction modelling techniques. Despite the uniqueness of each construction project, the prediction model is expected to provide a guide to understand what affects productivity, and hence, achieve improved productivity.

2. LITERATURE REVIEW:

Resource utilization optimization and productivity improvements became the key element for the stakeholders according to the status quo of the construction sector in the entire economy (Kazar et al., 2008). The decline or rise of the construction economic activity has a significant direct impact on the smooth functioning of the economy and the well-being of any country. Moreover, the competitive business environment nowadays has increasingly obliged the construction companies to focus on their major business activities to a greater extent (Sheng 2002). Issues like cost increase of energy, labor, and material has put the construction industry under pressure to improve efficiency. Therefore, it became necessary to get the maximum possible outputs from the most optimized inputs in order to increase productivity.

Numerous factors have been identified in literature to affect productivity, nevertheless, factors affecting the productivity in the developing countries still needs to be clarified (Makulsawatudom and Emsley 2002). A study by (Polat and Arditi 2005) stated that policies to raise productivity are not always similar in each country. Their study recognized various factors impacting labor productivity and categorized them according to their characteristics such as, design, execution plan, material, equipment, labor, health and safety, supervision, working time, project factor, quality, leadership and coordination, organization, owner/consultant, and, external factors. (Adrian 1987) classified the productivity factors causing low productivity as; industry-related factors, labor-related factors, and management-related factors. The uniqueness of construction projects, varied locations, adverse and unpredictable weather, and, seasonality were referred to as industry-related factors, in which they are the characteristics of the construction industry. Labor-related factors include the union’s influence, little potential for learning, and lack of motivation. Management-related factors usually refer to a lack of management for tools or techniques.

Various data collection techniques have been used to support construction productivity analysis such as: Time Study, Activity Sampling, Foremen delay survey and Craftsmen's questionnaire (Oglesby et al. 1989). Activity sampling is a method in which the data can be gathered not only fast and economically but also it allows the researcher to determine the desired levels of accuracy (Olomolaiye et al. 1998). It is a technique that measures the duration the labor spends in various activities (Thomas et al. 1991). Activity sampling study provides the required data to assess the time being employed by the labors, determine the problem area that leading delay of work, and maintain a standard measure for productivity improvement (Thomas et al. 1984). The main pros of adopting activity sampling is that it allows a huge number of labors to be assessed at one time. This results in a wider picture to record the efficiency of a specific activity than that resulted from a more concentrated but continuous study on a smaller group (Pilcher 1997). In construction industry, there are rules for using the activity sampling techniques such as (Oglesby et al. 2002): a) The observer must identify quickly to identify the labors to be included in and excluded from the sampling; b) The observer should exert same probability of observing every labor; c) No sequential relationship to be considered during the observation process; d) The basic fundamental of the activity must be the same as the normal conditions while the observations are being made.

Several prediction models have been developed to model and predict productivity based upon the considered factors for each model. The methodology used for the analysis depended mainly on the quantity and quality of data collected in addition to the type of data collected. Among the most widely used models is the Expectancy Theory Model which illustrates the variability in the performance by the effort that a labor is willing to make to an activity based on labor motivation. The Action Response Model is a qualitative model developed to represent how a variety of factors may interact to cause a productivity loss (Halligan et al. 1994). Regression Analysis also gained a good reputation in productivity estimation models due to its ability to unravel more about the relationships within the data being studied. Artificial Neural Network is also used whereas the connectivity between the Input, hidden and output layers is utilized to derive the relationship between productivity estimates and its independent variables.

3. RESEARCH METHODOLOGY

This research follows an inductive research approach as shown in Figure 1. The methodology starts with data collection using Activity sampling technique due to the numerous advantages stated in the literature review section. Once data is collected, linear and non-linear regression models are used to analyze the selected data and derive relationships between productivity and its independent. Data validation is carried out using different statistical techniques, moreover, sensitivity analysis is conducted to highlight the most influencing factors.

Figure 1 Research Methodology Process

The research scope of work will focus on studying the productivity of the major driving activities in the construction of an administrative building (Commercial Type) project as shown in Figure 2. The WBS is divided into several work packages; the Civil work package will be the focus of this research with focus on three main structural elements; columns, retaining walls, and, slabs.

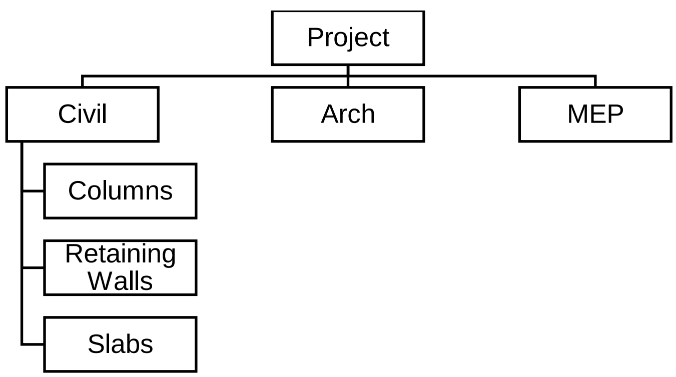

Figure 2 Research Scope WBS

4. CASE STUDY

The methodology was applied to a Fast-track commercial building project in Cairo, Egypt. The Project consists of mainly luxurious offices and various spacious areas (museum, conference halls, meeting rooms and VIP Areas). The Project built-up area is 65,000m2 and consists of Basement Floor, Ground Floor, and Three Repetitive Floors.

4.1 Data Collection

The Activity Sampling technique was selected as the main data collection tool in order to achieve the research objectives. The data collection process comprised the following steps;

- Frequent site visits were conducted to check the ongoing activities with the site staff;
- Staff to be included in the sampling were identified;
- Standard format for recording the observations as shown in Table 1 was prepared and distributed.

Accordingly, once the actual observations started, the following was done:

- All labors involved in the activity were clearly determined and their roles were precisely defined.
- Physical work measures were made and recorded on daily basis.
- Data outliers where removed from the collected data which was defined by all data having a value greater than one and half times the inner quartile range.

Table 1 Activity Sampling Format

S.N.	Activity name	Quantity installed	Occupation	# Labors
1	Columns Formwork		- Carpenters - Helpers	- ______ - ______
2	Columns Rebar		- Steel Fixers - Helpers	- ______ - ______
3	Columns Concrete Pouring		- Concrete - Labor	- ______ - ______
4	Slab Formwork		- Carpenters - Helpers	- ______ - ______
5	Slab Rebar		- Steel Fixers - Helpers	- ______ - ______
6	Slab Concrete Pouring		- Concrete - Labor	- ______ - ______
7	Cores Formwork		- Carpenters - Helpers	- ______ - ______
8	Cores Rebar		- Steel Fixers - Helpers	- ______ - ______
9	Cores Concrete Pouring		- Concrete - Labor	- ______ - ______

Data collection covered the main structural elements identified earlier. For each structural element, three construction activities are identified and assessed; formwork installation, rebar installation and concrete pouring. These activities were selected since they are the activities with the highest man-hours constituting approximately 34% of the total man-hours spent on this project based upon the data collected and presented in Table 2. The Slab Rebar Installation Activity is selected as the scope of this research paper. The Slab under construction type was a flat slab, with an average reinforcement diameter of 12 mm, and a slab height varying between 4 and 8 meters. 445 observations were collected for the rebar installation over the course of 3-month, sample data collection is shown in Figure 3. The maximum recorded productivity was 69 hrs/ton and the minimum recorded productivity reached 59 hrs/ton. From the literature review, numerous factors were identified to affect productivity for the selected type of work. The model only addressed factors observed as the most affecting and easily recorded factors. Therefore, for each observation, Weather, number of labors/m^2, height, and, % overtime were observed and recorded.

Table 2 Activities Man-hours Ratio

CSI Code	Activity Description	Man-Hrs
03 00 00	Columns Concrete Works	225,000
03 00 00	Retaining Walls Concrete Works	75,000
03 00 00	Slab Concrete Works	1,500,000
	Total Activities Man-hours	1,800,000
	Project Total Man-hours	5,300,000
	Ratio (Total Activities / Project Mhrs)	34%

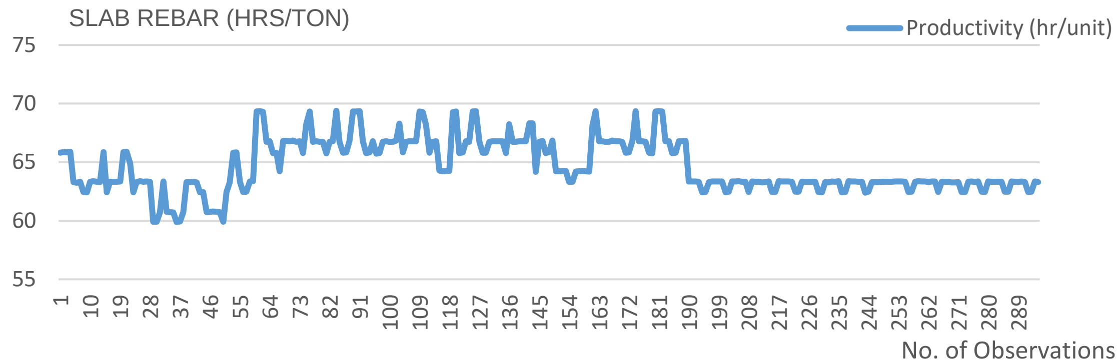

Figure 3 Slab Rebar Productivity

4.2 Data Analysis

The collected data quartiles are shown in Table (2) and illustrated in Figure 4. The box and whiskers plot demonstrations that the second quartile is within the value of 63.36 hrs/ton, which ensures that the data outliers where removed from the collected data. The outliers were assumed as all data greater than one and half times the inner quartile range. Data was analyzed using both linear and non-linear regression models.

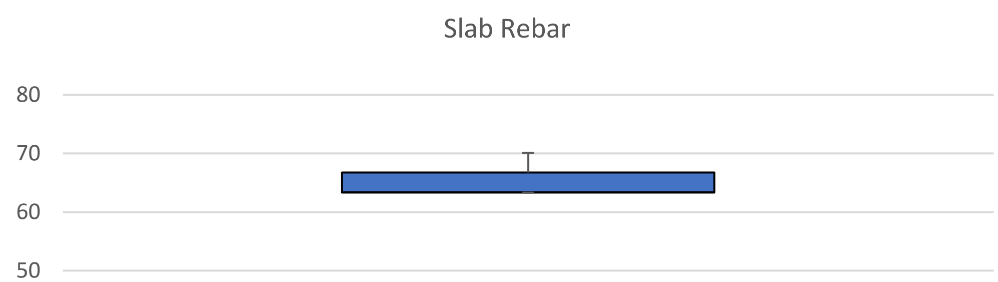

Figure 4 Slab Rebar Box and Whiskers

Table 3 Slab Rebar Data Quartiles

MIN	Q1	Q2	Q3	MAX	IQR
59.888268	63.30366	63.360882	66.7384284	69.391635	3.4347687

4.2.1 Linear Regression

Linear regression model was developed using ANOVA® software. The linear regression model of Rebar placement is shown in Equation (1):

[1] PR(SR)= a + H.Q + L.N + W.T + P.O

Where: PR(SR)= the calculated production rate for Slab Rebar in tons/hours; a =the regression constant; Q, N, T, O = regression coefficients; H, L, W, P = dependent variables (height, #labors, weather and percent overtime, respectively).

The regression statistics are given in Table 5, whereas Equation 2 shows the linear regression analysis equation using ANOVA®. The Adjusted $R^2 > 0.7$, which shows that the resulted equation has strong effect size. The liner regression model result shows that the height, weather, No of Labors/m^2 and % Overtime factors are inversely proportional to the Slab Rebar productivity.

[2] Slab Rebar Linear Productivity = 46.769315 + 0.8084551 **Heigh**t + 30.966189 **No. of Labors/m^2** + 0.4107892 **Weather** + 4.0250328 **Overtime%**

Table 4 Slab Rebar Linear Regression

Regression Statistics	
Multiple R	0.958637
R^2 Square	0.9189849
Adjusted R^2	0.9175881
Standard Error	0.6699561
Observations	237

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	4	1181.199	295.2999	657.91627	2.66E-125	
Residual	232	104.1311	0.448841			
Total	236	1285.330				
	Coefficients	*Stand. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	46.769315	0.816576	57.27490	6.915E-139	45.160463	48.378
Height (m)	0.8084551	0.022528	35.88607	1.1572E-96	0.7640687	0.8528
# Labors/m^2	30.966189	19.93095	1.553673	0.1216254	-8.302607	70.234
Weather (°C)	0.4107892	0.015221	26.98681	1.6452E-73	0.3807985	0.4407
%Overtime	4.0250328	0.396164	10.16000	2.6786E-20	3.244493	4.8055

4.2.2 Non-Linear Regression

Non- linear (NL) regression model was also developed to investigate the possibility of a non-linear relationship between variables. Height, number of labors, temperature and Overtime Percentage were the factors selected for modeling. The identified non-linear relationship against the productivity was plotted by using Curve Expert Professional® software. The regression statistics are presented in Table 6 and Equation 3. The adjusted R^2 is greater than 0.7, indicating the resulting equation has strong effect size. The non-liner regression model result shows that the height, weather, and, number of Labors/m^2 and % Overtime factors are inversely proportional to the Slab Rebar productivity.

Table 5 Slab Rebar Non-Linear Regression

Regression Statistics	
Multiple R	0.955801
R^2	0.913556
Adjusted R^2	0.912066
Standard Error	0.69204
Observations	237

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*	
Regression	4	1174.22176	293.555	612.954	4.9037E-122	
Residual	232	111.109155	0.47891			
Total	236	1285.33091				
	Coefficients	*Stand. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-112.203	16.6552047	-6.73683	1.26E-10	-145.0180172	-79.3885
Height (m)	0.813384	0.02571683	31.6284	4.31E-86	0.762715176	0.86405
No. of Labors / m^2	0.126161	0.23157394	0.54479	0.58641	-0.330095915	0.58241
Weather (°Celsius)	0.742221	0.02871781	25.8453	3.08E-70	0.68564028	0.79880
%Overtime	1.044386	0.10798598	9.67149	8.32E-19	0.831627793	1.25714

[3] Slab Rebar (NL) Productivity = -112.203 + {0.813384 (88.87* Exp(**Height**/23.69))} + {0.126161 (1/(0.00945+(8E-10*(**No. of Labors/m^2** ^4.29)))} + {0.742221 (3.7E+11*(1.203^ **Weather**)+(**Weather** ^-6.071)}+ {1.044386 *(91.66*((**Overtime%**-0.149)^-0.0387) }

4.3 Data Validation

The data validation for the linear regression model was done by using Equation 2 as a prediction model and substituting 20% of the collected data in the Equation 2. The result of the linear regression data validation is illustrated in Figure 5. The predicted productivity had a %error of -0.55% and a mean square error of 0.17. the original productivity versus the predicted productivity is plotted in Figure 5. Where the difference between the actual and predicted productivities is almost negligible.

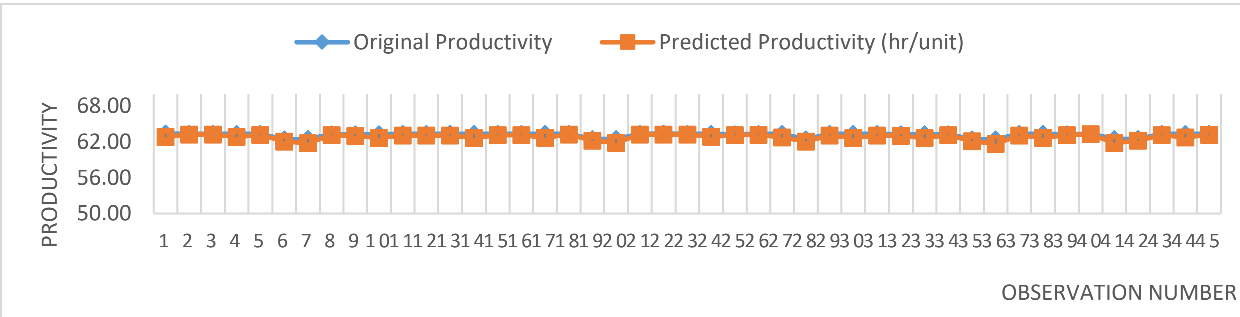

Figure 5 Linear Regression Data Validation

The data validation for the non-linear regression model used the same methodology by using Equation 3 as a prediction model and substituting 20% of the data into the model to obtain the expected predicted productivity. This resulted in a highly correlated predicted productivity with error of -0.77% and a means square error value of 0.31 as presented in Table 7. The original productivity versus the predicted productivity is plotted in Figure 6, as observed, the two probability estimate figures are very close.

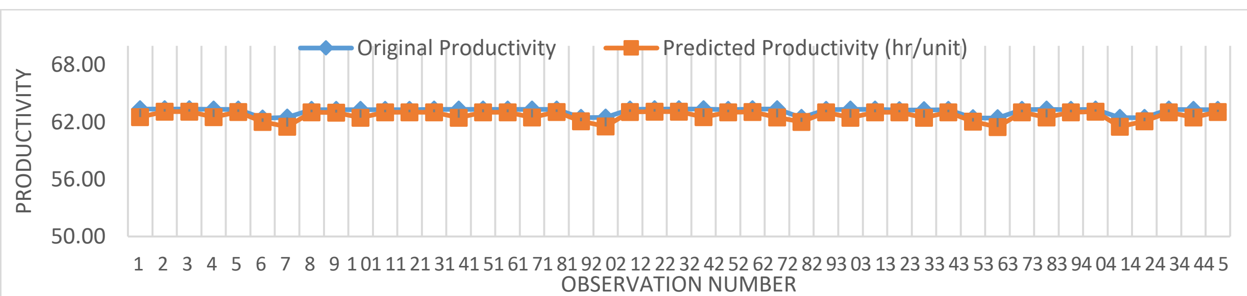

Figure 6 Slab Rebar Non-Linear Regression Data Validation

The data validation results for the Slab Rebar are shown in Table 7. While the two models had high correlation and very low error, based upon the data presented in Table 7, the linear regression model is the most preferable model according to the least root mean square error (RMSE) value.

Table 6 Slab Rebar Validation Results

Prediction Model	Avg. Actual Productivity	Avg. Predicted Productivity	Error%	MSE	RMSE
Linear Regression	63.15319398	62.80298508	-0.55%	0.17	0.41
Non-Linear Regression	63.15319398	62.66920761	-0.77%	0.31	0.56

4.4 Sensitivity Analysis

Sensitivity analysis was conducted for the selected model (Linear Regression Model). Results are presented in Table 8, the results indicate the Weather factor is the most leading factor to the productivity values, while the No. of Labors/m^2 is the least factor having impact on the productivity values. This complies with the fact that rebar placement is an external activity and largely affected with the weather conditions. Moreover, in case of non-favorable weather conditions, the productivity is expected to significantly drop.

Table 7 Slab Rebar Sensitivity Analysis Result

FACTOR	MIN_PROD	MAX_PROD	RANGE
Height	63.88	66.31	2.43
No. of Labors	63.02	63.27	0.24
Weather	60.63	68.02	7.39
%Overtime	62.31	63.03	0.72

4.5 Data Findings

Model validation was done through comparing the computed productivity against different national and international productivity measure to arrive at a conclusion on how the model developed can be used to optimize productivity.

Productivity data for similar types of work was compared against three sources

a. Productivity Data obtained for three ongoing construction projects with similar activities,
b. Productivity estimates used in tender and planning phase for two leading construction firms in Egypt,
c. RS-Means.

The average deviation between the predicted productivity and similar projects productivity was calculated at 16%. This deviation is acceptable given that every project is unique and that the model only considers 4 variables. The deviation between predicted and tender productivity was calculated at 6%. However, the deviation between the predicted productivity and the RS means was calculated at 47%. While this value is large and might raise a lot of questions, it is understandable since the RS means are not formulated towards the Egyptian environment and are considered very optimistic with respect to the actual productivity measures.

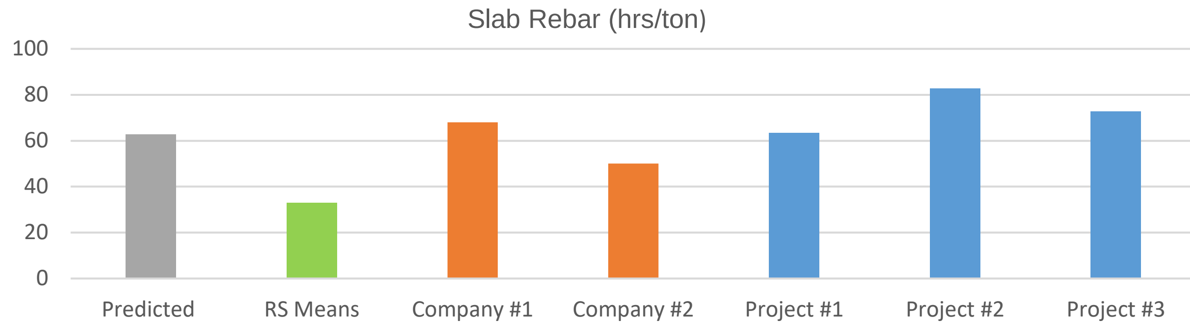

Figure 7 Slab Rebar Productivity Comparison

5 CONCLUSION & LESSONS LEARNED

Labor cost comprises 30% to 50% of an overall project's cost. Accordingly, labor productivity rates for the construction work of a project should be calculated at high accuracy to facilitate the overall total cost calculations. Most contractors in Egypt rely on experienced project managers or in-house data to estimate the manpower and productivity of the project. There are no unified publications to estimate productivity given the Egyptian working environment and construction methods; this inevitably results in inaccurate output and consequently time and cost overruns. This research uses data sampling to gather actual productivity measures in the construction site for different types of activities. Activities comprising the highest labor hours from the overall project manhours were selected for further investigation. The research conducts an extensive data gathering for the selected activities, the data is then analyzed using linear and non-linear regression models. Factors most pertaining to the working environment are considered as independent variables for the analysis model. 450 observations were collected for the activity of rebar installation for a flat slab. Both models revealed an inversely proportional relationship between productivity and the four selected variables (height, weather, %overtime, and #labors/m^2). Sensitivity analysis was conducted to assess the sensitivity of the dependent variable to the four independent variables. It was concluded the weather had the highest effect on the productivity whereas the #labors/m^2 had the lowest effect. This complies with the nature of the activity being an outdoor activity heavily affected by the weather conditions. Moreover, the model findings were compared against national measured and tender productivity measures and international productivity measures (RS Means). It was shown that the productivity during the tendering phase is usually underestimated from the actual productivity by average 6% deviation. While, the actual productivity varies from the international standards by average 45-50% deviation. This shows that the RS-means standard rates are far away and inapplicable to the Egyptian construction industry. Which further highlights the need of national productivity estimates in order to benchmark and predict the project productivity before the project start. The data gathering and analysis methodology presented is generic, whereas the research findings are regional due to the persistent need for reginal-based productivity measures. This is believed to assist in controlling the labors productivity in earlier phases to avoid cost overrun.

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