Predicting the Production Rate of Pouring Ready Mixed Concrete Using Regression Analysis

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***Abstract*-Ready mixed concrete (RMC) placing is an important operation on construction projects in many countries. This is particularly true as in Egypt high- rise buildings construction increased in the building industry, many of these buildings are still constructed using the traditional method of in-site concrete placing. Concrete must be batched remotely and delivered to sites by truck mixers Therefore, the production rate of Pouring Ready Mixed Concrete (PRMC) could be considered as great importance to improve the productivity of the whole construction industry in Egypt. The aim of this paper is to build a new regression model using correlation analysis method for predicting the production rate of PRMC using tower cranes. The model building was based on a close observation of 418 pours cycles from ten different construction building sites for the pouring concrete in columns, slabs, and beams, each from the beginning to end operation. In addition, it studied the factors affecting the production rate of PRMC using tower cranes. The results of the model implementation in concrete placing for columns, slabs and beams presented an average percentage error value of 2.8197%.**

Keywords- Multiple Linear Regression; Tower Cranes; Production Rate; Pouring Ready Mixed Concrete (PRMC)

I. INTRODUCTION

The construction sector is a major contributor to the Egyptian economy and one of its fastest-growing sectors. This growth, estimated at an average of 20 to 22 percent annually since the 1980s, is fuelled by the ever-increasing demand for housing and by the state's large infrastructure projects. The construction industry is expected to continue its upward trend in the coming years as a result of continued government and private business expenditure, anticipated to reach 20 billion Egyptian pounds annually [1]. Concrete is used more than any other man-made material to make dams, parking lots, building structures, roads, pavements, and more. Therefore, to manage a construction project effectively, it is essential to control concrete pouring production rate.

Accordingly, pouring concrete could be considered as one of the most critical activity in the construction site. For this purpose, it is necessary to develop a model to ensure effective management of construction projects to guide the planners and estimators in the planning phase to maximize project productivity and forecast activity durations to achieve lower cost and shorter project duration. The concrete placing process could be explained as shown in Fig. 1. The system can be treated as a single server queuing system and for this paper the method of concrete placement will be using tower crane and skip method, which is a very common method commonly used for high-rise buildings since it allows the integration of horizontal and vertical transportation and provides flexibility of access for concrete anywhere on work floors and does not require the pipe line with stationary pumps.

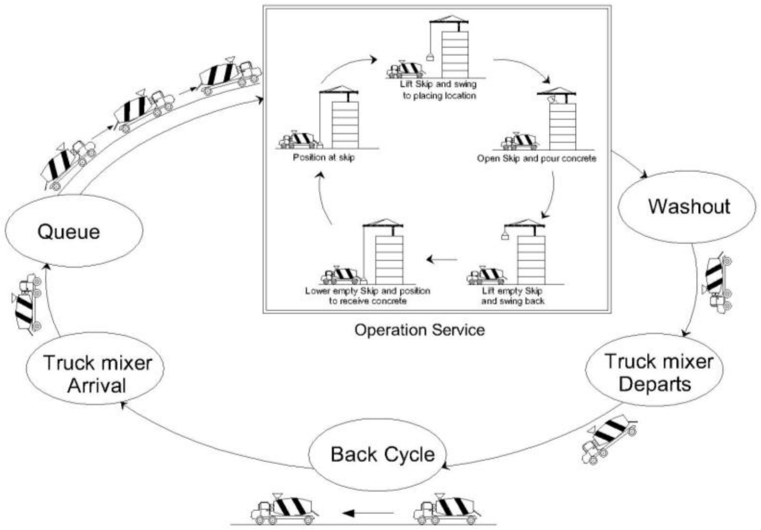

Fig. 1 Plan diagram of concrete placing cycle using tower cranes and skip method

In the concrete placing process, as concrete truck mixers arrive, they will join the service (if there are no other truck mixers in the queue to be served) or join the back of the queue of waiting truck mixers. Service requires the truck mixer manoeuvring in to position then discharging the concrete in to the skip bucket, after that Lift bucket and Swing to pouring location, then Lower skip bucket and Position to discharge concrete in the required element formwork (columns or slabs and beams), which next opens bucket and pour concrete in the required pouring element formwork. Subsequently, the empty bucket is lifted and swung back, and finally the empty bucket is lowered and positioned to receive concrete again until the whole pouring concrete operation is finished.

In an ideal system, the rate at which trucks arrive, are positioned and have their concrete placed would be constant, but unfortunately this could not be achieved in practically as there are a lot of factors that affect production rate of Pouring Ready Mixed Concrete (PRMC) operation. Through site observation, it could be mentioned that a lot of problems happened between site engineers at construction projects related to different usage of tower cranes. For example, in concrete placing, the crane is temporarily engaged in non concreting activities which means that the crane cannot serve other activities needs until the concrete placing activity is finished. Therefore, the prediction of pouring concrete production rate using tower cranes is worthy of study and is critical in formulating a realistic cranes schedule at construction projects. In addition, to help the estimators and planners in estimating the production rate of pouring ready mixed concrete which could affect time planning and scheduling of the project. In planning and scheduling, it is important for maximizing project productivity and forecast activity durations (specially pouring concrete activity) to minimize the cost and the project duration. It is important to predict projects costs in estimating the planning and scheduling process, if the estimate is too low, a company may lose money in the execution of the project. On the other hand, if the estimate is high, the company may lose the contract due to overpricing. Therefore, it is important to develop a model for giving an expert opinion to predict the production rate of PRMC using the factors that identified in this research in order to help planners and estimators to improve the accuracy of the production rate estimate in the future which affects the project productivity.

II. FACTORS AFFECTING POURING READY MIXED CONCRETE (PRMC)

Many researchers have already identified, investigated, and recognized the factors affecting PRMC. For example, Alinaitwe et al. [2] studied the factors affecting the productivity of construction building, through a survey carried out by a questionnaire and received responses. The results of the survey presented that lack of skills from the workers, lack of tools/equipment, poor construction methods, poor communication, lack of materials, weather conditions, poor site conditions, and accidents at work sites were among the most important factors affecting productivity in Uganda.

Moreover, Abdel Fattah and Ruwanpura [3] mentioned that the duration of concrete pouring operation depends on the following factors: number of concrete trucks, concrete trucks capacity, and number of batch planets available, batch plant capacity, and distance between the construction site and the concrete batch plant. Graham et al. [4] mentioned that type of operation (construction building element), truck volume (capacity), total operation volume, average inter arrival time based on batch plant location from the site, number of loads in operation, and the workability of the RMC using slump test are essential factors that influence the productivity of PRMC operation. In addition, Abd et al. [5] mentioned that factors such as planning, scheduling, quality control, worker’s ability and skills, motivation, and organization can improve the productivity for construction projects. Other researchers like Tam et al. [6] used stop watch technique to measure the hoisting times of tower cranes in construction sites, in order to identify the factors affecting cranes lifting operations. Data were collected from seven public housing projects in Hong Kong. In addition, Dunlop and Smith [7] mentioned that in concrete operations, unanticipated conditions and actions can result in a loss of productivity, factors like distance between batching plant and site, site characteristics, weather, truck mixers capacity, and truck mixers availability could be considered to influence the output in concrete operations. The factors were identified and classified into six groups: 1) Crane movements, which include: hoisting height, angular movement, and radial movement, 2) crane capacity, 3) skill of operators, 4) nature of load, which include weight, length, area similarly, hoisting orientation, 5) location of load include, loading point, unloading point, and 6) weather. Plus, Anson and Wang [8] mentioned that concrete placing productivity was influenced by many factors; the placing method is a major determinant of the speed of placing, but the shape of the pouring and its location are technical factors that also influence productivity. Besides, Sonmza and Rawings [9] found in their research that quantity, crew size, temperature, overtime, job type, and concrete pump were selected as the factors that may influence productivity for concrete pouring in the construction projects.

Table 1 below presented a list of the factors affecting the pouring ready mixed concrete using tower cranes and their related references based on the literature review.

TABLE 1 FACTORS AFFECTING PRMC BY USING TOWER CRANES

Factors (independent variables)	**Related References**
(1) Method of construction (pouring)	Ansonand Wang, 1998; Wang et al., 2001
(2) Type of project	Mohammed, 1996; Sonmez and Rowings,1998
(3) Building element	Mohammed, 1996; Proverbs et al., 1999 ; Graham et al. (2006)
(4) Project location	Abd-El-Razek, 2004b; Lu and Anson, 2004

(5) Pouring level (height)	Tam et al., 2002; Lu and Anson, 2004
(6) Equipment efficiency	Abd -El-Razek, 2004b
(7) Time planning and scheduling	Mohammed, 1996; Wang et al., 2001; Abd et al. (2008)
Quality control (8) Concrete temperature (9) Concrete slump (10) Concrete compressive strength	Lu and Anson, 2004; Abd -El-Razek, 2004b ;Graham et al. (2006)
(11) Degree of supervision	Mohammed, 1996; Proverbs et al., 1999
(12) Project organization and communication	Mohammed, 1996
(13) Site layout	Mohammed, 1996; Lu and Anson, 2004
(14) Availability of materials (RMC)	Mohammed, 1996; Choy and Ruwanpura, 2006
(15) Driver's skills	Tam et al., 2002
(16) Crew size for concrete operation	Mohammed, 1996; Sonmez and Rowings,1998; Wang et al., 2001
(17) No. of labour in each crew	Wang et al., 2001
(18) Labour's skills	Mohammed, 1996; Abd -El-Razek, 2004b; Ansonand Wang, 1998; Proverbs et al., 1999
(19) Carpenters and form-workers' performance	Pilot study
(20) Motivation	Mohammed, 1996
(21) Over time	Sonmza and Rawings, 1998
(22) Application of safety and health regulation	Mohammed, 1996
Weather conditions (23) Temperature (24) Humidity (25) Stopping due to rain	Mohammed, 1996; Sonmza and Rawings, 1998; Tam et al., 2002; Abd-El-Razek, 2004b; Choy and Ruwanpura, 2006
(26) Skip size	Pilot study
(27) No. of tower cranes used	Pilot study
(28) Type of tower crane used	Pilot study
(29)Tower crane capacity	Tam et al., 2002
(30)Tower crane working radius	Tam et al., 2002
(31) Location of batch plant	Christian and Hachey, 1995; Ansonand Wang, 1998; Feng et al., 2004; Silva and Ruwanpura, 2006; Choy and Ruwanpura, 2006
(32) Batch plant capacity	Abdel Fattah and Ruwanpura (2008)
(33) No. of batch plant used	Tang et al., 2005
(34) Truck mixer capacity	Feng et al., 2004
(35) No. of truck mixer used	Wang et al., 2001; Feng et al., 2004
(36) Pouring concrete quantity (pouring size)	Sonmza and Rawings, 1998; Wang et al., 2001

III. OBJECTIVES OF THE RESEARCH

The primary goal of this research is to develop a quantitative model (regression model) for predicting the production rate of PRMC using tower cranes for building construction projects. Consequently, the predicted production rates enable site planners and construction managers to plan and assess the duration of crane-related activities.

As stated earlier, the production rate of PRMC in construction projects is affected by several factors and the accuracy of estimate could be challenged when effect of multiple factors is considered simultaneously. In addition, the pouring concrete operation is considered as a critical activity at construction projects which affect the duration of the project. The increases in the project duration (related to any delays in pouring concrete activity) have negative effects on the project cost, as that time delays usually equal cost over runs. For this reason, developing the regression model to predict production rate of PRMC can assist planners and estimators to reduce the effort required to plan the construction operation and to improve the accuracy of production rate estimate to complete a project within budget and schedule.

There are three main objectives in developing the quantitative model. They are:

1) To examine and discover the variables for predicting production rate of PRMC using tower cranes.
2) Test the correlation between these variables as independent variables and the production rate variable as dependent variable using correlation analysis
3) To enable site planners to use the model to predict the production rate with reasonable accuracy.

IV. METHODOLOGY

The researcher performed a field study observation, by observing pouring concrete operations for a total of 418 concrete operation cycles of pouring slabs, beams, columns, and walls at ten residential and commercial construction projects in Cairo and Alexandria - Egypt (as shown in Table 2), in order to collect the required data to use them as input variables for building the model. These projects were selected because they used tower cranes extensively on pouring concrete activities. In addition, Cairo and Alexandria were chosen for being the mega cities with the largest concentration of construction sites in Egypt. The observation started with a questionnaire survey based on comprehensive literature review to identify the most important factors affecting pouring concrete and to get a link channel with site engineers and project managers. Then, the researcher established an oral discussion with site engineers and pouring concrete supervisors to explain the purpose of the observation, mutually with a confirmation of confidentiality regarding observed data, to establish trust between the respondents and the researcher. After that, the researcher used written descriptions, photographs and informal discussions to collect data through observation, regarding to schedule of pouring concrete operations at each project. In the written descriptions, the researcher recorded observations by taking notes for production rate of pouring concrete and the factors affecting it mean while taking some photographs for pouring concrete operation. Moreover, the researcher did informal discussions with site engineers to confirm the observations records. These observations provided 418 production rate of PRMC as a dependent variable based on 36 independent variables data based.

TABLE 2 CHARACTERISTICS AND CLASSIFICATIONS OF THE STUDIED PROJECTS

Project Number	Project Name	Project Description	Project Location	Numbers of Observed Concrete Pours	Average Concrete Pouring Size (m^3)
1.	Ceramica Cleopatra Plaza	Private residential and commercial project including construction of three adjoining reinforced concrete blocks each consisted of two basement structure and seventeen typical floors serviced by two tower cranes with 45m working radius for each and different capacities of 2 ton and 2.5 ton at the end of crane jib.	Alexandria	65	36.5
2.	Talaat *Moustafa* Tower	Government residential building project including site formation, foundation system with two basement structure, and construction of eight adjoining reinforced concrete blocks each thirteen typical floor serviced by two tower cranes with different working radius 45m,50m and different capacities of 2 ton and 2.5 ton at the end of crane jib.	Alexandria	61	38.78
3.	San Stefano Building Project	Private residential and commercial project including site formation, foundation system comprised of piles and diaphragm walls, three typical basement structure, and construction of two main reinforced concrete blocks each twenty typical floors serviced by four tower cranes with different working radius 55m, 60m and different capacities of 4ton, 6ton at the end of the crane jib.	Alexandria	40	33.87
4-	Borg El Arab International Airport	Government commercial project consists of an airfield, passenger terminal building, and an administration building. The airfield consists of a runway and two parallel taxiing lanes. The passenger terminal consists of four floors and four movable boarding bridges to connect the terminal building to aircraft. The project serviced by three tower cranes with different working radius 55m, 60m and different capacities of 1.6ton, 2.5ton at the end of the crane jib.	Alexandria	29	38.48
5-	El-Haras El-Gomhory Complex (Republican Guard Complex)	Government residential project including site formation, foundation system comprised reinforced concrete raft and one basement structure, and construction of eight residential blocks each fourteen typical floor, serviced by four tower cranes with different working radius 45m, 60m and different capacities of 2.5ton, 3ton.	Cairo	67	41.31
6-	Cairo Financial Center	Private commercial project including site formation and construction of nine adjoining reinforced concrete blocks with twelve typical floors serviced by seven tower cranes with different working radius 40m,50m,60m and different capacities of 3ton, 3.5ton at the end of the crane jib.	Cairo	64	35.1
7-	Bank BNP Paribas	private commercial development project including construction of three adjoining reinforced concrete blocks each one consists one basement structure and eight typical floors serviced by two tower cranes with 60m working radius each and 3ton capacity at the end of the crane jib.	Cairo	27	32.7
8-	Housing and Development Tower	Government residential and commercial project including construction of a reinforced concrete building with eleven typical floors and serviced by one tower crane with 65m working radius and capacity of 2.8 ton at the end of the crane jib.	Cairo	35	29.23
9-	Arab Contractors Hospital	Government commercial project including construction of a reinforced concrete building with one basement and nine typical floors serviced by one tower crane with 50m working radius and capacity of 3ton at the end of the crane jib.	Cairo	30	26.13
10-	Meridian Extension Hotel	Commercial project including foundation and construction of a reinforced concrete building with two basement and seven typical floors serviced by one tower crane with 40m working radius and capacity of 3 ton at the end of the crane jib.	Cairo	28	40.32

The researcher used the correlation matrix to obtain the variables significantly correlated with the dependent variable “R”. Then get the regression models for the variables obtained using *enter* method as defined in Statistical Package for the Social Sciences (SPSS) Program.

Accordingly, linear regression is used in this research because there is a strong reason to assume a linear relation between the dependent variable (production rate) and the independent variables (factors) as shown in Fig. 2 below which presents the linear relation between production rate (R) and some selected factors like Pouring Level (Q5), Time planning and scheduling (Q7), Project Communication (Q12), Pouring size (Q36).

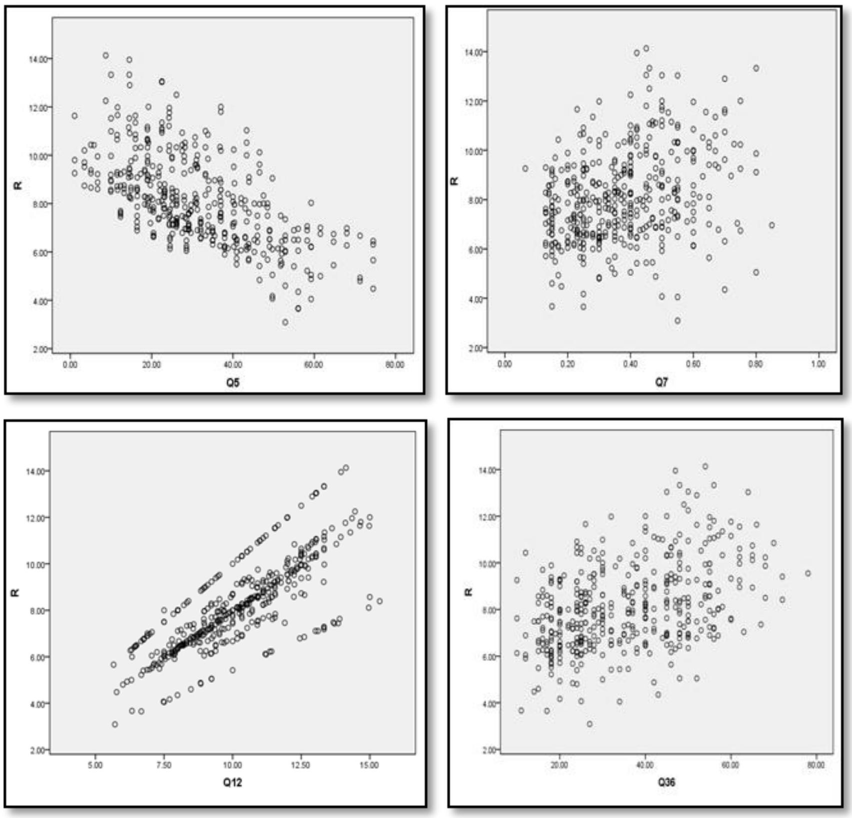

Fig. 2 Linear relation between the dependent variable (production rate (R)) and some selected independent variables (factors)

In order to insure that the regression model explained well the data observed the following assumptions should be tested:

1) *Tests for Multicollinearity:*

Multicollinearity is present whenever an independent variable is highly correlated with the other independent variables in a multiple regression equation. Such high correlations cause problems when trying to draw inferences about the relative contribution of each predictor variable to the success of the model [10]. But multicollinearity is a problem in the multiple regression models because the partial regression coefficient for any collinear variables is highly unstable [11]. Also, Kim et al. [12] mentioned that a correlation analysis application is important to confirm that the factors considered at any research are not significantly related to each other. If the correlation between factors is over 0.8, this may be an indication of multicollinearity. Besides, according to Montgomery and Runger [13], the variance inflation factor (VIF), provides a measure of how much the variance for a given regression coefficient is increased compared to the case when all predictors are uncorrelated. They add that if any VIF exceeds 10, then multicollinearity is a problem.

2) *Tests for Normality of Residuals:*

One of the assumptions of linear regression analysis is that the residuals are normally distributed. It is important to meet this assumption for the p-values of the t-tests to be valid [14]. To check for meeting the assumption that the residuals or error terms are normally distributed, the researcher looks at the Normal P-P Plot of Regression Standardized Residual. The criteria for normal distribution are the degree to which the plots for the actual values of expected values are close to each other.

3) *Tests for Issues of Independence (Auto-correlation):*

The statement of this assumption is that the errors associated with one observation are not correlated with the errors of any other observation. Violation of this assumption can occur in a variety of situations. When you have data that can be considered to be time-series you can use the Durbin-Watson statistic to test for correlated residuals (autocorrelation). The Durbin-Watson statistic has a range from 0 to 4 with a midpoint of 2. If the observed value is less than 2, or close to 2 this means that the errors associated with one observation are not correlated with the errors of any other observation. On the other hand, having the observed value close to 0 indicates a strong positive correlation, while a value close to 4 indicates a strong negative correlation [14].

4) Tests for Heteroscedasticity:

Another assumption of liner regression is that the variance of the residuals is homogeneous across levels of the predicted values, also known as homogeneity of variance (homoscedasticity) - the errorvariance should be constant. If the model is well-fitted, there should be no pattern to the residuals plotted against the fitted values. If the variance of the residuals is non-constant, then the residual variance is said to be “heteroscedastic” [14].

V. VARIABLES IN CONCRETE OPERATION USING TOWER CRANE AND SKIP METHOD

This research aims to establish and construct a multiple regression model to predict the production rate of PRMC using tower cranes. A total of 36 factors (independent variables) were considered to influence the production rate from literature review as shown in Table 1.

Method of pouring (Q1) as a qualitative method which was measured by tower crane and skip in this research.

Type of project (Q2) as a qualitative method which was measured by selecting from residential, commercial, or both.

Building Element (Q3) as a qualitative method which was measured by selecting from columns, walls, slabs and beams.

Pouring Location (Q4) as a qualitative method which was measured by selecting from urban, rural, and city.

Pouring Level (Q5) as a quantitative method which was measured by meter height from site plans and drawings.

Equipment efficiency (Q6) as a quantitative method which was measured as a ratio of the Actual Production Rate to Expected Production Rate, related to any stoppage in the equipment during pouring concrete.

Time planning and scheduling (Q7) as a quantitative method which was measured by hours, calculated by: (Time for start pouring concrete – Time for truck mixers arrival at site) * Numbers of trucks.

Concrete temperature (Q8) as a quantitative method which was measured by C °from site observation and records.

Concrete slump (Q9) as a quantitative method which was measured by Cm from site observation and records.

Compressive strength (Q10) as a quantitative method which was measured by Kg/cm^2.

Degree of supervision (Q11) as a quantitative method which was measured as a ratio of the No. of site engineers to the total area of the project (m^2).

Project Communication (Q12) as a quantitative method which was measured by skip/time (hr), related to frequency of the pouring operation.

Site layout (Q13) as a quantitative method which was measured by area available for pouring concrete / total area of the project, related to space management capability during concrete operation.

Waiting time for (RMC) (Q14) as a quantitative method which was measured by Hour related to any stoppage in placing operation waiting for concrete arrival.

Driver’s skill (Q15) as a quantitative method which was measured by experience years.

Number of crews (Q16) as a quantitative method which was measured by number from site observation.

Number of workers/Crew (Q17) as a quantitative method which was measured by Number / Crew from site observation.

Labour’s skill (Q18) as a quantitative method which was measured by experience years.

Carpenters and form-workers performance (Q19) as a quantitative method which was measured by experience years.

Motivation (Q20) as a quantitative method which was measured by Index 1 to 100, according to site observation.

Overtime (Q21) as a quantitative method which was measured by hour.

Application of safety (Q22) as a quantitative method which was measured by Index 1 to 100, according to site observation.

Temperature (Q23) as a quantitative method which was measured by C °from Egypt observatory.

Humidity (Q24) as a quantitative method which was measured by Percentage % from Egypt observatory.

Stopping due to Rain (Q25) as a quantitative method which was measured by hours from site observation.

Skip Size (Q26) as a quantitative method which was measured by m3 from site data.

No. of tower cranes (Q27) as a quantitative method which was measured as a ratio of the Total area of the project to the Number of cranes covering this area.

Type of tower crane (Q28) as a qualitative method which was measured by selecting from Luffing boom, Horizontal boom, Fixed position, Climbing crane, and Rail mounted crane.

Tower crane capacity (Q29) as a quantitative method which was measured by Ton obtained from crane technical data.

Tower crane working radius (Q30) as a quantitative method which was measured by Meter obtained from crane technical data.

Location of batch plant (Q31) as a quantitative method which was measured by Km related to the distance between batch plant and construction site.

Batch plant capacity (Q32) as a quantitative method which was measured by m^3/ hr obtained from batch plant technical data.

No. of batch plant used (Q33) as a quantitative method which was measured by Number.

Truck mixers capacity (Q34) as a quantitative method which was measured by m^3 from the following equation: equivalent truck mixer capacity = (number of trucks*capacity)/total number of trucks.

No. of truck mixers used (Q35) as a quantitative method which was measured by Number.

Pouring size (Q36) as a quantitative method which was measured by m^3.

Actual production rate (m^3/hour), as a dependent variable measured by [total volume of the pouring (m^3) divided by the total pouring time (hr)].

VI. REGRESSION MODEL FOR PRODUCTION RATE OF PRMC

A. Correlation Analysis

Through which the researcher used the correlation matrix to obtain the variables significantly correlated with the dependent variable “R”(production rate) using *Pearson product-moment correlation coefficient* (Correlation coefficient) to find the degree of the association of two sets of variables [15, 16]. It is also a measure that determines the degree to which two variable’s movements are associated. The *correlation coefficient* varies from -1 to +1. Negative one (-1) indicates perfect negative correlation, while positive one (+1) indicates perfect positive correlation. A correlation coefficient of zero means that the two numbers are not related. A non-zero correlation coefficient means that the numbers are related. The closer the correlation coefficient is to zero the lower the correlation, and low correlation coefficients means that the relationship is not certain enough to be useful and vice versa [17, 18]. Based on correlation matrices (Tables 3-7), it could be observed that there are correlations between independent variables (factors affecting production rate of PRMC) and the dependent variable R (production rate). Independent Variables as Q3, Q4, Q5, Q6, Q7, Q12, Q13, Q14, Q15, Q17, Q26, Q28B, Q31, Q32, Q34, Q35, and Q36 presents a correlation significant at level 0.01 with the dependent variable, other independent variables as Q9, Q30 presents a correlation significant at level 0.05 with the dependent variable, while there are some independent variables that have no significant correlation with R. However regression model could be built to test the effect of all independent variables on dependent variable (R).The correlations between the variables mentioned were checked as well to observe if multicollinearity may arise. Multicollinearity is present whenever an independent variable is highly correlated with the other independent variables in a multiple regression equation. Such high correlations cause problems when trying to draw inferences about the relative contribution of each predictor variable to the success of the model [10]. Kim et al. [12] mentioned that a correlation analysis application is important to confirm that the factors considered at any research are not significantly related to each other. If the correlation between factors is over 0.8, this may be an indication of multicollinearity.

As it can be seen the correlation analysis was conducted to confirm that factors are not significantly related to each other, as that the correlation between factors is less than 0.85, this may be an indication that multicollinearity is not presented as shown in Tables 3-7. The correlation between pairs of variables can be seen from those tables, and found that all the correlation coefficients are less than 0.85 which means that the variables are not strongly correlated to each other and multicollinearity is not found. Also, when considering the above mentioned variables, it was found that for some variables and values were difficult to collect. So, the Motivation (Q20) and Application of Safety (Q22) variables were excluded due to lack of reliable data required for them from the construction sites.

TABLE 3 CORRELATIONS (1)

		R	Q2	Q3	Q4	Q5	Q6
R	Pearson Correlation	1	0.078	.340**	-.151**	-.606**	.389**
	Sig. (2-tailed)		0.113	0	0.002	0	0
	N	418	418	418	418	418	418
Q2	Pearson Correlation	0.078	1	0.003	.220**	.338**	-.138**
	Sig. (2-tailed)	0.113		0.948	0	0	0.005
	N	418	418	418	418	418	418
Q3	Pearson Correlation	.340**	0.003	1	.110*	0.073	.159**
	Sig. (2-tailed)	0	0.948		0.024	0.134	0.001
	N	418	418	418	418	418	418
Q4	Pearson Correlation	-.151**	.220**	.110*	1	.561**	-0.029
	Sig. (2-tailed)	0.002	0	0.024		0	0.557
	N	418	418	418	418	418	418
Q5	Pearson Correlation	-.606**	.338**	0.073	.561**	1	-.162**
	Sig. (2-tailed)	0	0	0.134	0		0.001
	N	418	418	418	418	418	418
Q6	Pearson Correlation	.389**	-.138**	.159**	-0.029	-.162**	1
	Sig. (2-tailed)	0	0.005	0.001	0.557	0.001	
	N	418	418	418	418	418	418

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 4 CORRELATIONS (2)

		R	Q7	Q8	Q9	Q10
R	Pearson Correlation	1	.309**	-0.058	-.096*	0.076
	Sig. (2-tailed)		0	0.239	0.049	0.122
	N	418	418	418	418	418
Q7	Pearson Correlation	.309**	1	0.004	0.033	-.429**
	Sig. (2-tailed)	0		0.93	0.503	0
	N	418	418	418	418	418
Q8	Pearson Correlation	-0.058	0.004	1	.329**	0.07
	Sig. (2-tailed)	0.239	0.93		0	0.152
	N	418	418	418	418	418
Q9	Pearson Correlation	-.096*	0.033	.329**	1	-.173**
	Sig. (2-tailed)	0.049	0.503	0		0
	N	418	418	418	418	418
Q10	Pearson Correlation	0.076	-.429**	0.07	-.173**	1
	Sig. (2-tailed)	0.122	0	0.152	0	
	N	418	418	418	418	418

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 5 CORRELATIONS (3)

		R	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19
R	Pearson Correlation	1	.051	.779**	.128**	.139**	.199**	-.071	.395**	.009	.055
	Sig. (2-tailed)		.294	.000	.009	.004	.000	.148	.000	.850	.259
	N	418	418	418	418	418	418	418	418	418	418
Q11	Pearson Correlation	.051	1	.297**	.031	.157**	-.276**	.055	-.043	-.387**	-.140**

	Sig. (2-tailed)	.294		.000	.530	.001	.000	.260	.377	.000	.004
	N	418	418	418	418	418	418	418	418	418	418
Q12	Pearson Correlation	.779**	.297**	1	.119*	.244**	-.043	.017	.318**	-.253**	-.080
	Sig. (2-tailed)	.000	.000		.015	.000	.385	.728	.000	.000	.104
	N	418	418	418	418	418	418	418	418	418	418
Q13	Pearson Correlation	.128**	.031	.119*	1	-.199**	.112*	-.108*	.177**	.226**	.100*
	Sig. (2-tailed)	.009	.530	.015		.000	.022	.027	.000	.000	.040
	N	418	418	418	418	418	418	418	418	418	418
Q14	Pearson Correlation	.139**	.157**	.244**	-.199**	1	-.142**	-.069	.105*	-.182**	-.149**
	Sig. (2-tailed)	.004	.001	.000	.000		.004	.159	.032	.000	.002
	N	418	418	418	418	418	418	418	418	418	418
Q15	Pearson Correlation	.199**	-.276**	-.043	.112*	-.142**	1	-.211**	.160**	.369**	.206**
	Sig. (2-tailed)	.000	.000	.385	.022	.004		.000	.001	.000	.000
	N	418	418	418	418	418	418	418	418	418	418
Q16	Pearson Correlation	-.071	.055	.017	-.108*	-.069	-.211**	1	-.386**	-.155**	-.076
	Sig. (2-tailed)	.148	.260	.728	.027	.159	.000		.000	.001	.121
	N	418	418	418	418	418	418	418	418	418	418
Q17	Pearson Correlation	.395**	-.043	.318**	.177**	.105*	.160**	-.386**	1	.159**	.101*
	Sig. (2-tailed)	.000	.377	.000	.000	.032	.001	.000		.001	.040
	N	418	418	418	418	418	418	418	418	418	418
Q18	Pearson Correlation	.009	-.387**	-.253**	.226**	-.182**	.369**	-.155**	.159**	1	.207**
	Sig. (2-tailed)	.850	.000	.000	.000	.000	.000	.001	.001		.000
	N	418	418	418	418	418	418	418	418	418	418
Q19	Pearson Correlation	.055	-.140**	-.080	.100*	-.149**	.206**	-.076	.101*	.207**	1
	Sig. (2-tailed)	.259	.004	.104	.040	.002	.000	.121	.040	.000	
	N	418	418	418	418	418	418	418	418	418	418

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

TABLE 6 CORRELATIONS (4)

		R	Q23	Q24	Q26	Q27	Q28A	Q28B	Q29
R	Pearson Correlation	1	.045	-.085	.465**	.004	.[a]	-.276**	-.077
	Sig. (2-tailed)		.355	.083	.000	.927	.	.000	.118
	N	418	418	418	418	418	418	418	418
Q23	Pearson Correlation	.045	1	.016	.028	.048	.[a]	-.165**	-.004
	Sig. (2-tailed)	.355		.739	.565	.324	.	.001	.933
	N	418	418	418	418	418	418	418	418
Q24	Pearson Correlation	-.085	.016	1	-.076	.013	.[a]	.158**	-.061
	Sig. (2-tailed)	.083	.739		.119	.793	.	.001	.215
	N	418	418	418	418	418	418	418	418
Q26	Pearson Correlation	.465**	.028	-.076	1	.253**	.[a]	.331**	.519**
	Sig. (2-tailed)	.000	.565	.119		.000	.	.000	.000
	N	418	418	418	418	418	418	418	418
Q27	Pearson Correlation	.004	.048	.013	.253**	1	.[a]	.470**	.416**
	Sig. (2-tailed)	.927	.324	.793	.000		.	.000	.000
	N	418	418	418	418	418	418	418	418

Q28A	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.		.	.
	N	418	418	418	418	418	418	418	418
Q28B	Pearson Correlation	-.276**	-.165**	.158**	.331**	.470**	.[a]	1	.734**
	Sig. (2-tailed)	.000	.001	.001	.000	.000	.		.000
	N	418	418	418	418	418	418	418	418
Q29	Pearson Correlation	-.077	-.004	-.061	.519**	.416**	.[a]	.734**	1
	Sig. (2-tailed)	.118	.933	.215	.000	.000	.	.000	
	N	418	418	418	418	418	418	418	418

**. Correlation is significant at the 0.01 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

TABLE 7 CORRELATIONS (5)

		R	Q30	Q31	Q32	Q34A	Q35	Q36
R	Pearson Correlation	1	.103*	-.178**	.242**	.162**	.232**	.429**
	Sig. (2-tailed)		.035	.000	.000	.001	.000	.000
	N	418	418	418	418	418	418	418
Q30	Pearson Correlation	.103*	1	-.374**	-.019	.211**	-.152**	-.106*
	Sig. (2-tailed)	.035		.000	.693	.000	.002	.030
	N	418	418	418	418	418	418	418
Q31	Pearson Correlation	-.178**	-.374**	1	.247**	-.555**	.521**	.033
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.501
	N	418	418	418	418	418	418	418
Q32	Pearson Correlation	.242**	-.019	.247**	1	-.322**	.220**	.001
	Sig. (2-tailed)	.000	.693	.000		.000	.000	.981
	N	418	418	418	418	418	418	418
Q34A	Pearson Correlation	.162**	.211**	-.555**	-.322**	1	-.174**	.378**
	Sig. (2-tailed)	.001	.000	.000	.000		.000	.000
	N	418	418	418	418	418	418	418
Q35	Pearson Correlation	.232**	-.152**	.521**	.220**	-.174**	1	.661**
	Sig. (2-tailed)	.000	.002	.000	.000	.000		.000
	N	418	418	418	418	418	418	418
Q36	Pearson Correlation	.429**	-.106*	.033	.001	.378**	.661**	1
	Sig. (2-tailed)	.000	.030	.501	.981	.000	.000	
	N	418	418	418	418	418	418	418

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

B. Regression Analysis

Regression analysis is a powerful tool that enables the researchers to learn more about the relationships within the data being studied. Regression analysis has been used in similar cases, for example; Sonmez and Rowings [9] developed an initial regression model including the factors: quantity, crew size, temperature, overtime, job type, and concrete pump for predicting production rate of concrete pouring base on data collected from eight building projects in Iowa. In addition, Leung and Tam [19] identified twenty factors effecting the hoisting times of tower cranes at construction sites in Hong Kong, in order to develop reasonably accurate prediction model to assess hoisting times of tower cranes.

Multiple regression methods were used to analyze and build up the model based on the data collected from three typical residential housing projects. The model testing has shown that about 93% of predicted supply hoisting items is within ±20% of the actual hoisting times, where as 88% of the predicted return hoisting times were within ±20%. Also, Leung and Tam [20] represented a mathematical model to predict the hoisting times for a tower crane for public housing construction in Hong Kong.

Multiple regression models were used to predict supply hoisting times and return hoisting times based on a twelve factors influencing hoisting time and 278 observed cases recorded for the installation of the pre-cast concrete units and 88 observed cases recorded on the installation of pre-cast slab. Furthermore, Dunlop and Smith [7] presented and discussed some of the key characteristics in concrete operation productivity in order to develop a multiple linear regression model for concrete productivity. A total of 202 separate concrete operations were observed from three sites in the North-East of Scotland. The model validation has shown that the model derived for estimating a actual concrete productivity produced good results for productivity greater than $6m^3$/hr, and was seen to be quite poor at predicting productivities less than $6m^3$/hr. Olaoluwa et al [21] stated that the results of using multiple regression analysis in studding the factors affecting productivity of concrete placing by crane with skip in Nigeria showed that type of pouring, pouring size, fractional delay(the delay time expressed as a fraction of the pouring duration) were the most significant factors.

And Kim et al [12] used multiple linear regression analysis to estimate the actual labour productivity work, in order to calculate the productivity achievement ratio (PAR). The multiple liner regression analysis was conducted by setting the following factors: workers responsibility (motivation), order and delay of approval, intervention between items, delay of material delivery, and stoppage as independent variables and the actual productivity as dependent variable using stepwise method. The results of the study indicated that PAR could aid construction practitioners in achieving more balanced and effective productivity management.

Accordingly, based on the above mentioned literature and the research objectives, the researcher carried out a regression analysis on the observed data (418 pouring concrete cycles) to obtain a model that will estimate productivity rates of concrete operations to help planners and estimators to predict the production rate of PRMC using tower cranes.

The regression analysis methodology used in this study is Enter method as it named in Statistical Package for the Social Sciences (SPSS) programme. This method is the standard and simplest method for estimating a regression equation, the researcher specifies the set of predictor variables that make up the model, and the success of this model in predicting the criterion variable is then assessed. The study begins with a full set of predictor variables in the model and eliminates “non-significant” variables one at time until all the remaining variables are “significant”. At any step the variable with the biggest sig p-value were eliminated, the p-value could be defined as that it is the probability of obtaining a test statistic at least as extreme as one that was actually observed, assuming that the null hypothesis is true (all factors are significant). It ranges from 0 to 1, the smaller the p-value <0.05 in this research, the more evidence to have against null hypothesis. According to Sullivan [22], if the p-value is less than α (alpha), which is often, 0.05 or 0.01, then the findings are “*statistically significant at the 5% level*”. He adds that, the 5% level is a feasible level for research as it usually set up an experiment which will show effects large enough to be of interest to the researchers. Accordingly, in this research, the significance level α is equal to 0.05.

In addition, the R squared value may be used as a statistical measure of how well a regression line approximates real data points. It is a descriptive measure between 0 and 1, indicating how good one term is a predicting another. If R2=1 or closer to1 this indicates that the fitted model explains almost all variability independent variable, will R2 = 0 or closer to 0 indicates no linear relationship between the response variable (R) and predictor variables. Also the analysis of variance (ANOVA) used to determine the impact independent variables have on the dependent variable in the regression analysis, it basically tells us whether the regression equation is explaining a statistically significant portion of the variability in the dependent variable from variability in the independent variables. These variables were tested through fitting a model and the results were shown that the predictors (variables) with sig p-value > 0.05 should be deleted from the model to obtain better model fitting the dependent variable under study. So the following variables were deleted from the model sequence as shown in Table 8.

TABLE 8 EXCLUDED VARIABLES FROM REGRESSION ANALYSIS

Excluded Variables	**Sig. P-Value**
Q3	.348
Q6	.905
Q7	.198
Q8	.090
Q9	.181
Q10	.218
Q11	.247
Q13	.679
Q15	.446
Q16	.982
Q18	.868
Q19	.651
Q23	.894
Q30	.257
Q31	.999
Q32	.273
Q35	.814

The model significantly value considered at level of 0.05 with the value of R-squared of 0.984 are shown in Table 9, which means that the model fits strongly the data and 98.4% of the total variation in production rate is explained by the regression model equation. So it could be mentioned that the variablesQ2, Q4, Q5, Q12, Q14, Q17, Q24, Q26, Q27, Q28B, Q29, Q34, and Q36 are the ones that significantly affect the dependent variable (production rate R) under study. Each of these variables affects the dependent variable (R) by an amount of change shown in column of Beta in Table 11.

Table 10 indicated that regression model predicted the outcome variable significantly well through looking to the regression row to the sig P-value column which determined whether the model is a good fit for the data. The sig P-value column indicates that the statistical significance of the regression model that was applied is less than 0.05 and also indicates that overall the model applied is significantly good enough in predicting the production rate outcome.

In addition, Table 11 shows that the percentage error of the residual sum of squares is 1.629%, which means that only 1.629% of the total variation in production rate was not explained by the regression model equation.

Table 11 presented the beta coefficients for each predictor and the sig p-value column (last column) shows that all the predictors have a sig p-value <0.05, which means that the final obtained model is shown to be the one in the above table and it could be written as follows:

E(Y) = -7.041 + 0.129Q2 + 0.076Q4 - 0.016Q5 + 0.667Q12 - 0.257Q14 + 0.056Q17 + 0.004Q24 + 10.528Q26 - 4.986E-5Q27 -0.076Q29 - 0.030Q34 + 0.006Q36 - 0.257Q28B

TABLE 9 MODEL SUMMARY

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.992[a]	.984	.983	.25388	1.923

TABLE 10 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1564.165	13	120.320	1866.678	.000[a]
	Residual	25.912	402	.064		
	Total	1590.076	415			

TABLE 11 COEFFICIENTS

Model		Unstandardized Coefficients		Sig.	Collinearity Statistics	
		B	Std. Error		Tolerance	VIF
1	(Constant)	-7.041	.241	.000		
	Q2	.129	.025	.000	.498	2.008
	Q4	.076	.023	.001	.388	2.581
	Q5	-.016	.002	.000	.169	5.924
	Q12	.667	.014	.000	.203	4.934
	Q14	-.257	.131	.050	.810	1.235
	Q17	.056	.017	.001	.372	2.688
	Q24	.004	.001	.001	.825	1.211
	Q26	10.528	.138	.000	.588	1.701
	Q27	-4.986E-5	.000	.003	.357	2.804
	Q29	-.076	.034	.027	.296	3.373
	Q34	-.030	.012	.011	.513	1.951
	Q36	.006	.002	.000	.286	3.496
	Q28B	-.257	.093	.006	.216	4.619

VII. TESTING THE ASSUMPTIONS OF LINEAR REGRESSION USING ENTER METHOD

A. Tests for Multicollinearity

In addition to testing the Multicollinearity using correlation matrix, the variance inflation factor “VIF” also provides us with a measure of how much the variance for a given regression coefficient is increased compared to if all predictors were uncorrelated and Tolerance is simply the reciprocal of VIF. Multicollinearity does not exists in this research because Tolerance is bigger than 0.1; and VIF is less than 10 as shown in Table 11.

B. Tests for Normality of Residuals

Through checking the Normal P-P Plot of Regression Standardized Residual for meeting the assumption that the residuals or error terms are normally distributed, it could be observed that the plot for the actual values of expected values are even closer as shown in Fig. 3 which means that the residuals are normally distributed.

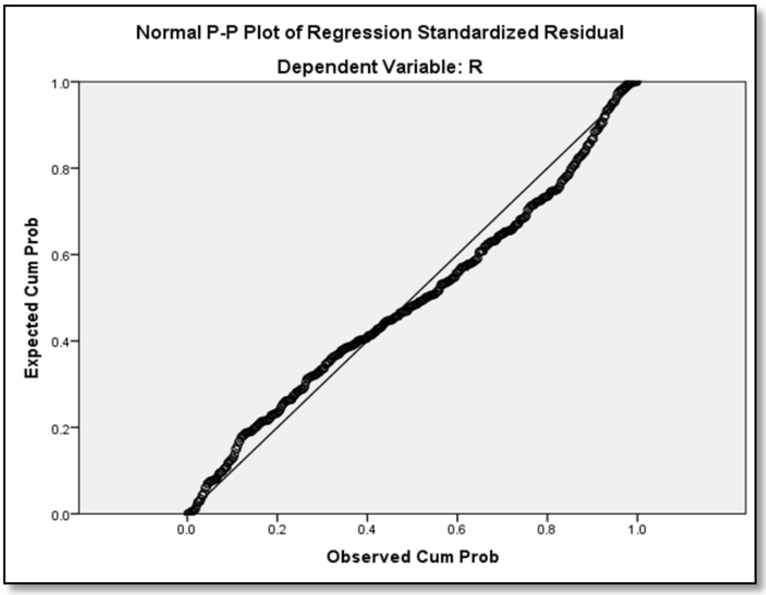

Fig. 3 Normal P-P plot of regression standardized residual

C. Tests for Issues of Independence (Auto-correlation)

The model summary Table 9 presented that Durbin-Watson statistic value to test for correlated residuals (autocorrelation) is 1.923 (close to 2) which means that the errors associated with one observation are not correlated with the errors of any other observation.

D. Tests for Heteroscedasticity

Fig. 4 represents the regression standardized residual plot of the data in Enter regression model. The residual plot shows the difference between the calculated and the measured values of the dependent variable (R) as function of the measured values. The regression model represents the data correctly as the residuals are randomly distributed around the line of error with zero mean and the variance of the residuals is constant which means that variance of the residuals is homogeneous across levels of the predicted values (homoscedasticity).

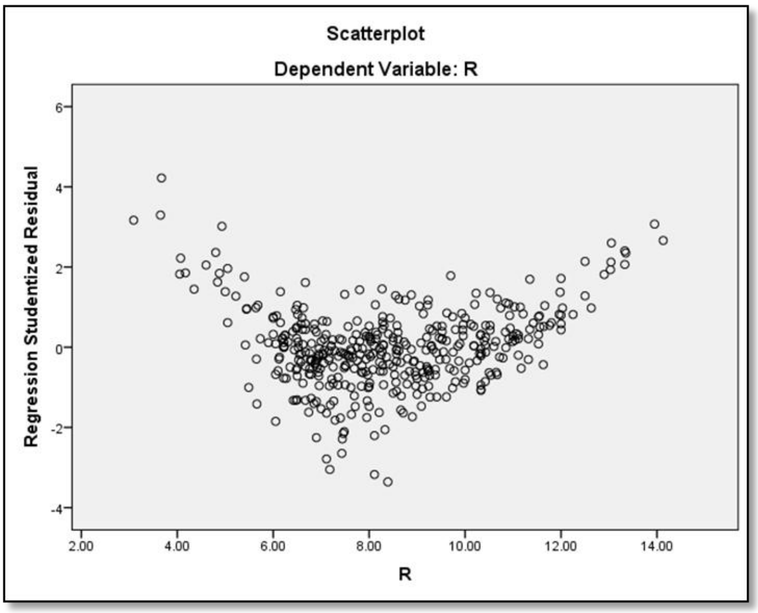

Fig. 4 The regression standardized residual scatter plot

VIII. MODEL TESTING AND VALIDATION

In order to test the regression model the data collection and observation (a total of 418 pouring concrete cycle) were used as a new data in the model regression equation to test the model and ensure that it is fitting the requirement level of error. The error of the model was calculated using the following equation: percentage error = (actual production rate – predicted production rate)/actual production rate *%. The average percentage error through model testing was found to be 4.8007% based on Table 12. In order for this to be of practical use on construction projects it must first be validated. For the objective of this study the regression model was validated using actual production rate for PRMC to discover if the developed model could be valid. A total of 28 pouring concrete operations using tower cranes were observed from the same projects and compared to the predicted production rate using the derived regression model to be able to find the percentage of error in the model applied. Table 13 shows the data collected, the data obtained from estimation and prediction as well as the amount of error data according to regression model. The result of the model validation presents an average percentage error of 2.8197% between actual production rate and estimated production rate which is reasonable and acceptable error.

TABLE 12 MODEL TESTING RESIDUALS

	Actual R	Estimated R	Residuals	%	Round
1	7.43	8.17747	-0.73747	-0.09926	0.099256
2	11.96	12.04220714	-0.07221	-0.00604	0.006037
3	7.11	7.84987	-0.70987	-0.09984	0.099841
4	10.4	10.3984	0.0116	0.001115	0.001115
..	..				
..	..				
..	..				
415	6.25	6.28241	-0.01241	-0.00199	0.001986
416	6.15	6.49681	-0.32681	-0.05314	0.05314
417	7.37	7.9685	-0.5385	-0.07307	0.073066
418	6.05	6.288653333	-0.23365	-0.03862	0.03862
Average Error				**-0.048**	**0.048007**

TABLE 13 MODEL VALIDATION ERROR

Actual R	Estimated R	Residuals	%	Round
12.03	11.6467	0.3843	0.031868	0.031868
11.56	11.0957	0.4643	0.040164	0.040164
13.35	12.5693	0.7807	0.058479	0.058479
11.32	11.0875	0.2325	0.020544	0.020544
12.63	12.1658	0.4642	0.036753	0.036753
11.42	11.1619	0.2601	0.0227757	0.0227757
10.42	10.2869	0.1333	0.012773	0.012773
11.11	10.7936	0.3164	0.028478	0.028478
12.5	12.0889	0.4111	0.032888	0.032888
12	11.5958	0.4042	0.033683	0.033683
10.33	10.517	-0.1873	-0.018102	0.018102
10.09	9.7595	0.3305	0.032755	0.032755
12	11.6892	0.3108	0.025953	0.025953
10.72	10.5881	0.1319	0.012304	0.012304
11.53	11.6454	-0.1154	-0.010006	0.010006
11.11	10.7696	0.3404	0.030639	0.030639
10.79	10.5564	0.2336	0.021649	0.021649
9.74	9.48735	0.2526	0.025939	0.025939
10.91	10.7964	0.1136	0.010412	0.010412
11.32	11.5848	-0.2648	-0.023392	0.023392
10.5	10.2845	0.2155	0.020524	0.020524
10.54	10.1864	0.3536	0.033545	0.033545
10	10.474	-0.4745	-0.04746	0.04746
9.61	9.87807	-0.26807	-0.027887	0.027887
10.62	11.1848	-0.5648	-0.0531828	0.0531828
9.3	9.4776	-0.17767	-0.01911	0.01911
10.24	10.5473	-0.30737	-0.030052	0.030052
10.33	10.7584	-0.42845	-0.041475	0.041475
Total				**0.028197**

IX. CONCLUSIONS

This paper has presented and discussed a new model for predicting the production rate of PRMC using tower cranes by using the multiple liner regression analysis. The researcher developed the regression model by identifying 36 factors affecting PRMC using tower cranes. The researcher used correlation analysis to identify the most independent variables correlated to the dependent variable (production rate). The correlation analysis has shown that the following variables: Building Element (Q3), Pouring Location (Q4), Pouring Level (height) (Q5), Equipment efficiency (Q6), Time planning and scheduling (Q7), Project Communication (Q12), Site layout (Q13), Waiting time for (RMC) (Q14), Driver's skill (Q15), Number of workers/ crew (Q17), Skip Size (Q26), Type of tower crane(Q28B), Location of batch plant (Q31), Batch plant capacity (Q32), Truck mixers capacity (Q34), No. of truck mixers used (Q35), and Pouring size (Q36) are considered to be significantly correlated at level 0.01 and were tested through fitting the regression model. The significant variables (variables with sig p-value <0.05) which are: Q2, Q4, Q5, Q12, Q14, Q17,Q24,Q26, Q27, Q28B, Q29, Q34, and Q36, they are considered to be the variables that significantly affect dependent variable (production rate) according to regression analysis. The data for the regression model were based on data collected from 10 construction projects in Egypt with 418 pouring concrete cycles. The validation exercise demonstrated that the model derived for estimating pouring concrete production rate produces good results when comparing with the actual pouring concrete production rate.

The results of model testing indicated that the average percentage error through model application was found to be 2.8197%. Further research is recommended to improve the concrete placing productivity measurement by conducting more observations on various types and methods of pouring, which required the cooperation of a large number of site engineers, project managers, contractors, and RMC suppliers, and the support of government agencies. In addition, simulation models covering both the construction site and batching phases for the whole RMC operation should be undertaken in order to improve the overall RMC industry in Egypt. There is always a limit to what a researcher can achieve during a research study (or model building) and recognizing the limitations of a study strengthens the validity of the findings and the reliability of the research process. The limitations of this research are: this research collected data only from Egyptian construction projects, so the results may not be applicable to environments outside Egypt, this research used tower cranes and skip pouring concrete method only, and this research is limited to the activities related to pouring concrete. Thus, to use the model in other places and at other times, the statistical model update will use the universally valid variables (factors) and update its formulae according to their collected 'training data'.

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