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Performance Improvement of Concrete Pouring Process Based Resource Utilization Using Taguchi Method and Computer Simulation

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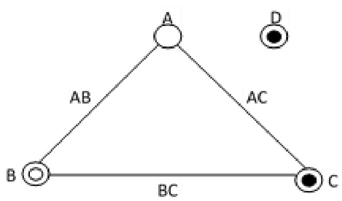
Graphical abstract



Abstract

One of the most controversial issues in construction management is performance measurement. Construction managers are always involved in evaluation of resource changes which effect process performance. Due to limitations and also cost of resources, resource allocation has become a complex task in construction projects. To evaluate the effects of different resources on total project performance, managers strive to allocate limited resources by determining resource combinations. This paper aims at conducting Taguchi method along with computer simulation to determine the optimum combination of resources for a real world case study involving a concrete pouring operation in order to reduce cycle time and process costs. The proposed simulation model was conducted under Arena 13.9. Final result shows that the optimum resource combination will be achieved when all of resources are located in the low level. This means that number of trucks, spreader crew, vibrator crew and finisher crew should be equal to 3, 1, 1, and 1 respectively to improve the total performance.

Keywords: Concrete pouring process; performance measurement; resource combination; computer simulation; Taguchi method

Abstrak

Salah satu isu yang paling kontroversi dalam pengurusan pembinaan adalah pengukuran prestasi. Pengurus pembinaan sentiasa terlibat dalam penilaian perubahan sumber yang prestasi proses kesan. Oleh kerana keterbatasan dan juga kos sumber, peruntukan sumber telah menjadi satu tugas yang kompleks dalam projek pembinaan. Untuk menilai kesan sumber yang berbeza pada prestasi keseluruhan projek, pengurus berusaha untuk memperuntukkan sumber yang terhad dengan menentukan kombinasi sumber. Kertas ini bertujuan untuk menjalankan kaedah Taguchi bersama-sama dengan simulasi komputer untuk menentukan kombinasi yang optimum sumber untuk kajian kes dunia sebenar yang melibatkan konkrit mencurah operasi untuk mengurangkan masa kitaran dan kos proses. Model simulasi yang dicadangkan ini telah dijalankan di bawah Arena 13.9. Keputusan akhir menunjukkan bahawa gabungan sumber yang optimum akan dicapai apabila semua sumber-sumber yang terletak di tahap yang rendah. Ini bermakna bahawa beberapa trak, anak-anak kapal penyebar, anak-anak kapal dan anak kapal penggetar *finisher* hendaklah sama dengan 3, 1, 1, dan 1 masing-masing untuk meningkatkan jumlah persembahan.

Keywords: Proses menuang konkrit; pengukuran prestasi; gabungan sumber; simulasi komputer; kaedah Taguchi

■1.0 INTRODUCTION

Performance measurement is a vital task in each step of the construction process. Performance measurement was defined by the procurement executive association[1] as a process of evaluating advances toward achieving predetermined objectives, including efficiency and productivity of process.

In the last two decades, a wide variety of innovative management philosophies, techniques and approaches, such as continuous improvement, just-in-time, and improvement in total quality management have been developed[2]. In addition, continuous improvement in a system cannot be acquired without measuring its performance[3]. Continuous improvement in construction process based on performance evaluation is a major area of research in the field of construction management. On the other hand, resource management is another critical issue in the construction industry. In fact, construction planners and decision makers try to manage resource consumption in construction industries[4].

Among performance criteria, cost and cycle time have been given much attention over the last two decades by both industry practitioners and researchers in the construction context[5]. Practitioners in construction process deal with problems such as resource limitation which are caused by lack of efficient available resources for contractors[6]. Limited resources cause disruption time as well as increase related costs during the construction process[7].

This paper aims at determining the optimum combination of resources for a real world case study involving a concrete pouring operation in order to reduce cycle time and process costs. To apply statistical conditions into the model, Taguchi method is combined with computer simulations. In the first step of experiment, the construction process was simulated. In the second step, Taguchi method was performed to determine the optimum combination of resources.

■2.0 BACKGROUND OF RESEARCH

The role of the construction industry in the economy is important in most countries. Indeed, construction industries have considerable influence on quality of general public life as well as the economy[8]. One investigation reported that the industry has wasted over £1 billion due to errors and reworks[9]. The significance of enhancement of productivity, quality, profit safety and project performance was identified[10]. A new approach was suggested that entitled “Government R and D policies and practices” includes investment in construction industry research and progression in order to increase the discipline of teams and the workforce, which are the greatest assets in the construction industry[8].

Construction process implementation requires various initial resources such as labour, equipment and materials which require precise planning to enhance their performance. In other words, improvement in the productivity of the construction process depends on any combination of these resources[11].

Recently, reducing cost and cycle time of construction projects have drawn the attention of researchers and practitioners[12]. In addition most of the resources used in a construction process are limited and costly. This fact motivates construction researches to find the most cost effective tools to determine the optimum level of resources[13]. Furthermore, resource availability is another fundamental requirement of any construction process. Resource limitation in construction process creates major problems which affect the performance of the project leading to construction delays and possible loss of investment[14].

Complexity of the construction projects is another critical issue. In fact construction processes usually include many complicated activities. Therefore, performance enhancement of complicated activities mainly depends on efficient management of different resources[11].

On the other hand, computer simulation have been widely applied to deal with operational problems and to improve the productivity and performance in the different fields such as construction management , manufacturing system , port container terminal that are not easy to model[15-16]. Application of simulation is still limited in the literature. Complexity in construction processes makes a simulation study a necessity in this regard. One study used simulation to evaluate different solutions for managing resources[17]. A fuzzy dynamic resource allocation model was proposed based on fuzzy decision-making approach. In this research, they attempted to improve construction productivity by minimizing parameters such as number of resources waiting in queues and waiting times[14]. Furthermore, another investigation introduced five schemes for sensitivity analysis by using computer simulation software “Micro Cyclone”. The goal of their research was to assess the effect of varying resources on productivity. The results indicate that different scenarios of resource allocation have a considerable effect on the duration of the project as well as project cost[18].

In order to determine the optimum resource combination of each construction activity as well as to improve the productivity of construction process an integrated simulation system known as “construction operation project scheduling” was studied[19]. Additionally, sensitivity analysis was performed for a construction project using computer simulation. They claimed that their research improved the productivity of construction process by nearly 10% by finding the optimum resource combination[20]. Their approach aimed at determining the optimum allocation of resources such as material, man labour, and space, and takes into account resource limitations. They used simulation approaches to allocate different levels of priorities to construction activities. Finally, combined design of experiment and computer simulation was conducted to determine the resource level in concrete construction process[21].

Since limited resource planning and complexity of construction process activities are difficult to manage, a simulation study is conducted in this paper to evaluate a construction process performance based on resource costs. Finally, Taguchi method is applied to investigate the influence of different factors on construction performance. The optimum combination of resources is determined as well.

■3.0 MATERIALS AND METHODS

3.1 Research Framework

The methodology structure of this paper is described in the below chart. Figure 1 shows different steps of this research.

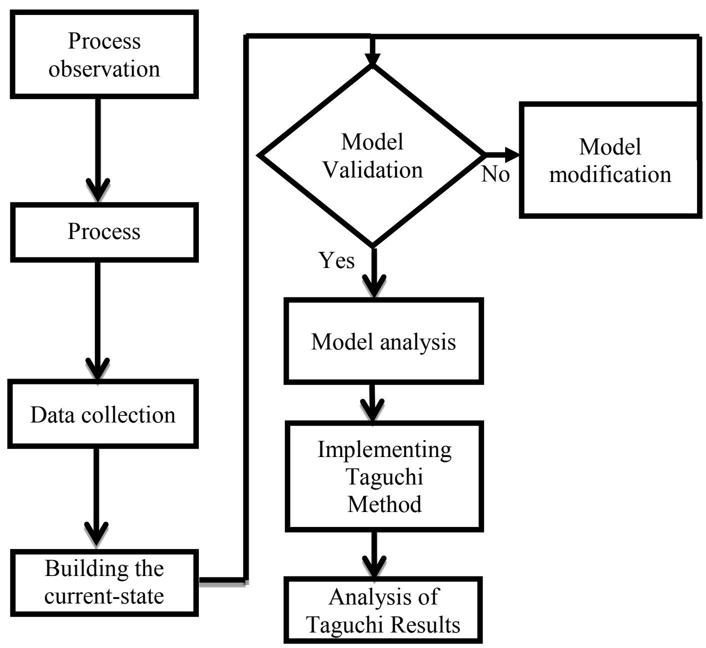


Figure 1 Research methodology flowchart

As shown in Figure.1, the first step of the case study process is observation in order to understand its various features. Next is drawing a process map of the construction process to represent the activity relationships and flow of material and information. Data collection for constructing the simulation model is the third step. Fourth step tries to identify fitting distribution for the collected data. Based on the process map and fitted distributions, an initial simulation model of the process which reflects the current state of the process is constructed.

Model validation steps were done by comparing the achieved results from simulation model and real process. Results obtained from simulation experiments are applied in Taguchi method to find the optimum resource combination. Finally, the results are analyzed to determine the best resource combination based on productivity and cycle time as the performance criteria.

3.2 Case Study

Concrete pouring in a construction project was selected as a case study. This process includes two floors and each floor, based on design specifications, needs 420 m^3 of concrete to be poured. The concrete operation involves two main activities. First operation is concrete pouring of slabs and beams followed by pouring of walls and columns. In this paper, we focus on the concrete pouring of beams and slabs which are divided into 4 x 90 m^3 of concrete.

3.3 Process Mapping

Figure 2 illustrates a process map which begins at the entrance point of the construction site. A concrete truck is to haul nine cubic meters of concrete to the construction site. After the truck has entered the construction site, it is ready for pumping. If the pump is busy, it should wait in the queue until the pump becomes free. If not, the concrete truck goes for slump testing to test and prepare the concrete using responsible labour. Next step is to test and prepare the concrete. A concrete pump is used to pour the concrete. In this step, one operator is responsible for the concrete pumping. Concrete pumping involves the pouring of nine one cubic meter units of concrete. To do so, resource crews perform the remaining concrete activities which include spreading, vibrating and finishing, respectively. Processes of spreading, vibrating and finishing nine cubic meters of concrete were assumed to be conducted in nine parts, the same as the concrete pumping. It should be noted that each activity is allocated one resource crew.

3.4 Data Collection

In this paper "stop watch" method was applied to collect needed data. In this method, all activities were recorded by a video camera and the duration of each operation was recorded by a chronometer. A statistical test which is called goodness-of-fit test was performed. The necessary input data of the simulation model are:

1. Duration of operations such as spreading, finishing, etc.
2. Time between successive arrivals of concrete trucks.

3.5 Simulation Model

Having drawn the process map of the concrete pouring process, the necessary data for the simulation model need to be gathered next. After collecting the required samples of data, a probability distribution function should be fitted to each of them because the inputs of a simulation model are in the form of probability distribution. Following that the model is intended to reflect the current state of the concrete pouring process. In this paper, Arena 13.9 is chosen as the simulation software for developing the simulation model. Figure 3 shows the current-state model for the concrete pouring process. In order to build the simulation model below assumptions were considered:

1. The working times are 24 hours per day and 5 days in week.
2. The employer fulfils a short-term contract to use the trucks and the trucks did not pay based on the time in the system.
3. Trucks breakdown is not considered in this model.

The Table 1 depicts the distributions of process in simulation model that are fitted to the collected data.

Table 1 Distribution fitted to the collected data

Activity	Distribution	Distribution Parameters
Ready to pump and Slump Testing	Johnson	γ= 0.693 ε=3.497 δ=2.508 λ=1.6073
Pumping	Johnson	γ= 0.952 ε=0.754 δ=1.43 λ=0.87
Spreading	Johnson	γ= -0.101 ε=0.58 δ=0.91 λ=0.47
Vibrating	Johnson	γ= -1.189 ε=-0.218 δ=1.497 λ=1.506
Finishing	Johnson	γ= 1.55 ε=0.502 δ=2.194 λ=1.381

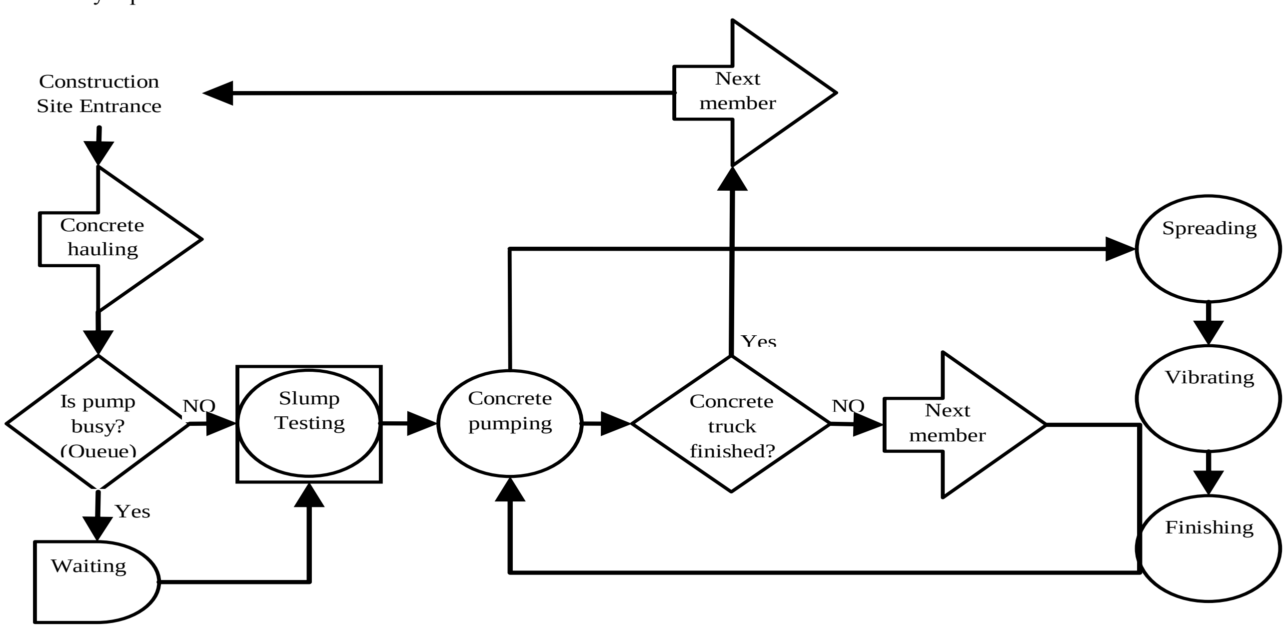


Figure 2 Process map for concrete pouring process

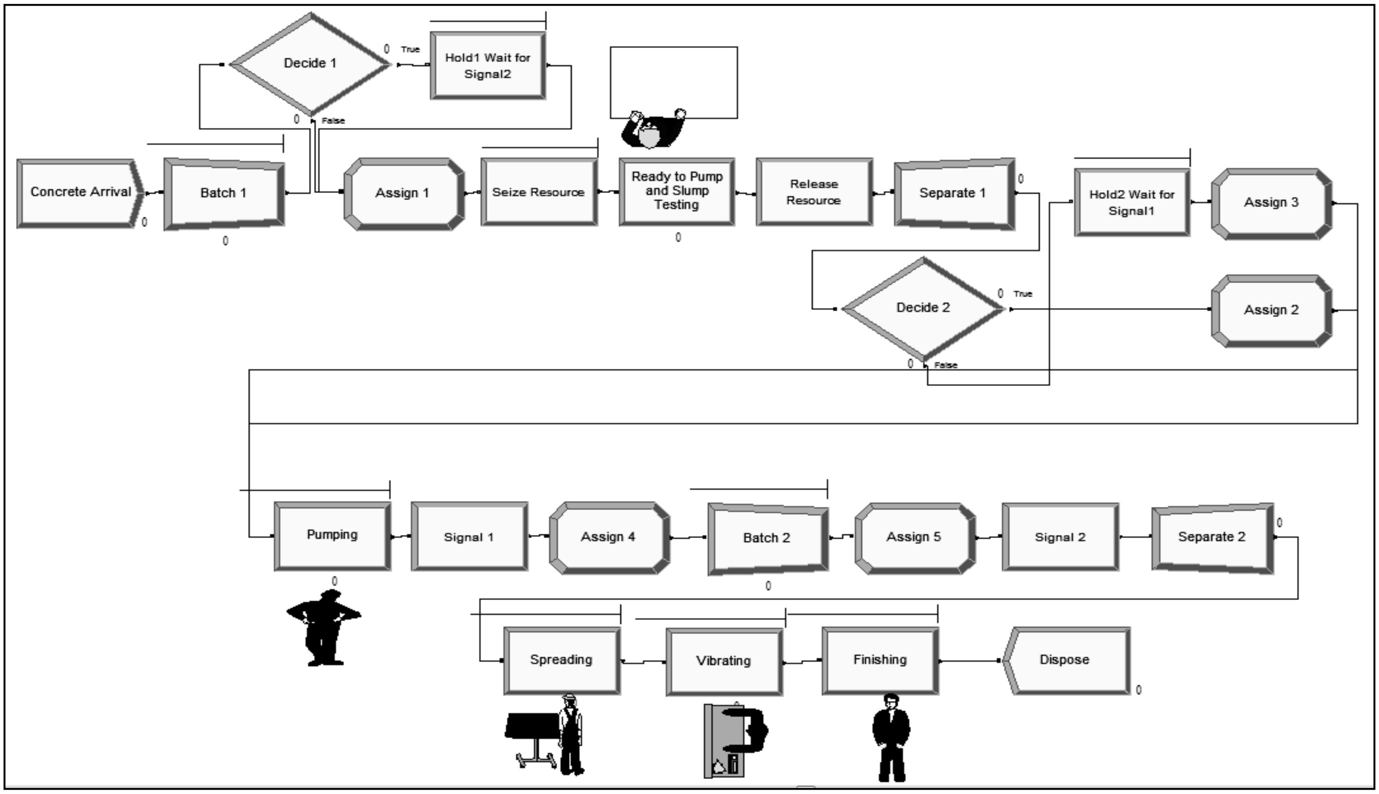


Figure 3 Simulation model of concrete pouring process in Arena 13.9

4.0 RESULTS AND DISCUSSION

4.1 Model Validation

Process cycle time was selected to validate the simulation model. Equation 1 illustrates the number of replications to obtain desired level of accuracy[22].

$$N(m) = \frac{(t a_{/2,n-1} * S(m))}{\bar{x}_m \varepsilon} \quad (1)$$

The definition of parameters in the above equation is explained briefly below:

$N(m)$ = number of simulation replications for obtaining the desired level of accuracy;

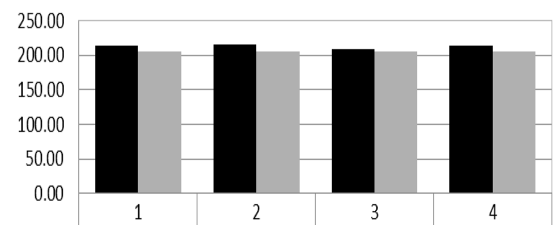
$\bar{x}(m)$ = the mean estimate of an initial m number of replications;

$S(m)$ = the standard deviation estimate of m number of replications;

α = level of confidence;

$t(a/2, n-1)$ = t-value based on the confidence level and the number of runs

The real average cycle time of the concrete pouring process is 205.8 minutes. Figure 4 depicts the comparison between simulation and real outputs. The average process cycle time of the simulation model is 213.55 minutes. The variation between the simulation model and real process is 3.7%.



	1	2	3	4
Simulated Cycle Time (Minutes)- ARENA	214.56	215.64	209.49	214.53
Real-world Cycle Time (Minutes)	205.8	205.8	205.8	205.8

■ Simulated Cycle Time (Minutes)- ARENA ■ Real-world Cycle Time (Minutes)

Figure 4 Comparison of simulation model and real-world process

4.2 Performance Measuring

Total cost of the performance criteria was defined by the total cost of process resources. Each resource cost was calculated by Equation 2. Table 2 shows quantity and cost of each process resource.

Resource Cost = Number of resources*process Cycle Time*Resource cost/hour (2)

Table 2 Resource cost and quantity

Name	Cost/Hour ($)	Quantity
Truck	25	4
Spreader Crew	10	1
Vibrator Crew	12	1
Finisher Crew	15	1

Average cycle time for simulation model is 213.55 minutes and total resource cost is equal to $487.61.

4.3 Implementing Taguchi Method and Computer Simulation

There are various methods used for improving the quality in variety of industries. Taguchi method is one of the best optimization techniques to achieve high quality without increasing cost. It is a simple, systematic and powerful method to increase the quality[23-24]. The advantage of this method is to reduce both product cost and number of experiments required[25]. Mathematical and statistical techniques are combined in Taguchi method[26]. Taguchi method was proposed by Dr Genichi Taguchi in Japan. The main goal of the Taguchi method is decreasing the effects of noise factors as well as determining the optimum level of the main controllable factors by considering the model's robust design[27-28].

Orthogonal array designs for allocating the chosen experimental factors were applied by Taguchi. The most useful orthogonal array designs are L8, L16 and L18. An orthogonal array design can play an important role in the success of an experiment and should be selected carefully. The orthogonal array is applied for calculating the main and interaction effects by running the minimum number of experiments[29].

Taguchi method uses signal-to-noise rate (SNR) to minimize the effect of noise and maximize process performance. In other words, the SNR is the response (output) of the experiment. In order to conduct the Taguchi method, different steps as expressed below should be followed[30].

4.3.1 Choosing Control and Noise Factors

Selected controllable factors in this study are number of critical resources. There are some noise factors which can affect the concrete pouring process and its related cost but they were not considered in this research. The noise factors in this study are concrete supplier, weather condition, and skill level of finishing crew. In terms of concrete supplier, two suppliers can be accommodated in the process. Each supplier has its own concrete truck with a specific amount of concrete load. Therefore, the simulation model can have different batches of concrete based on concrete supplier. Weather condition and skill level of finishing crew also affect the model as they can vary some simulation model elements. As noted earlier, inputs of any simulation model are probability distribution with a specified standard deviation. A noise factor can affect a specific simulation element in a way that varies the standard deviation of its probability distribution. For weather condition, two statuses are defined: fine or bad. This can affect the variability of a simulation model element, Concrete Arrival, by varying the standard deviation of its probability distribution. The skill level of finishing crew can be high or low. This can vary the standard deviation of duration of an activity, Finishing, in the simulation model.

4.3.2 Choice of Factors Levels

The variation range or levels of control and noise factors are indicated in Table 3. As can be seen, each factor has a low (-1) and high (+2) level. The specified levels are considered based on discussion with the construction practitioners and with an awareness of process limitations.

Table 3 Factor levels

	Main Factors				Noise Factors		
Level	(A) Truck	(B) Spreader Crew	(C) Vibrator Crew	(D) Finisher Crew	(E) Concrete Supplier (Concrete batches)	(F) Weather Condition (Std. dev. of Concrete Arrival)	(G) Finisher Crew Skill (Std. dev. of Finishing)
Low Level (1)	3	1	1	1	9	2	1
High Level (2)	5	3	3	3	10	4	2

4.3.3 Selection of the Orthogonal Array Design

In this research L8 was used which indicated assignment of seven factor levels in two levels. Just 8 experiments were required (Table 4). Thus, it is more cost effective in comparison to full factorial experimentation. In addition, there are two linear graphs for L8 orthogonal array (Figure5). Estimation of independent main factors was done using these graphs. Furthermore, if the interaction effect between the main effects is significant, we can assign it to other columns[29].

Table 4 Table of L8

L8 (2^7) Series							
	Factor						
Experiment	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2
	Group 1	Group 2			Group 3		

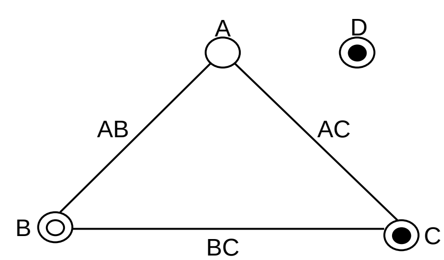


Figure 5 Linear graph for L8 design

4.4 Performing Simulation Experiments

After considering the above conditions, the simulation model is run for different experiments. Table 5 indicates the results of performing the simulation experiment.

Table 5 Data from simulation experiments

					Exp.1	Exp. 2	Exp. 3	Exp. 4
				E	1	1	2	2
				F	1	2	1	2
				G	1	2	2	1
A	B	C	D					
1	1	1	1		427.24	404.10	389.35	422.13
1	1	2	2		594.83	588.89	495.43	545.09
1	2	1	2		559.25	569.97	570.81	558.58
1	2	2	1		570.47	553.85	562.95	546.73
2	1	1	2		642.24	649.73	652.86	649.89
2	1	2	1		602.36	643.78	619.63	669.88
2	2	1	1		637.85	623.53	625.26	741.56
2	2	2	2		514.68	517.98	521.44	530.80

[a] All data are in US dollars

Data analysis was done in Minitab software. Table 6 shows Minitab results for initial data analysis. In comparison with Table 5, the below table has two additional columns which calculate the values of Signal-to-Noise Ratio (SNR) and Mean.

Table 6 Result of data analysis

				Exp.1	Exp.2	Exp.3	Exp.4	Signal-to-Noise	Mean
A	**B**	**C**	**D**						
1	1	1	1	427.24	404.1	389.35	422.13	-52.276	410.705
1	1	2	2	594.83	588.89	495.43	545.09	-54.925	556.060
1	2	1	2	559.25	569.97	570.81	558.58	-55.036	564.653
1	2	2	1	570.47	553.85	562.95	546.73	-54.942	558.500
2	1	1	2	642.24	649.73	652.86	649.89	-56.241	648.680
2	1	2	1	602.36	643.78	619.63	669.88	-56.048	633.913
2	2	1	1	637.85	623.53	625.26	741.56	-56.376	657.050
2	2	2	2	514.68	517.98	521.44	530.8	-54.341	521.225
				Average				-55.023	568.848

Since the response is a nonnegative value and is to be minimized, calculation of SNR is done based on the situation “Smaller is better”. In this situation, the below formula is applied for calculating the SNR:

$$SNR = -10log\frac{\sum_{i=1}^{n} y_i^2}{n} \quad (3)$$

4.5 Determining the Optimum Condition

Having obtained initial analysis of the data, the graphical analysis of mean and SNR were done based on the graphs produced by Minitab for these variables. Figures 6 and 7 show the plots of main effects for mean and SNR.

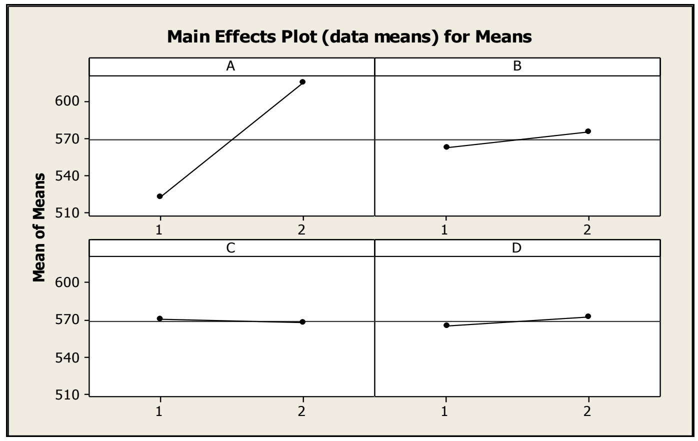


Figure 6 Main effects plots for means produced

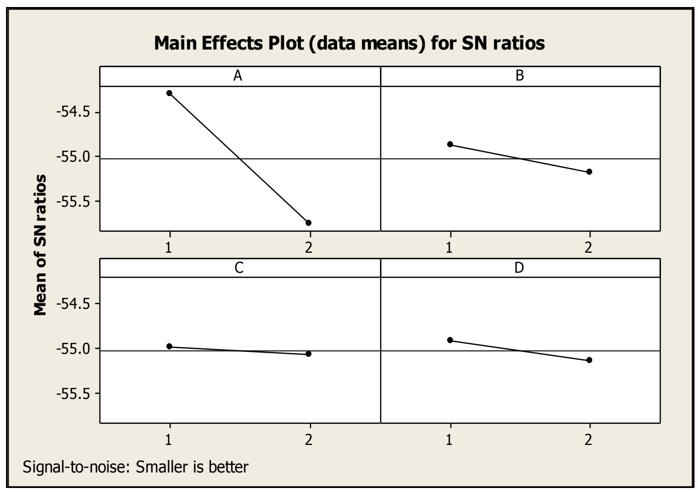


Figure 7 Main effects plots for SNR produced

As can be seen in the above two figures, the most significant factor is factor A which is the number of Trucks. It can also be inferred that the least significant factor that has a poor effect on mean and SNR is factor C which is the number of vibrator crew. According to the effect plots for mean and SNR, the optimum conditions for the control factors are shown in the below tables.

In studying the construction process, the optimal control factor settings regarding the highest SNR have been identified. Table 7 and 8 ranked the studied factors based on their effect value. In order to make decisions about which level is better for minimizing cost, the SNR values at both levels of each factor were compared. Based on Taguchi experiment results (Table 8), the optimum level of the all factors is located in the low level. This means that number of trucks, spreader crew, vibrator crew, and finisher crew should be 3, 1, 1, and 1, respectively to optimize the performance of the construction process based on the resource cost.

Table 7 Table of mean for control factors

	Control Factors			
	A	**B**	**C**	**D**
High Level (1)	522.479	562.339	570.272	565.042
Low Level (2)	615.217	575.357	567.424	572.654
Effect	92.738	13.017	-2.847	7.612
Ranking	1	2	4	3
Optimum Level	1	1	2	1

Table 8 Table of SNR for control factors

	Control Factors			
	A	**B**	**C**	**D**
High Level (1)	-54.295	-54.872	-54.982	-54.910
Low Level (2)	-55.751	-55.174	-55.064	-55.136
Effect	-1.457	-0.301	-0.081	-0.225
Ranking	1	2	4	3
Optimum Level	1	1	1	1

4.6 Regression Model

Based on the estimated effects, ranking and optimum level of control factors, the regression models shown in Equations 4 and 5 are obtained for the mean and SNR, respectively.

$$\hat{Y} = 568.848 + (A_1 - \bar{Y}) + (B_1 - \bar{Y}) + (C_2 - \bar{Y}) + (D_1 - \bar{Y}) \quad (4)$$

$$\hat{Z} = -55.023 + (A_1 - \bar{Z}) + (B_1 - \bar{Z}) + (C_1 - \bar{Z}) + (D_1 - \bar{Z}) \quad (5)$$

4.7 Confirmation

Regarding the achieved optimum condition and regression models of mean and SNR, the predicted value of mean and SNR at the optimum condition are computed as follows:

$$\hat{Y} = 568.848 + (522.479 - 568.848) + (562.339 - 568.848) + (570.272 - 568.848) + (565.042 - 568.848) = 513.588$$

$$\hat{Z} = -55.023 + (-54.295 + 55.023) + (-54.872 + 55.023) + (-54.982 + 55.023) + (-54.91 + 55.023) = -53.99$$

For confirmation, the optimum condition was run 4 times. Simulation model for the optimum condition was also run 4 times and results were compared with the predicted value. Simulation results show values of $464.37, $457.33, $475.91 and $509.94 for average value, which is $ 476.89 and -53.58 for SNR. The calculated variation in mean and SNR values are 7.7 and 0.77 respectively. The values of variations confirm that the regression models were fitted to the data.

5.0 CONCLUSION

In today's competitive market, high quality service expectation and customer demand have forced decision makers to pay much more attention to enhancing construction process performance. This paper aims to conduct Taguchi method along with computer simulation for determining the best combination of resources involved in a real-world construction process. The concentration of this research is on finding a resource combination which has a considerable effect on performance measures. Computer simulation was applied as an effective tool for running experiments in order to conduct the Taguchi method. Based on the Taguchi experiment final results the optimum level of the all factors is located in the low level. This means that number of trucks, spreader crew, vibrator crew, and finisher crew should be equal to 3, 1, 1, and 1 respectively. Therefore we proposed that the application of Taguchi method as a new approach in construction management and resources combination in terms of process cost and cycle time should be investigated in more case studies in future researches. Further study can be done by using other statistical approaches such as response surface methodology to find the global optimum of construction resources.

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