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Full paper

Characterization of Manufacturing System Computer Simulation using Taguchi Method

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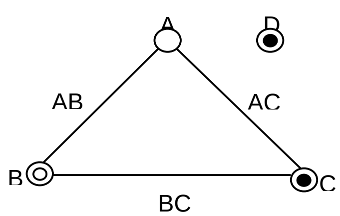
Graphical abstract



Abstract

In the manufacturing industry, managers and engineers are trying to sustain their competitiveness by achieving high output and productivity. There are some common problems such as waiting times, failures, reworks in production line that impose extra cost to the companies. Therefore, companies are striving to find methods in order to determine and deal with problems using different methods such as mathematical, statistical and computer simulation. The goal of this paper is to increase the total output production and to improve productivity using computer simulation and Taguchi method. This paper introduces a color manufacturing line as a case study which is simulated using *arena* 13.9 software. Following that the Taguchi method is applied to assess the effect of controllable and uncontrollable factors on the total output production. According to the result of JMP 10 software to conduct Taguchi experiment, the maximum desirability of productivity will be achieved when the value of factors such service rate of delpak machine=UNIF (30, 40), number of labor=14, inspection time=120 and number of Permil=5. Taguchi Method plays an efficient and suitable role in the process improvement, proposing adjustments that will provide an improvement in the productivity.

Keywords: Computer simulation; Taguchi Method; productivity improvement; manufacturing system; case study

■1.0 INTRODUCTION

Companies require novel tools and techniques to improve performance, profits in order to stay competitive in today's highly aggressive business world [1]. In the manufacturing industry, managers and engineers are seeking to find methods in order to eliminate the common problems in manufacturing systems such as failures, reworks and waiting times. This is because that all of these kinds of problems impose extra cost to the companies. In addition, manufacturing companies are striving to sustain their competitiveness by improving productivity, efficiency and quality of manufacturing industry through higher total output and resource utilization. To achieve this, the companies need to find ways to deal with various industrial problems which have affected the productivity of manufacturing systems [2]. Therefore, there is an essential need to evaluate the different factors which can increase productivity and achieve the high level of quality and high production rate. There are several methods and approaches such as computer simulation, statistical analysis and lean tools for improving the productivity by determining the best combination of resources [3]. Computer simulations have been widely applied to solve operational problems and to improve the productivity and performance in different fields such as manufacturing systems, port container terminal, supply chain management, energy, services, different industries and construction management which are not easy to model [4-9]. There are many advantages of using computer simulation in the manufacturing systems viz saving the money investment, enhance the resource utilization, reducing the process cycle time, and increment of throughput [10].

Manufacturing system includes the complicated combination of resources such as material, labor, machines and methods. So, when the manufacturing systems are faced with a problem, it is difficult to identify the root of problem accurately and effectively. In order to deal with these problems engineers, would apply experimental design to recognize the important factors which have affected system performance. In fact, by using the design of experiments, it is possible to estimate how changes in input variables influence on the result of response of the experiment [11]. Statistical Process Control (SPC), Pareto chart, Quality Function Development (QFD) and Design of Experiments (DOE) are some of the tools used to increase the quality and productivity [12].

DOE is known as an experiment or series of experiments that are done through changing the input process variables, which may have an effect on the output responses [13]. On the other hand simulation can generate and evaluate to provide perception about the performance of system but it is time consuming and difficult work. Therefore, by using DOE and computer simulation, companies can deal with one of the most challenges in modern simulation that is how to reduce simulation times [14]. Mishra and Pandey [15] used the DOE and simulation study of flexible manufacturing systems in order to evaluate the system performance. Some factors such as number of tardy jobs, number of completed jobs, number of running and waiting jobs, mean processing time, inter arrival time and average machine utilization considered for determination of optimized value of these factors to optimize the system performance. Basler and Sepulveda [16] constructed a discrete event simulation model of sawmill industry in Chile. In order to increase the productivity of wood process, a simulation model of manufacturing system was developed for analysing bottlenecks and proposing alternatives that would yield to an improvement in the system productivity. The minimum numbers of human and physical resources needed to meet the required demand were determined by conducting the design of experiment. Productivity improvement up to 25% was recorded by using the computer simulation and design of experiment [16]. Nazzala *et al*. [17] integrated the design of experiment, simulation and economic analysis in the process of decision making at a semiconductor company, applying the validated technique of simulation model. The advantage of the DOE along with the computer simulation is mostly a great help to improve the performance of the simulation process, decreasing the trial and error to seek solutions [18]. Zahraee *et al*. [19] used the DOE and computer simulation in order in order to find the optimum combination of factors that have the significant effect on the process productivity. Another investigation applied statistical analysis and computer simulation to recognize and to weigh the significance of different factors in the production line. Based on the final result, the two factors i.e. B (Number of labor) and C (Failure time of lifter) have the most significant effect on the manufacturing system productivity [20].

The goal of this paper is applying statistical Taguchi method and computer simulation to recognize and to weigh the significance controllable and uncontrollable factors in the production line as well as to achieve the maximum desirability of total production output and productivity.

2.0 MATERIALS AND METHODS

2.1 Computer Simulation

A color factory is selected as a case of study in this paper. The production line of this manufacturing system was simulated using Arena 13.9 software. This company is a leading manufacturer of industrial and building paint. Since the products are produced according to the customer order, the layout of the factory is based on job shop system.

2.2 Taguchi Method

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 [21]. It is a simple, systematic and powerful method to increase the quality [22]. Taguchi method was introduced by Dr Genichi Taguchi in Japan. The main objective of the Taguchi method is to decrease the effects of noise factors as well as determine the optimum level of the main controllable factors by considering the Taguchi's robust design [22]. Orthogonal array (OA) designs for allocating the chosen factors for experiment were applied by Taguchi. The most useful OA designs are L8, L16 and L18 [23]. The orthogonal array is applied for calculating the main and interaction effects by running the minimum number of experiments [24]. Taguchi method applies the signal-to-noise rate (SNR) to minimize the effect of noise and optimize the process performance. In other words, the SNR is the response (output) of the experiment. In order to conduct the Taguchi method, different steps discussed subsequently should be followed [25].

2.2.1 Choosing Control and Noise Factors

The selected controllable factors in this study are service rate of delpak mixer (A), number of labor (B), inspection time (C) and number of permil machine (D). The selected noise factors are rework rate after inspection (E), repair time of lifter (F) and mean time to repair (MTTR) of big mixer (G). The range or levels of main and noise factors are shown in Table 1. As can be seen, each controllable and noise factor has a low level (1) and high (2) level.

2.2.2 Selection of the Orthogonal Array Design

This study chose four main factors with two levels so the L8 OA was used which indicated assignment of seven factor levels in two levels. Only 8 numbers of experiments are required (Table 2). So it is more cost effective in comparison to full factorial design of experiment. In addition, there is a linear graph for L8 orthogonal array (Figure 1). Estimation of independent main factors was done by using these linear graphs. Furthermore, if the interaction effect between the main effects is significant, we can assign it to other columns [25].

Table 1 Main and noise factors and levels

Level	Main Factors				Noise Factors		
	Service Rate of Delpak machine (A)	**Number of labor (B)**	**Inspection time (min) (C)**	**Number of Permil (D)**	**Rework rate after inspection (E)**	**Repair time of lifter (min) (F)**	**MTTR of Big Mixer (G)**
Low level (1)	UNIF (20,40)	14	120	3	0.05	30	25
High level (2)	UNIF(30,40)	20	300	5	0.25	60	250

Table 2 Table of L8 OA

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

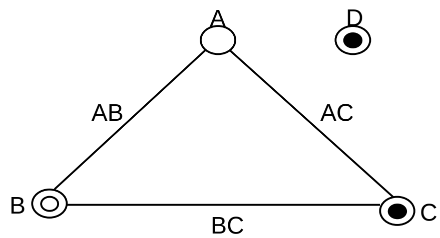


Figure 1 Linear graph for L8 OA design

3.0 RESULT AND DISCUSSION

3.1 Performing Simulation Experiments and Data analysis

Simulation model was conducted using Arena 13.9 software. In this paper, the total output production in unit was considered as the output response. After running the computer simulation model the results of Taguchi design of experiment are shown in Table 3.

Table 3 also illustrated the calculated mean and SNR for each 8 runs.

Since the output response is a nonnegative value and is aimed at maximizing the total output production, the calculation of SNR is based on the situation "Larger is better" [25]. In this case, the formula based on Equation (1) is applied for calculating the SNR. In this formula, n=number of values in each experimental conditions and y_i=each observed value.

$$SNR= -10\log \left[\frac{1}{n}*\sum \frac{1}{y_i^2}\right] \quad (1)$$

Table 3 Analysis of the data produced by JMP software

L8 OA Controllable Factor						L4 OA (Noise Factor)				Mean	SN Ratio
					E	1	1	2	2		
					F	1	2	1	2		
					G	1	2	2	1		
Run	**A**	**B**	**C**	**D**							
1	1	1	1	1		12050	12654	11150	12654	12127	81.63
2	1	1	2	2		15995	14765	12400	13020	14045	82.81
3	1	2	1	2		14700	15100	16202	14650	15163	83.59
4	1	2	2	1		14156	13980	14050	12505	13672.75	82.68
5	2	1	1	2		16250	16980	17020	16995	16811.25	84.5
6	2	1	2	1		16050	16540	16140	16960	16422.5	84.30
7	2	2	1	1		16150	16404	16450	17345	16587.25	84.38
8	2	2	2	2		13456	13560	13775	13950	13685.25	82.72
Average										14814.25	83.33

3.2 Determining the Optimum Condition

The graphical analysis of mean and SNR were done based on the graphs produced by JMP software for each cancellable factor which are service rate of delpak machine, number of labor, inspection time and number of permil machine. Figures 2 and 3 show the plots of main effects for mean and SNR for each four controllable factors.

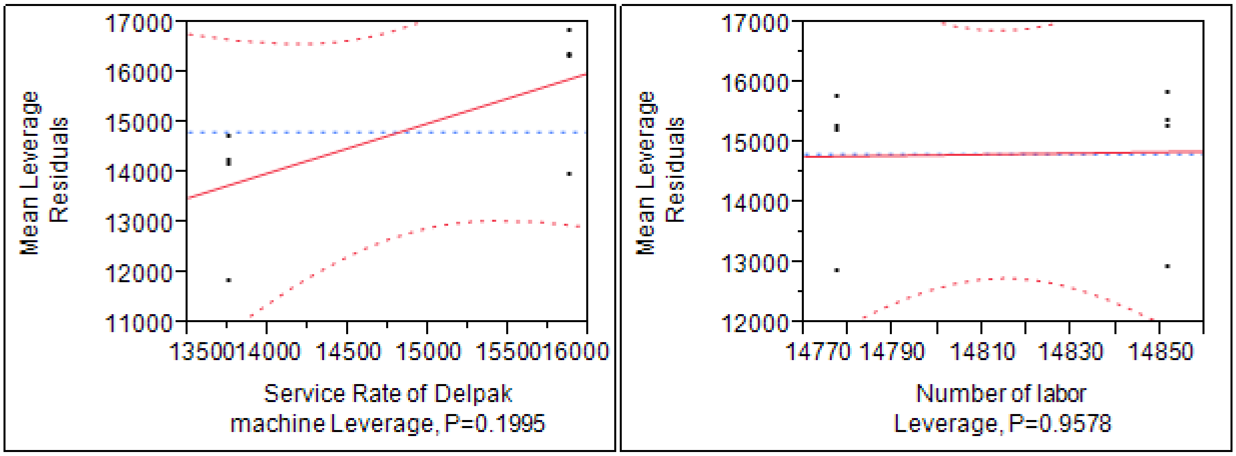


Figure 2 Main effect plot of mean

Table 4 Effect and ranking of mean for each controllable factor

Factors / Levels	Service Rate of Delpak machine (A)	Number of labor (B)	Inspection time (min) (C)	Number of Permil (D)
Low level (1)	13751.938	14851.438	15172.125	14702.375
High Level (2)	15876.563	14777.063	14456.375	14926.125
Effect	2124.625	-74.375	-715.75	223.75
Ranking	1	3	4	2

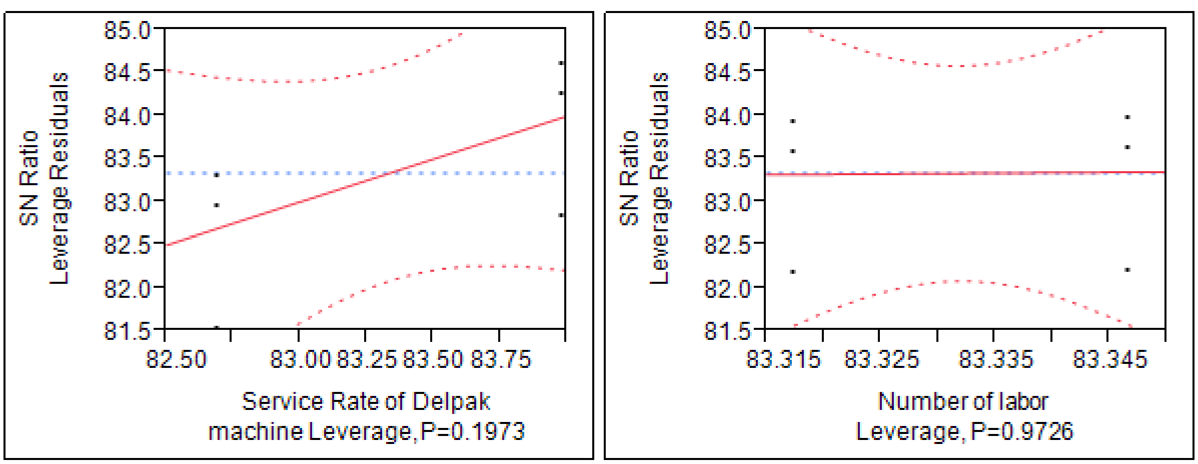


Figure 3 Main effect plot of SN ratio

Table 5 Effect and ranking of SN ratio for each controllable factor

Factors / Levels	Service Rate of Delpak machine (A)	Number of labor (B)	Inspection time (min) (C)	Number of Permil (D)
Low level (1)	82.68	83.32	83.53	83.25
High Level (2)	83.99	83.35	83.13	83.41
Effect	1.31	0.03	-0.4	0.16
Ranking	1	3	4	2

Table 4 and 5 showed the most significant factors affecting the output response based on the analyzing of mean and SN ratio are the service rate of delpak machine, number of labor as an example. It can also be inferred that the least significant factor that poorly affects means and SNR is factor B which is the number of labor.

3.3 Discussion

In order to make decision which factor setting or level is selected to maximize the output response, the SNR values at the both levels (High or Low) of each factor were compared. According to the main effect plots for mean and SNR as shown in Figure 4, the optimum conditions for the controllable factors based on the result of maximum desirability of JMP software, service rate of Delpak machine (A) and Number of permil machine (D) should be placed at high level while the Number of labor (B) and Inspection time (C) should be located at low level. This means that the highest output and maximum productivity will be achieved when the factors A=UNIF (30, 40), B=14, C=120 and D=5.

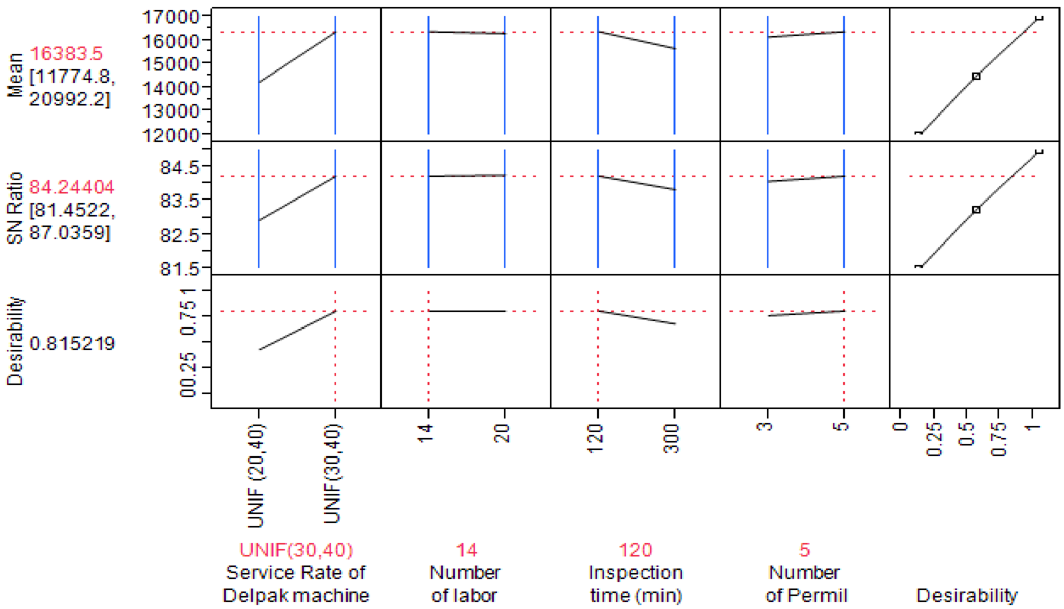


Figure 4 Maximum desirability of controllable factors

3.4 Confirmation

In order to do the confirmation test the simulation experiment is run in the optimum condition of main factors. In addition, Equations (2) and (3) shows the regression model of mean and SN ratio. Table 6 shows the comparison result of simulation model with regression model. It can be seen in the table that the variability is less than 5 percent thus showing the adequacy of the model.

$$\hat{Y} = 14814.25 + (A_2 - \overline{Y}) + (B_1 - \overline{Y}) + (C_1 - \overline{Y}) + (D_2 - \overline{Y}) \quad (2)$$

$$\hat{Z} = 83.33 + (A_2 - \overline{Z}) + (B_2 - \overline{Z}) + (C_1 - \overline{Z}) + (D_2 - \overline{Z}) \quad (3)$$

$\hat{Y}$ = 14814.25+(15876.563 − 14814.25)+(14851.438 − 14814.25) + (15172.125 − 14814.25) + (14926.125 − 14814.25) =16383.501

$\hat{Z}$ = 83.33+(83.98 − 83.33)+(83.35 − 83.33) + (83.53 − 83.33) + (83.41 − 83.33) =84.28

Table 6 Result of confirmation test

No.of experiment	(mean)	(SN ratio)	$\hat{Y}$	$\hat{Z}$
1	16720	84.45	16383.501	84.28
2	16450	84.20		
3	16160	83.80		
4	17050	84.80		
Average	16595	84.1	Variability=1.27%	Variability=0.21%

■4.0 CONCLUSION

This paper employed the Taguchi method to rank and analyse the manufacturing system. Through its simultaneous consideration of the main and interaction effects of controllable factors, this framework by configuring the parameters of an adopted Taguchi method as noise factors in an orthogonal array, the integrated framework yields a more objective improving result, enabling decision makers to generate more competitive strategies. In this paper, after running the computer simulation experiments, it was possible to identify the influence of factors on the productivity and to determine the main factor setting that gave the optimum results affected the total output production and productivity. According to the result of the Taguchi experiment, the maximum desirability of productivity will be achieved when the value of factors such service rate of delpak machine=UNIF (30, 40), number of labor=14, inspection time=120 and number of permil=5. Taguchi Method plays an efficient and suitable role in the process improvement, proposing adjustments that will provide an improvement in the productivity. It is suggested for the future study the other optimization methods such as response surface methodology can be applied to find the local optimum value of main factors.

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