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Productivity Improvement of Pre-cast Concrete Installation

Souma M. Alhaj Ali [1]***, Ayman A. Abu Hammad*** [2]***, Ghaleb J. Sweis***[3] ***and Murad S. Samhouri*** [4]

[1] Assistant Professor, Department of Industrial Engineering, Hashemite University, P.O.Box: 330127, Zarqa 13115, Jordan, Email: souma@hu.edu.jo. (Corresponding Author)
[2] Assistant Prof., Department of Civil Engineering, Applied Science University, Amman, Jordan, Email: dr-abuhammad@asu.edu.jo
[3] Assistant Professor, Department of Civil Engineering, The University of Jordan, Amman 11942, Jordan. Email: gsweis@ju.edu.jo
[4] Assistant Professor, Department of Industrial Engineering, Hashemite University, P.O.Box: 330127, Zarqa 13115, Jordan, Email: samhouri@hu.edu.jo

ABSTRACT

The production process of pre-cast concrete installation is analyzed to investigate possible ways for onsite productivity improvement. Although manufactured construction enjoys higher quality and productivity, it is observed that it suffers delays compared to site built construction. Delay causes and respective severity are analyzed for improvement.

Firstly, the production process is investigated using the production delay model. Forty cycle data are used in the analysis. The comparative impact and severity are measured for five delay causes, namely: labor, environmental, management, equipment and material on overall system productivity. It is found via the production delay analysis that material, followed by equipment availability then labor were major contributors to system delay. Secondly, statistical analysis on the installation cycle time of three pre-cast component types is carried out, in order to insure whether the delay observed via the first step is attributed to variation of pre-cast pieces. The data used in step one above were not pertinent to product type; therefore, other 90 cycle data are utilized in the statistical analysis, which indicated high variability in cycle time due to product type. Improvement can be achieved through proper scheduling of project equipment and resources. In addition, improvement should target the reduction of installation cycle time variability due to product type.

KEYWORDS: Pre-cast concrete, Productivity, Construction operations, Method productivity delay model (MPDM).

INTRODUCTION

Pre-cast concrete is a major type of factory built construction that is completely produced in a plant environment, transported and erected onsite.

Cost, time and quality play in favor of pre-cast construction compared to other conventional methods. Nevertheless, maintaining these criteria would qualify this industry to be the major provider of construction units to satisfy the growing demands in Jordan. However, the earned values of pre-cast construction don’t hold in practice due to delay. Pre-cast production problems stem from the fact that a typical plant is unable to meet the high production demand due to the lack of a streamlined assembly process. Moreover, the pre-cast construction industry has not been able to emerge as a technologically

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advanced industry due to the adoption of labor driven processes, coupled with the lack of applied technology (Abu Hammad, 2004).

RESEARCH BACKGROUND

Pre-cast concrete installation process is analyzed herein for improvement by the use of productivity delay model (MPDM). The MPDM technique is a modification of the traditional time and motion study concept (Adrian, 1974; Halpin and Riggs, 1992). The technique was developed to give the construction firm a means of measuring production, predicting delay causes and improving productivity via scenarios and mitigation of root causes. The MPDM was used frequently in modeling construction operations, i.e., concrete placement with a crane and bucket, placement of concrete using a concrete pump and hand mining of a soft-ground tunnel. The data collection and analysis for these examples was done by Bradshaw in 1978 (Halpin and Riggs, 1992). Park et al. (2005) established a survey tool in order to collect standard productivity data at appropriate level. The proposed productivity metrics model is based on MPDM and contains a list of direct and indirect accounts and 56 data elements grouped into seven major categories. Park (2006) performed an extensive literature review on productivity in construction to support the rationale of a proposed productivity estimation model based on project environment and management effort factors.

On the other hand, pre-cast plant productivity affects onsite installation activities; thus, contribute to construction delay. Furthermore, previous research on manufactured construction operations at a plant underlined that modularization and mass production of construction components are undermined by the unique nature of the construction product. Therefore, production managers should apply new innovative techniques to identify system bottlenecks and to maintain a balance between efficiency and the implications of product design variations (Abu Hammad, 2004). Abu Hammad (2004) showed through the example of manufactured housing plants that a streamlined assembly line can be achieved through balancing the stations' activities and their workloads. Abu Hammad et al (2002 a&b) and Koskella (1999) indicated that factory production lines are constrained by the mixed model manufacturing that involves the production of different unit sizes and shapes at the same production line. In order to streamline the performance, it is important to equalize the work variability per lean production theory. The plan of attack of this research is to analyze the probabilistic nature of cycle times in support to the application of the MPDM. Deterministic models do not include dynamic interactions existing in the system. However, they provide a rough estimate of the system performance, or system delay causes, in particular (Williams, 1999; Winston, 1997; Hillier, 2002; Rolstad, 1995).

Recent literature focused on pre-cast concrete research aimed to aid pre-cast suppliers in examining if contractors are ready to adopt JIT in receiving and installing pre-cast (Pheng, 2001). Another research focused on identifying the appropriate methodology for designing and managing the stockyard layout that ensures efficient storage and dispatch of pre-cast products. Additionally, the research proposed a simulation model to evaluate and help manage stockyard space (Marasini et al., 2001). A radio frequency and GPS technology are introduced for the objectives of delay avoidance, late deliveries and incorrect installation due to manual methods of locating customized prefabricated components (Ergrn, 2007).

Finally, a mathematical model is proposed to predict the hoisting times (supply and return times) for a crane using multiple regression; additionally, twelve factors influencing hoisting time are reviewed (Leung, 1999).

METHOD PRODUCTIVITY DELAY MODEL

On-site installation activities are time consuming and have diverse effects on project duration. The system should be analyzed for potential process bottlenecks which need to be located and solved. The ultimate goal hereunder is to reduce project delivery time throughout improving the installation process of the pre-cast components. The following objectives are in support of the above goal: i) Model the installation process; ii) Locate process bottlenecks and iii) Propose solutions through scenario analysis for improvement.

Method Indicators

As mentioned above, 40 installation cycles are recorded onsite by observing the installation activities of different precast piece types and sizes using a mobile telescopic crane. Table (1) depicts part of the data collection sheet showing the ordered tabulation of factors and respective onsite estimates. Column 2 of Table (1) includes the total cycle time in seconds. Columns (3 to 7) include the delay designation as percentage for each of the five delay causes. The last column includes the calculation of column 2 cell-mean non-delay cycle of 1496.15, shown at the third row of Table (2).

Table (1): Production Delay Sampling.

Number	Production Cycle (Sec.)	Environment	Equipment	Labor	Materials	Management	Minus Mean Non Delay Time
1	1400						96.15
2	1550						53.85
3	1500						3.85
4	1450						46.15
5	1500						3.85
6	1800		100%				303.85
7	1900	20%		50%	30%		403.85
8	1750				100%		253.85
9	1600		30%	25%	20%	25%	103.85
10	1700	35%	20%		45%		203.85

Table (2): Statistical Analysis.

?Production Cycles=	65250
? Non-Delay Cycles=	19450
Mean Non-Delay Cycles=	1496.15
Overall production Cycles=?Cycle Time-Delay Cycle Time/n=	149.14
Non-Delay Cycles= ?Cycle Time-Delay Cycle Time/n=	561.54

Table (2) depicts the statistical analysis performed on Table (1) data. The delayed cycles include delay percentages; however, the non-delayed cycles were not observed to have any delay cause out of the five listed causes during the data collection.

Table (3) includes calculations of certain statistics for delayed and non-delayed data.

There are four types of information involved in the model. The first is called the variability of the method productivity, i.e., ideal cycle and overall cycle variability which provide a measure of the variable nature of the process according to the two following equations:

$$\text{Ideal cycle variability} =$$

$$\frac{\text{Variation measure or (Row A of Table3)}}{\text{Mean nondelay cycletime}} =$$

$$561.54/1496.15 = 0.375$$

$$\text{Overall cycle variability} =$$

$$\frac{\text{Variation measure or (Row B of Table3)}}{\text{Mean overall cycletime}} =$$

$$149.13/1631.25 = 0.0914$$

The above two equations are applied by dividing the last column of rows A and B of Table 3 by the next-to-last column of rows A and B, respectively.

MODEL RESULTS

Table (4) depicts the relative impact of delay causes on productivity. Material, equipment availability and labor rank first, second and third, respectively.

Row (E) of Table (4) is the relative frequency probability of occurrence for each delay type, i.e., occurrence of delayed cycles due to environment divided by the sum of occurrences (sum of row C) = 10 / 66= 0.152.

Table (3): Model Processing.

Units	Total Production Time	Number of Cycles	Mean Cycle Time	∑ (│(Cycle Time) - (Non-Delay CycleTime)│) / n
A) Non-delayed productiuon Cycles	19450	13	1496.15	561.54
B) Overall Production Cycles	65250	40	1631.25	149.13

Table (4): Delay Information.

	Delays				
	Environment	Equipment	Labor	Material	Management
C) Occurrences	10	16	16	17	7
D) Total added time	631.15	1356.5	1195.38	1662.5	558.27
E) Probability of Occurrence	0.152	0.242	0.242	0.258	0.106
F) Relative severity	0.039	0.052	0.046	0.060	0.049
G) Expected % delay time per production cycle	0.59	1.26	1.11	1.54	0.519

Table (5): Model Results.

1 minus percentages of row G of Table 4= 1-(0.58%)-(1.26%)-(1.11%)-1.54%)-(0.52%)	0.950	
Ideal Productivity	2.41	Units / hour
Method Productivity= product of the above two values	2.35	Units/ hour
Overall Method Productivity= (60*60)/ mean cycle time of 1631.25	2.21	Units/ hour
Ideal Cycle Variability= Row A/Mean nondelay cycle time	0.38	
Overall Cycle Variability= Row B/ Mean nondelay cycle time	0.10	

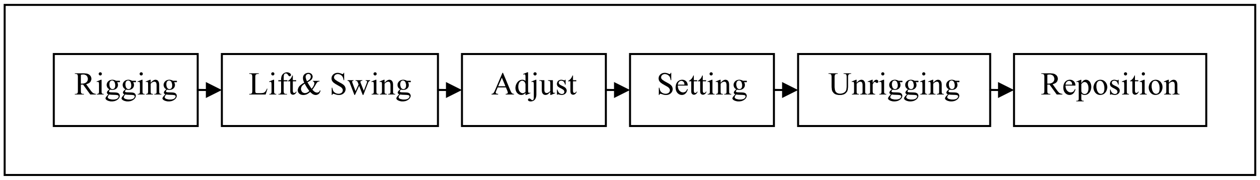

Figure (1): Installation Process Chart.

Row (F) of Table (4) is calculated as follows: (row D/ row C)/ overall mean cycle time equal to 1631.25. The overall mean cycle time is computed in Table (3) above (intersection of row B with column four of Table 3).

Row (G) of Table (4) is calculated per the formula: Row E * row F *100

Table (4) shows that material unavailability, equipment and management rank first (0.06), second (0.052) and third (0.049) in their severity to system productivity.

Table (5) includes the system productivity calculations. In row (3), production is computed by multiplying the row (1) by row (2) results. However, in row (4), production = (60 seconds/minute* 60minutes/ hour) divided by the mean cycle time of 1631.25 (row 1 of Table 2 divided by 40 data points).

There are no limits that could be defined for acceptable variability because of the widely-differing types of construction methods. In general, a value greater than 1.0 for the overall cycle variability means that productivity prediction should be viewed with caution. The other three types of indicators are simply repeats of row E, row F and row G of the delay information.

The above results of the MPDM analysis suggest further analysis on the product cycle time variation using statistical method. It is imperative to know whether the delay causes are attributed to significant difference of production cycle time relative to pre-cast piece type. The following section includes statistical analysis of variance in order to investigate significant difference in installation cycle times relative to piece types.

STATISTICAL ANALYSIS ON THE PROCESS CYCLE TIME

Three distinct types of pre-cast pieces are installed; namely: columns, double T-beams and void slabs. Thirty cycle time data are collected for each component type. Each cycle time data is computed as the sum of activity process times of the exact sequence of installation activities depicted in Fig. (1).

Table (6): Summary Statistics of Installation Cycle Time and Productivity Measure.

Title	Double T	Columns	Void Slabs
Mean (minutes)	20.03	45.17	15.40
SD (minutes)	1.60	4.45	1.05
Sample size	30.00	30.00	30.00
Std. error of mean	0.29	0.81	0.19
Lower bound 95% CI	19.44	43.51	15.01
Upper bound 95% CI	20.63	46.83	15.79
Minimum (minute)	17.00	40.00	13.50
1st Quartile (minute)	19.00	40.00	14.50
Median (minute)	20.00	45.00	15.50
3rd Quartile (minute)	21.00	50.00	16.00
Maximum (minute)	24.00	50.00	18.00
KS normality test	0.14	0.26	0.12
Normality test P-value	>.1	<.0001	>.1
Normally distributed?	Yes	No	Yes
2-tail test significance (P-value)	0.99	1.00	1.00
Productivity (Cycle/ Day)	19.97	8.86	25.97

Table (6) depicts the summary statistics of the installation cycle time data of the three distinct pre-cast concrete pieces. The 95% CI are shown in rows 5 and 6 of the table. The CI statistics indicate that the installation time of the column pieces is approximately twice the time of the other two types.

Productivity measures are calculated at the bottom of Table (6) for 50min/hr efficiency. Productivity measures underline the fact that the productivity of installing column pieces is the lowest amounting to approximately 9 pieces/hr compared to 20 and 26 pieces/hr for the double-T and void slabs, respectively.

Mean Cycle Times Comparison of Piece Types Using One-way ANOVA with Post Test

Ordinary one-way analysis of variance (ANOVA) is performed on the three columns of data with the assumption that the data is sampled from Gaussian (normal) distribution; therefore, standard parametric method is used.

Table (7): Piece Types Comparisons Test.

Comparsion	Mean Difference	95% Confi dence interval of mean Diff.		q	P-value
		Lower	Upper		
Double-T vs Columns	-25.13	-26.86	-23.41	49.23	< 0.001
Double-T vs Void Slabs	4.63	2.91	6.36	9.08	< 0.001
Columns vs Void Slabs	29.77	28.04	31.49	58.30	< 0.001

Table (8): Intermediate Calculations of ANOVA.

Source of Variation	Degrees of freedom	Sum of squares	Mean square
Treatment (between columns)	2	15392	7696
Residuals (within columns)	87	680.33	7.82
Total	89	16072	
F= 984.16= MS treatment/ MS residual			

Table (9): Calculation Detail of the Kruskal-Wallis Test.

Group	Number of Point	Sum of Ranks	Mean of Ranks
Double-T	30	1360.5	45.35
Columns	30	2265	75.5
Void Slabs	30	469.5	15.65
KW= 79.245 (corrcted)			

Kruskal-Wallis statistic KW= 79.245 (corrected for ties).

Table (10): Calculation Details of the Dunn's Multiple Comparison Test.

Comparison	Mean Rank Difference	P-value
Double-T vs Columns	-30.15	P< 0.001
Double-T vs Void Slabs	29.7	P< 0.001
Columns vsVoid Slabs	59.85	P< 0.001

One-way Analysis of Variance (ANOVA)

The P-value is less than 0.0001, considered extremely significant. Thus, variation among cycle time means is significantly greater than expected by chance.

Tukey-Kramer Multiple Comparison Test

If the value of q is greater than 3.38 then the P-value is less than 0.05.

The last column of Table (7) indicates significant difference of means among the three types of pre-cast pieces.

Since ANOVA assumes that the data are sampled from populations with identical SD's, this assumption is tested using the method of Batlett as a check whether the above analysis holds valid. Batlett statistic (corrected)= 61.221.

The P-value is < 0.0001. Therefore, the test suggests that the differences among the SD's is extremely significant. Since ANOVA assumes populations with equal SD's, nonparametric test should be considered.

Additionally, nonparametric test is called for because Table (6) above shows that at least one column failed the normality test (the columns data set) using Kolmogorov-Smirnov method with P-value < 0.0001. Thus, the assumption that the Data is sampled from a Gaussian distribution is not valid. Nonparametric ANOVA is performed by using Kruskal-Wallis test in the following section. Unlike the analysis above performed using the ordinary one-way ANOVA, the Kruskal-Wallis test considers estimating variation among column medians instead of column means.

Kruskal-Wallis Test (Nonparametric ANOVA)

The calculated P-value of the test is less than 0.0001, the P-value is considered extremely significant. Therefore, variation among cycle time medians of the three piece types is significantly greater than expected by chance. The P-value is approximated from chi-square distribution because at least one column has two or more identical values.

Dunn's Multiple Comparison Test

Table (10) depicts the Dunn's pair comparison test among the pre-cast piece types. The last column of the table shows significant difference of the mean ranks with P-values amounting to less than 0.001.

CONCLUSIONS

The scope of research documented herein covers the onsite installation activities. Although, the pre-cast concrete plant production impacts the installation productivity; however, productivity improvements at the plant level is left for future work. The analysis performed in this research indicated that material unavailability, equipment unavailability and management errors ranked first, second and third in their severity to system productivity, respectively (per Table 4). Material unavailability realized as the major delay cause via the MPDM analysis indicates problems at the pre-cast plant. Plant production lines failing to produce at desired production levels should be streamlined in order to provide material just-in-time for installation at the jobsite. The other two causes should be tracked on site in order to solve the most important causes of work disruptions. On the other hand, ANOVA analysis indicated significant differences in the mean time of installation among the three pre-cast concrete pieces. Although, lean production theory underlines the reduction of system variability as a main strategy for productivity improvement. Future studies are called for in order to reduce the installation time of column pieces by introducing a replacement technology or an alternative construction method.

Future work is to develop a decision model that could be used by production and construction managers in order to improve plant and onsite production.

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