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REDESIGN OF PCB PRODUCTION LINE WITH SIMULATION AND TAGUCHI DESIGN

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ABSTRACT

This paper presents the problem of determining the optimum condition of printed circuit board (PCB) manufacturing process in an electronic company in Ankara, Turkey. In the optimization stage of the study Taguchi method is integrated with simulation model considering minimum total cost under stochastic breakdowns. Using this methodology we investigate the system performance of the current PCB line and determine the optimum working conditions with reduced cost, time and effort.

1 INTRODUCTION

In today's highly competitive electronics industry, a company must be able to adapt to its customers' ever changing needs and improve the quality of its products in order to survive. It is crucial to quickly respond to major challenges such as rapid changes in technology, demand fluctuations, and design changes.

A typical electronic product contains several components that are assembled on laminated boards, called printed circuit board (PCB). PCB is a critical part of many technological devices such as computers, printers and cell phones. In order to enhance the efficiency of the fabrication process and to maximize throughput it is desirable to achieve the minimum cycle time of a product. It is known that PCB manufacturing is highly capital and labor intensive. A PCB line usually includes several stations involving mechanical, chemical and photographic processes. In addition to the complexity of the processes involved and the variation in process times, at stages, the boards may have to be accumulated in batches before they are processed. Therefore, a flow process analysis becomes necessary to achieve a balanced and efficient system. This is a very complex optimization problem and is considered to be a decision making process.

Because of the complex structure of this chemical operation based system and the batch work in most stages, classical flow line techniques are not applicable to analyze and redesign of this system. Therefore, simulation is used as an effective tool. Simulation is a computer model or an inverse transformation function that transforms the inputs into its outputs (Tsai and Mort 1996).

This study demonstrates how Taguchi design is used in practice to find the optimum levels of design factors to redesign the PCB production system considered in this study. In other words, simulation model couple optimization is used both to analyze the performance of the current PCB production line to reveal its bottlenecks at some stages and to determine the optimum working conditions. Validated simulation outputs are collected via Taguchi design to optimize the system.

Taylor and Gravers (1990), Kung and Changchit (1991), Kiran (1993), Nelson and Wille (1995), Rajqumar and Narendran (1997), Kim, Lim and Park (1996), Malmon and Braha (1998), Khoo and Ong (1998), Rajkumar and Narendran (1998), Dengiz and Akbay (2000) studied the assembly operations of the PCB lines with different objectives using simulation as well as simulation based optimization techniques.

This paper is laid out as follows. The next section explains PCB production line simulation and Taguchi design. Section 3 summarizes Taguchi method and optimization. Lastly, conclusions regarding the simulation optimization results are presented in Section 4.

2 PCB PRODUCTION LINE SIMULATION AND TAGUCHI DESIGN

The PCB flow line of an electronic company in Ankara, Turkey is shown in Figure 1. The PCB card considered in this study are used in 15 projects as given in Table 1. In this paper, each product is called a project such as project 1, project 2, etc. because the company does not give any permission to use their original product names.

At the beginning of a month, based on work orders, raw materials come to the material preparing station. These materials are prepared and checked in this station. Then, the boards are sent to pressing station in batches. After this stage, the boards are routed to assembly station. In this station, the small components are assembled on the board. The following two stations are the control and test stations, respectively. The assembled boards are checked for proper assembly in the control station and all the processes up to this stage are tested in the test station. In this station, while defective boards are identified and repaired, the good boards are sent to the mechanic assembly station in batches. After that the boards are plated with a chemical liquid in plating station and are sent to the last test station. Final process is packing and the packed boards go to the warehouse. At the end of each year, the new production plans are prepared for each month of the following year using historical data. Based on our observations, the customer orders can not be regularly delivered at the due dates. On the other hand, in some stages, the average equipment utilization is very low, so it is of interest to see the cost of lost production (delay time). The purpose of this study is to solve these problems with the help of the integration of simulation modeling and Taguchi design. There is clearly an optimization problem here to balance the input (resources) and the output (performance measures) of the system considering working conditions. The performance measures of the system are the number of delayed orders and the percentage of idle resources.

There are many approaches to carry out the integration of simulation model and optimization techniques such as response surface methods, gradient search methods, stochastic approximation methods and heuristic search methods (Azadivar 1992). These methods can find the optimum response but lack a means of evaluating the relationship of the parameters (Tsai 2002). Taguchi Method is another technique that can be used and it limits the number of experiments so that these experiments provide us a solution space for finding the optimum combination of levels.

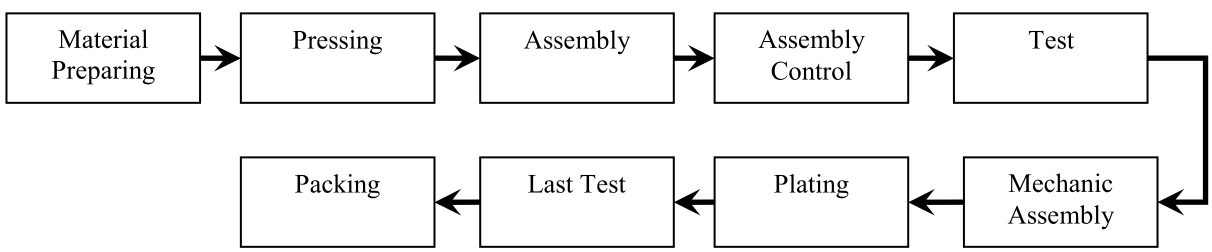

Figure 1. System flow between workstations

Table 1: Groups of set-up requirements at plating machine

Group	Projects	Set-up Time(min)
Group 1	Project 1, Project 3, Project 15	3
Group 2	Project 2, Project 4, Project 5, Project 6, Project 7, Project 8, Project 14	3
Group 3	Project 9, Project 10, Project 11, Project 12, Project 13	3

In this study, the best working condition of the PCB production line is determined using the Taguchi method as explained in Figure 2. Taguchi recommends a three-stage optimization process, namely: system design, parameter design and tolerance design (Phadke 1987). In the parameter design stage, Taguchi develops orthogonal arrays (OA), interaction tables and linear graphs based on the design of experimental theory to study a large number of decision variables with a small number of experiments (Taguchi and Konishi 1987). This process is similar to the simulation optimization process in terms of simulation cost as is mentioned in Tsai (2002). Because of the complex structure of the chemical operation based systems and the batch work in most stages, classical flow line techniques are not applicable to analyze and redesign of this system. Therefore, simulation is used as an effective tool to redesign the PCB production system.

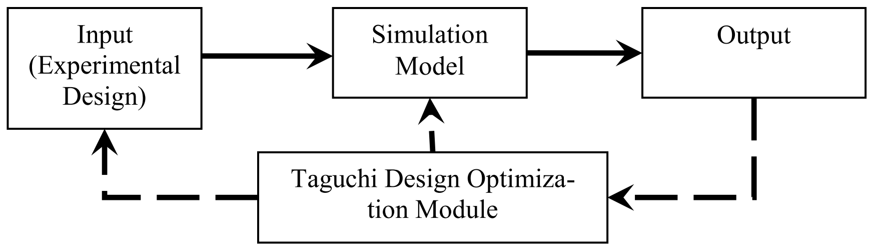

Figure 2: The general structure of the simulation optimization (Tsai and Mort 1996)

The current system is investigated and observed for a six months period to fined out the problems existing in the system. Due to the lack of enough statistical data to determine the appropriate distribution of stochastic processes, and lack of time to collect new data, processing times are modeled with a heuristic method – triangular distribution –, based on expert opinion. Moreover, those processing times are confirmed by consulting the operators working at each workstation. Simulation model of the system is coded using ARENA simulation language. The simulation model is verified partially with the animation property of ARENA software. It is shown that there is no significant difference between the average throughput of the real system and the simulation model for each month at 97.5% confidence level.

2.1 Simulation Model of the PCB Production Line Assumptions

- Percentages of non-defective (true) products passing the test stations for each project are given in Table 2.
- The efficiency of the operators, and daily effective working hours are computed as 0,85 and 6,8 Hours, respectively..
- The batch size is taken as 10 for large sized cards and 60 for smaller sized cards for three stations; pressing, assembly and plating stations.
- Raw material is assumed to be unlimited.
- Material transportation time between stations is ignored.
- Break-downs and repair times are considered as given in Table 3.
- Assembly and pressing machines require set-up for each Project and plating machine requires a set-up procedure for each group. Projects are classified into three groups based on their operation sequence at plating machine as given in Table 1. Setup time is three min. for each group.

Table 2: The percentages of non-defective products at the test station

Project	Test	Last Test	Project	Test	Last Test
Project 1	95	100	Project 9	90	95
Project 2	95	100	Project 10	65	80
Project 3	90	95	Project 11	75	85
Project 4	70	85	Project 12	80	90
Project 5	80	90	Project 13	80	90
Project 6	80	90	Project 14	80	90
Project 7	80	90	Project 15	80	90
Project 8	90	95			

Table 3: The probability distributions of the time between failures and repair times

	Time Between Failures (Day)	Repair Time (Day)
Assembly Machine	2+WEIB(34.9,0.529)	LOGN(0.924,0.765)
Reflow Machine	5+WEIB(55.7,0.645)	0.14+LOGN(0.664,0.553)
Plating Machine	0.5+LOGN(20.5,40)	EXPO(1.07)

2.2 Objective Function

The objective of the study is to minimize the delay cost caused by the product by not being delivered on time and the cost of idle time of the resources.

The delay cost (GM) is:

$$\mathrm{GM}=\sum_{i=1}^{15}\sum_{j=1}^{12}\mathrm{BM}_i\times a_{ij}$$

BM: The unit cost of the Project i
a_{ij} :The number of undelivered or late delivered products of Project i in Month j

The cost of the idle time of resources (KBM) is:

$$\mathrm{KBM}=\sum_{i=1}^{7}\mathrm{YB}_i\times\mathrm{KM}_i$$

YB_i : The annual idle time of resource (hours)
KM_i : Cost of resource (per hour)

Objective Function:

$$Z_{\min}=\sum_{i=1}^{15}\sum_{j=1}^{12}\mathrm{BM}_i\times a_{ij}+\sum_{i=1}^{7}\mathrm{YB}_i\times\mathrm{SM}_i+Other \qquad (1)$$

Other: Machine cost (in the case of buying machines)
The additional assembly machine increases the annual cost. We also take into consideration the amortization and the annual upkeep to compute other cost.

2.2.1 Justification

Headings of sections, subsections, and subsubsections should be left-justified. One-line captions for figures or tables should be centered. A multiline caption for a figure or table should be fully justified. All other text should be fully justified across the page (that is, the text should line up on the right-hand and left-hand sides of the page).

3 THE TAGUCHI METHOD AND OPTIMISATION

The Taguchi method separates the factors that can affect the performance of a system as controllable factors and non-controllable factors. The aim of the Taguchi method is to determine the best levels of controllable factor combinations and design products and processes that show the least change possible in case of non-controllable factors.

The Taguchi method's experimental design consists of eleven basic steps (Ross, 1998) as follows:

1. Determination of the problem to be solved
2. Determination of the performance criterion
3. Selection of the factors that affect the performance criterion and determination of their levels
4. Separation of the factors as controllable and non-controllable
5. Determination of the compound effects to be investigated
6. Selection of the appropriate orthogonal array
7. Drawing of the linear graphics of the controllable factors and their interaction and designation of the variables to the relevant columns
8. Selection of the lost functions and performance statistics
9. Setting up of the experiment and recording of its results
10. Data analysis and determination of the best values of the controllable variables
11. Testing of the results

The first two steps of the experiment are given in the section 1 and 2. Other steps are explained in the following subsections.

3.1 Determination of the factors and their levels

Table 5: Factors and their levels

Factors		Factor levels 1	2
A	Batch-size 1 (Project 3 – Project 15)	10	8
B	Batch-size 2 (Project 1, Project 2)	60	80
C	Number of Test Operators	8	3
D	Number of Mechanic Assembly Operators	14	6
E	Number of Assembly Control Operators	3	4
F	Number of assembly Machine	1	2
G	Number of Material Preparing and Packing Operators	3	2

The current PCB production system is analysed by the simulation model emphasizing the bottlenecks and poorly utilized machines and it is observed that the utilization rate of Tests, Mechanic Assembly, Preparation of Materials and Packaging Operators are low. Therefore, in the alternative systems to be designed, it has been decided that, the number of operators can be decreased according to their utilization percentage. On the other hand, it has been observed that the utilization rates of assembly control operator and assembly machine are high and thus the number of operators and machines has been decided to be increased.

Considering the physical conditions and the management policy of the current system, seven factors and their levels(two levels for each factor) have been determined. These are given in Table 5.

3.2 Selection Of Orthogonal Table And Designing The Experiment

The L_8 Orthogonal Array, suitable for 7 factors with 2 levels has been selected. The design of the experiment of this array has been given in Table 6. This table shows the combinations of levels of each factor which will be considered for each experiment of the simulation run as input.

3.3 Simulation Results and Analysis

At first, five replication of the simulation model are conducted for each experiment. It is shown that the number of experiments is sufficient with the level of 5% relative sensitivity.

The total cost values (objective function value) computed by Equation 1 using the simulation results for each factor combinations are given in Table 7.

Table 6: L_8 Orthogonal Array

Experiment No	A	B	C	D	E	F	G
1	1	1	1	2	2	2	1
2	1	1	2	2	1	1	2
3	1	2	1	1	2	1	2
4	1	2	2	1	1	2	1
5	2	1	1	1	1	2	2
6	2	1	2	1	2	1	1
7	2	2	1	2	1	1	1
8	2	2	2	2	2	2	2

Table 7: Objective function values

Experiment no	A	B	C	D	E	F	G	Total Cost (TL)
1	1	1	1	2	2	2	1	469.336.326.042
2	1	1	2	2	1	1	2	630.331.823.563
3	1	2	1	1	2	1	2	1.018.379.302.070
4	1	2	2	1	1	2	1	640.886.022.406
5	2	1	1	1	1	2	2	772.041.930.214
6	2	1	2	1	2	1	1	741.104.349.716
7	2	2	1	2	1	1	1	704.995.992.282
8	2	2	2	2	2	2	2	471.482.369.863

Experiments for analyzing the effects of seven factors at two levels each are based on Table 6. Each factor is assigned one of the column in Table 6. Table 6 is reproduced in Table 7 as given in Figure 4.21(response table) in Lochner and Matar (1990) on page 88. Assignments of factors to the design matrix columns for seven factors are: A to column 1, B to column 2, C to column 3, D to column 4, E to column 5, F to column 6, G to column 7, then, A=BD=CE=FG is in column 1, B=AD=CF=EG is in column 2, G=AE=BF=DG is in column 3, D=AB=EF=CG is in column 4, E=AC=BG=DF is in column 5, F=AG=BC=DE is in column 6, G=AF=BE=CD is in column 7. The alias relationships for main effects and two-factor interactions are also provided. The factor effects are estimated in response table and “effect” row is computed. The values in the “effect” row are arranged from the minimum value to the maximum value and these arrangements are written in the “sequence” row. The next step after the calculation table is to decide which factor’s statistical effects on cost are important. For this decision the “normal probability graph” (NPG) is used. According to NPG, it has been concluded that the statistical effects of the C (number of test operators), D (number of mechanic montage operators) and F (number of assembly machines) factors are important. The levels of these factors should be chosen in a way that will decrease the cost. These levels are : C_2=3, D_2=6, F_2=2. As the other values are either on the line or near the line, their effects on the cost are not important. Yet as the aim is to decrease the cost as much as possible, the levels with the lowest values of these factors in the average row of the calculation table are chosen. As a result of the values from the levels of the new factors, the system has been redesigned and thus the total cost has been calculated via simulation. It has been concluded that the new system is better than the current system and the redesigned system cost is less by 46,63 %.

4 CONCLUSIONS

Taguchi design is used to find the optimum levels of the design factors in redesigning a PCB production system. Simulation model coupled with optimization is used both to analyze the performance of the current PCB production line to reveal bottlenecks and determine the optimum working conditions.

In this study, the aim was to minimize the costs arising from idle time of the resources in the production line and the costs of products not delivered on their due dates. First the seven factors and their levels have been determined. Then, to determine the effected levels of these factors, the Taguchi method has been applied to design the experiment. As an outcome of this analysis, the effect of the number of test operators, mechanic montage operators and assembly machines on the cost have been found high. The optimal system (redesigned system) has 60 batch size (remain same) for the Project 1 and Project 2, 8 batch size for the other projects (decreased from 10 to 8), three test operators (decreased from 8 to 3), six mechanic operators (decreased from 14 to 6), five assembly and assembly control operators (increased from 4 to 5), two assembly machines (increased from 1 to 2), three material preparation and packaging operators (remain same).

The simulation model is run with the parameter values (factor values) of the alternative system with optimal working conditions obtained from the optimization of simulation. It is shown that the total cost of the system has been decreased by 46.63 percent.

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