Jurnal Teknologi

Full paper

Application of Design of Experiment and Computer Simulation to Improve the Color Industry Productivity: Case Study

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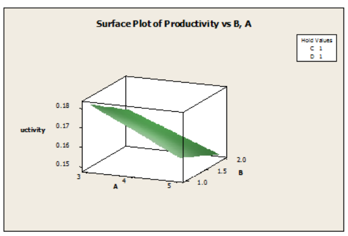
Article history

Received :29 July 2013
Received in revised form :
23 September 2013
Accepted :25 February 2014

Graphical abstract



Abstract

One of the controversial issues in manufacturing companies is bottleneck. Managers and engineers try to deal with this difficulty to improve the productivity such as increasing resource utilization and throughput. One color factory is selected as a case study in this paper. This company tries to identify and decrease the bottlenecks in the production line. The goal of this paper is building the simulation model of production line to improve the productivity by analyzing the bottleneck. To achieve this goal, statistical method named design of experiment (DOE) was performed in order to find the optimum combination of factors that have the significant effect on the process productivity. The analysis shows that all of the main factors have a significant effect on the production line productivity. The optimum value of productivity is achieved when the number of delpak mixer (C) and number of lifter (D) to be located at high level that is equal to 2 and 2 respectively. The most significant conclusion of this study is that 3.2 labors are required to reach maximum productivity based on the resource utilization and cost. It means that 3 full time labors and one part time labor should be employed for the production line.

Keywords: Computer simulation; design of experiment; manufacturing system; productivity improvement; ARENA 13.9

1.0 INTRODUCTION

Now days, manufacturing companies are trying to find useful methods to decrease the common problems in the production line such as bottlenecks and waiting times. On the other hand, companies are striving to increase their competitiveness by decreasing the extra cost and as well as improving the production line productivity and quality of products. To achive these goals, different methods can be applied to deal with different kinds of industrial problems which have effect on the manufacturing system productivity [1].

Computer simulation is an empirical approach to assess the system behavior by developing hypothesis and theories for anticipating future activities based on the changes in operational inputs [2]. In general, computer simulation has many applications in different fields such as improving the process, programming and scheduling, production control and construction management. One of the most useful application of simulation is in manufacturing industry to improve the productivity by enhancing the resource utilization, decreasing the cycle time and increment of throughputs [3-4]. ARENA software is also one of the most useful simulation software which is being applied by practitioners and industrial experts because of its ability in simulating stochastic environment [5].

On the other hand there are statistical methods such as design of experiment that can help the researchers to determine the main factors affecting the process productivity. Indeed engineers are able to estimate how changes in input variables influence on the result of response of the experiment by using the design of experiment [6]. Mishra and Pande [7] applied the design of experiment and computer simulation to analyze the performance of flexible manufacturing system. Basler *et al*. [8] constructed a simulation model of hospital combined use of design of experiment for evaluating the highest number of demand increase in an emergency room in hospital. Basler *et al*. [9] developed a discrete event simulation model of sawmill industry in Chile for analysing bottlenecks and proposing alternatives that would yield to an improvement in the system productivity. One of the most important advantages of using design of experiment 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 [10]. Liu *et al*. [11] applied the DOE as a novel approach to optimize the system. A problem of microsatellite system was proposed to shows the productivity of cited framework. In order to solve the optimization problems of satellite system they simulate the system then DOE was performed to acquire a complicatedly designed plan. Finally the effect of each factor on the system performance was analyzed. Barton [12] showed a tutorial about the experimental design combined with the simulation runs to assess the effect of system design factors on simulation output productivity.

This paper presents the application of design of experiment and computer simulation to recognize as well as to weight the significance of different factors affecting the productivity of color industry production line.

2.0 RESEARCH METHODLOGY

As mentioned earlier, the main objective of this paper is improving the manufacturing system productivity by applying design of experiment and computer simulation. First the ARENA 13.9 software is applied to construct the production line model. Second the DOE approach is applied to conduct the experimental design to determine the significant factors that affecting process productivity. Finally the optimum values of the resource level combination that will result in the best process productivity are identified.

2.1 Design of Experiment

Table 1 shows the factors and levels that are selected to do the experimental design. Based on the small number of factors the full factorial design (2^n) is used. The experiment is also replicated for two times. The Replicate is done by using the random numbers stream in ARENA software. As can be seen from Table 1, each factor has two levels. Each factor has a high (+) and low (-) level. Therefore, a full factorial experiment includes 32 runs.

Table 1 Factors and levels

Factor	level	
	-1	+1
Number of Labor	3	5
Number of Big Mixer	1	2
Number of Delpak Mixer	1	2
Number of Lifter	1	2

2.2 Calculating the Performance Measurement (Response Variable)

In this case study one performance measure based on the cycle time, throughput and resource utilization is selected to evaluate the process productivity. It can be defined as:

$$\text{Process Productivity} = \frac{output}{input} * (100)$$

3.0 CASE STUDY

A Color Factory is selected as a case study in this paper. 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. The production line of different products (such as industrial paint, plastic paint, stone putty, and thinner) is located separately as well as the packaging section and laboratory. The production line of industrial paint has the largest number of machines. Therefore, the industrial paint production line is simulated to conduct the experimental design.

3.1 Production System Description

For production of industrial paints at first, raw material is moved from the inventory part and resin is added to the cauldron and then carried to the mixer by jack pallets. At this level, the paint base is produced. After that the base of paint should be made which can be done by 5 available gloss mills. When the base paint is ready, it is brought to the big mixer and some solvents (according to the type of product) are added to the mixer as well. When the paint is produced, samples are taken for the laboratory tests. If the product does not meet the standards it is mixed again and other necessary material are added to the paint. Finally, when the quality of the product is approved, it is carried to the bascule for weighting and then, moved to the packaging area by the big lift.

3.2 Simulation Model

Figure 1 shows the logic view of production line simulation model.

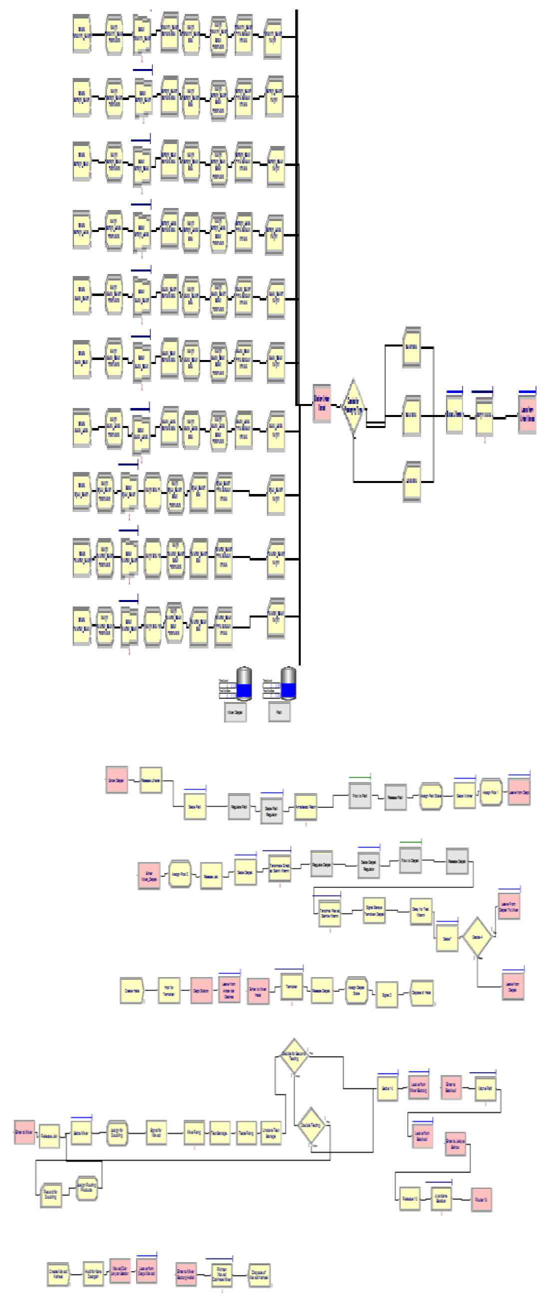


Figure 1 Simulation model of manufacturing system

4.0 RESULT AND DISCUSSION

Table 2 illustrates the result of the 16 experiments which have done. Each scenario was simulated for 720 days and 2 replications.

Table 2 Result of experiment

	A	B	C	D	Response	
1	-	-	-	-	0.1826	0.1810
2	+	-	-	-	0.1627	0.1557
3	-	+	-	-	0.1680	0.1670
4	+	+	-	-	0.1505	0.1486
5	-	-	+	-	0.1649	0.1650
6	+	-	+	-	0.1483	0.1491
7	-	+	+	-	0.1519	0.1521
8	+	+	+	-	0.1423	0.1412
9	-	-	-	+	0.1615	0.1601
10	+	-	-	+	0.1540	0.1512
11	-	+	-	+	0.1497	0.1484
12	+	+	-	+	0.1470	0.1476
13	-	-	+	+	0.1501	0.1503
14	+	-	+	+	0.2017	0.2006
15	-	+	+	+	0.1404	0.1398
16	+	+	+	+	0.1829	0.1894

In this paper Minitab software was applied to do the statistical analysis. Table 3 indicates the results of analysis of variance (ANOVA) for identifying significant factors. Decision about the significance of a factor or effect is made based on the P-value. If the P-value of a factor or effect is less than 0.05, it is considered as significant factor [13].

Table 3 ANOVA result

Term		Coefficient	SE Coefficient	T	P
Constant	**Effect**	0.159550	0.000333	478.65	0.000
A	0.002500	0.001250	0.000333	3.75	0.002
B	-0.01075	-0.005375	0.000333	-16.12	0.000
C	0.002150	0.001075	0.000333	3.22	0.005
D	0.002737	0.001369	0.000333	4.11	0.001
A*B	0.001525	0.000762	0.000333	2.29	0.036
A*C	0.015125	0.007562	0.000333	22.69	0.000
A*D	0.019262	0.009631	0.000333	28.89	0.000
B*C	-0.00050	-0.000250	-0.000333	0.75	0.464
B*D	0.000213	0.000106	0.000333	0.32	0.754
C*D	0.014813	0.007406	0.000333	22.22	0.000
A*B*C	-0.00125	-0.000625	0.000333	-1.87	0.079
A*B*D	-0.00113	-0.000569	0.000333	-1.71	0.107
A*C*D	0.011613	0.005806	0.000333	17.42	0.000
B*C*D	-0.00151	-0.000756	0.000333	-2.27	0.037
A*B*C*D	-0.00158	-0.000794	0.000333	2.38	-0.03

Figure 2 shows the normal probability of the effects. It should be noted that the effects which lie along the line are negligible, whereas the significant effects are far from the line [13]. The significant effects that emerge from this analysis are the main effects of A, B, C, D, two and three way interactions.

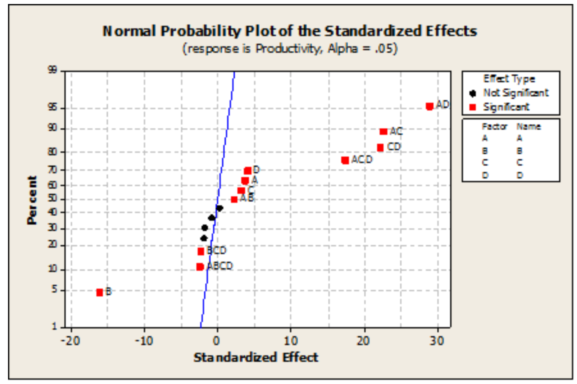


Figure 2 Significant factors

Figure 3 shows the main effect of A, B, C and D. Based on this figure it is concluded that all of the significant factors except B have positive trend. Therefore, in order to achieve high rate of productivity all these three significant factors should be placed on the high level. However it should be noted that main effects do not have much meaning when they are also involved in significant interactions.

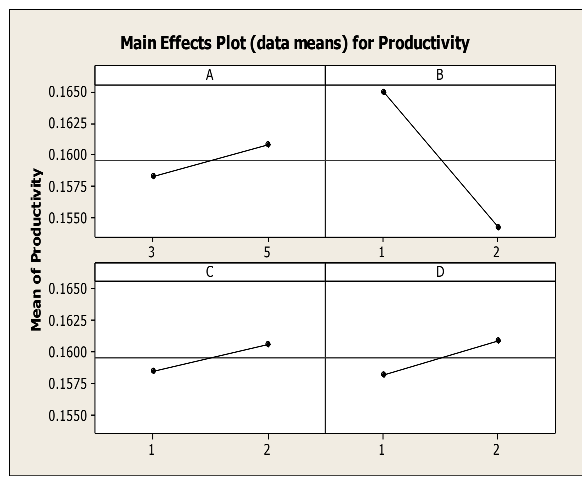


Figure 3 Main effect plots

Surface plot (Figure 4) shows if factors C and D be fixed in high levels, how the factors A and B must be set to maximize the manufacturing system productivity.

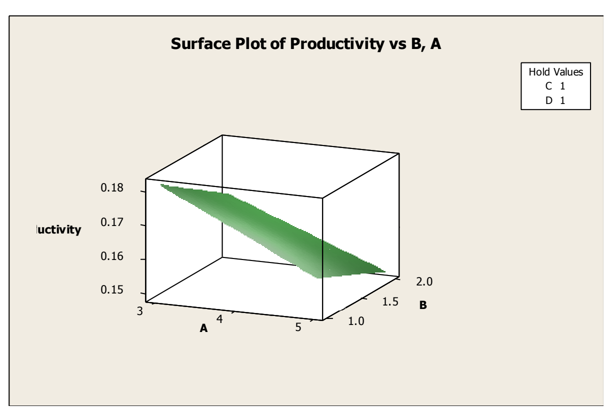


Figure 4 Surface plot of productivity versus A and B

4.1 Regression Model

Equation 1 indicates the regression model fitted to the data produced by Minitab. According to the regression model and the Pareto chart of main effect (Figure 5), the optimum value of productivity is achieved when the all the factors A, C and D to be at high levels and B to be at low level.

$$Y = B_0 + B_1 x_1 + B_2 x_2 + B_{12} x_1 x_2 + \varepsilon \qquad (1)$$

$Y = 0.159550 + 0.002500 (X_A) + (-0.01075) (X_B) + 0.002150 (X_C) + 0.002737 (X_D) + 0.014813 (XC\ X_D) + 0.015125 (X_A X_C) + 0.019262 (X_A X_D) + 0.011613 (XA\ X_C\ X_D)$

$Y = 0.2351$

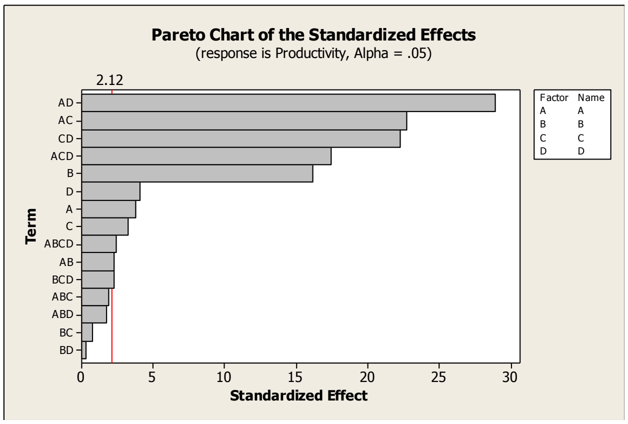


Figure 5 Pareto chart

As can be seen in Figure 6 the dark green area expresses that in order to reach more than 0.18 productivity improvements it is suggested to set the two factors in a low level that are 3 labors and 1 number of Big mixer.

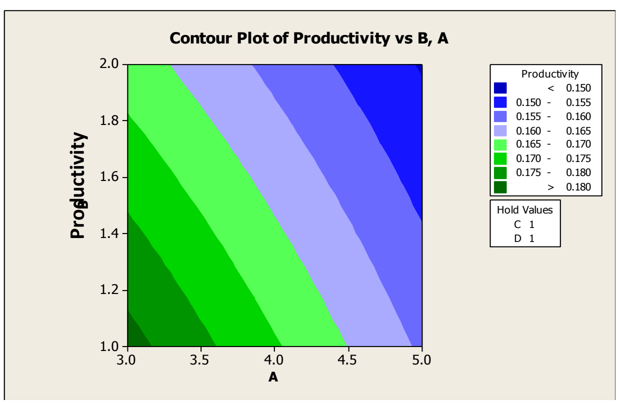


Figure 6 Contour plot of productivity

4.2 Confirmation Test

Based on the result of regression model, the optimum value of productivity is achieved when the all the factors A, C and D to be at high levels and B to be at low level. The productivity at the optimum point is 0.2351. Having achieved the optimum point, the regression model should be tested at the obtained optimum point. Therefore, the simulation model is run at the optimum point that is predicted by the regression model. Following that the result are compared with the outcome of regression model. Table 4 shows the result of 5 runs of simulation model at optimum point predicted by the regression model. It is concluded that the variation between the simulation results and that of regression model is 9.5% which is acceptable [13].

Table 4 Result of confirmation test

Replication	Simulation Productivity	Regression Model Productivity
1	0.2037	
2	0.2206	
3	0.2076	0.2351
4	0.2115	
5	0.2221	
Average	0.2131	
Variation	9.5%	

5.0 CONCLUSION

The main goal of this paper was to investigate the productivity improvement of a color manufacturing company as a case study. This paper indicates that how computer simulation and design of experiment can be combined in order to analyze productivity improvement by evaluating different scenarios as the experiment. The analysis shows that all of the main factors have a significant effect on the production line productivity. The optimum value of productivity is achieved when the number of delpak mixer (C) and number of lifter (D) to be located at high level that is equal to 2 and 2 respectively. The most significant conclusion of this study is that 3.2 labors are required to reach maximum productivity based on the resource utilization and cost. It means that 3 full time labors and one part time labor should be employed for the production line. Moreover, 1.5 number of mixer that means adding another mixer to the production line can help to increase the productivity however it may increase the cost. As the future study of this paper it is recommended to perform more detailed analysis by applying other kind of optimization methods such as response surface methodology.

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