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# AHP를 활용한 반도체부품 생산공정 시뮬레이션 연구

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# A Simulation Study on the Manufacturing Process of Semiconductor Parts Using AHP

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ABSTRACT

The semiconductor manufacturing process normally includes a great number of complex sequential steps those are related with various types of equipment. Such equipments are installed with the mixed patterns of serial or parallel structures while considering a number of engineering or environmental factors at the same time. It is thus extremely difficult to change the layout after installation due to expensive costs and other related factors. Because of these reasons, a new investment or layout change, which is usually caused by the production policy such as product mix or production quantity, must be carefully considered. This case study introduces a simulation conducted in a semiconductor parts production company which produces the Board on Chip (BOC)-type of packaging substrate and has plans to change the facility layout. For this study, we used QUEST® for simulation modeling and evaluated various strategies which may cause layout changes. Further, the Analytic Hierarchy Process (AHP) is applied to select the best strategy from several alternatives with multiple decision criteria.

**Key words** : Simulation, Semiconductor, Manufacturing process, Layout, AHP

요 약

반도체 생산공정은 다양한 장비들이 복잡하게 서로 연관된 일련의 작업들로 구성되어 있다. 이들 장비들은 공학적 또는 환경적 요인들을 고려하여 직렬 또는 병렬의 혼합구조로 배치되어 있다. 따라서 많은 비용이 발생하고, 동시에 고려해야할 사항이 복잡하므로 한 번 설치되면 레이아웃 변경이 거의 불가능한 실정이다. 따라서 생산량의 변동이나 신제품의 개발과 같은 상황에서 새로운 설비의 투자나 레이아웃의 변경은 매우 신중하게 결정되어야 한다. 본 논문은 반도체의 부품을 생산하는 공장에 대해 시뮬레이션을 적용한 사례연구다. 시뮬레이션 모델은 QUEST®라는 도구를 이용하여 개발되었으며, 시뮬레이션을 통하여 생산환경의 변화에 대응하는 다양한 전략을 검토하였다. 또한 본 연구에서는 결정인자가 다수인 대안에서 최적안을 도출해 내기 위하여 AHP 기법을 사용하였다.

**주요어** : 시뮬레이션, 반도체, 제조공정, 배치안, AHP

## 1. 서 론

From space ships to mobile phones, semiconductors have pervaded every fabric of modern society. The process of manufacturing semiconductors produces chips and integrated circuits that are presented by many electrical and electronic sequences.

The chip-scale package (CSP) is a type of integrated circuit chip carrier, which has been developed to satisfy ever growing challenges to improve a format's small form factor and to facilitate excellent electrical performance [7]. It can be classified into different groups based on different substrates, such as the package substrate

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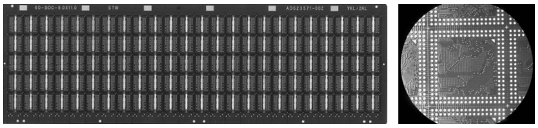

**Fig. 1.** Package substrate product

and the tape substrate.

Figure 1 shows samples of package substrates produced by a Korean company which adopts the Board On Chip (BOC) technology. This technology transmits electrical signals through a solder ball not leads, and it minimizes thermal and electric degradation due to high capacity and high speed. Thus, a BOC substrate enables high speed of DDR DRAM to overcome signal delays by short electrical paths [12].

Due to the complexity of the processes involved, a semiconductor production line generally includes various equipments. Therefore, how to design a good layout becomes an intractable study during a long period. Facility layout design (FLD) has a very important effect on the performance of a manufacturing system [3]. The concept of FLD usually consists of numerous mathematical methods or algorithms that have been studied to achieve the optimal design of a facility layout. However, there are many limitations in applying the results to the actual factory layout. Thus, virtual manufacturing technologies have been recently used to verify the design alternatives. Simulation technology has also been utilized to complement FLD in order to identify the design error or provide suggestions for improving line performance.

In the manufacturing process, several basic types of layouts are usually mentioned and used in the layout design phase. These include the product layout and the process layout. The process layout is used in a job shop producing customized, low-volume products that may require different processing requirements and sequences of operations. On the other hand, the product layout is used in a flow shop producing high-volume, highly standardized products that require extremely standardized and repetitive processes [5]. The package substrate production shop of the company considered in this paper can be regarded as a flow shop which adopts the product layout.

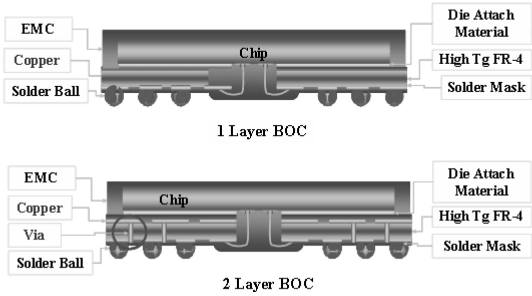


**Fig. 2.** Features of BOC

A complex system like semiconductor product line usually requires more than one measure to analyze its performance. The decision for choosing a best solution among these factors with fuzzy relationships belong to the multiple criteria decision making (MCDM) problem, that may be defined as a situation in which one has a set of criteria to consider along with a set of alternatives in order to: (1) determine the best alternative or a subset of best alternatives (choice problem), (2) rank alternatives from best to worst (ranking problem), or (3) divide the set of alternatives into subsets according to existing norms (sorting problem) [10].

Developed by Saaty, the Analytic Hierarchy Process (AHP) is one of the most powerful approaches in solving the MCDM problem as proven by many managers and authors [2,4, and 11]. By using AHP, experts believe that the best solution can be found among similar simulation alternatives.

## 2. CONFIGURATION OF THE SYSTEM

A manufacturing layout design is usually restricted by various actual factors such as space availability, machine size and production process, among others. Thus, a manufacturing layout design generally needs to achieve in a circumscription and the information of this circumscription should be collected first.

### 2.1 Products Mix

There are two types of features in the BOC substrates: the one-layer type and the two-layer type (Figure 2). Our case study company has produced hundreds of different products characterized as the one-layer type (Type A), in accordance with the customer's orders. Recently, the company has made plans to produce products with two-layer type (Type B) features. Thus, a new investment and corresponding layout should be considered.

## 2.2 Manufacturing Processes

Figure 3 shows the manufacturing processes of two types of products in which we can see that the processes of Type B are more complex than those of Type A. Overall, there are 34 processes with 61 machines in the existing shop. Distinctly, from Process_8, both types of products have similar process flows. Meanwhile, in the cleaning machines (Op25 and Op28 in Figure 4), the different processes are conducted in the same machine.

The raw materials of the products consist of the reel type of Copper Clad Laminate (CCL). The width of a reel is 80-350mm, and the length of a reel is 50-100m. In the window-punching process (Op23 in Figure 4), one reel is divided into four reels, each of which is called a "lot." One lot contains about 40,000 pieces of substrates that actually vary depending on the product.

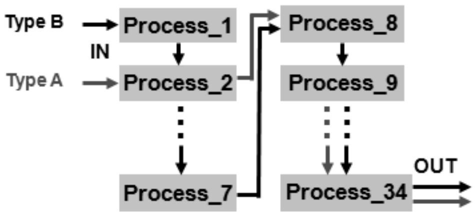


**Fig. 3.** Processes of the product

## 2.3 Layout

The basic layout concept of the shop is a product layout with parallel machines. However, the ideal concept of a process layout has already collapsed because of frequent layout changes. One important restriction in this shop is the class of the clean room which causes many backtracks in the shop and a more complex material flow.

The design of new layout consists of three areas, because the machines are installed in three different buildings (Figure 4). In the figure, squares denote the machines, and the numbers on each square denote the process sequence.

## 2.4 Data Collection

Data collection plays a crucial role in the proposed simulation methodology as it can affect the quality and duration of the preparation period. The data below were gathered for the simulation analysis.

- Cycle time and loading/unloading time;
- Setup change time;
- Down time distributions of machines and labors including breakdown, maintenance, defects of raw material, tool change, etc;
- Shift works;
- Labor assignment;
- Buffer location and capacity; and
- Defect rates.

Mainly, elevator and AGV(Automatic Guided Vehicle) are used as the transfer tools between buildings. Due to the fact that there are no conveyors between machines, all the transportation processes conducted between pro-

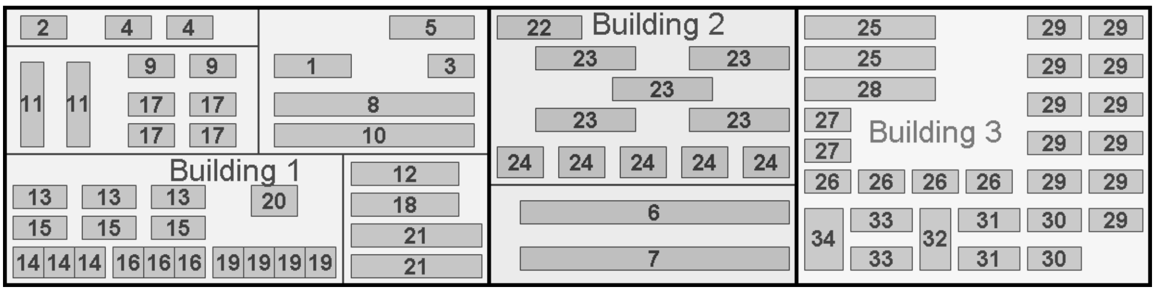


**Fig. 4.** New block layout of the shop

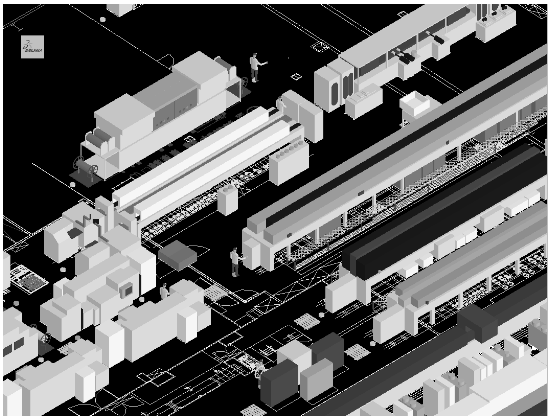

**Fig. 5.** 3D simulation model

cesses are manually accomplished by workers. About 37 workers are needed in this line. The working shifts among workers are different, because machines either work 24 or 16 hours per day. Except the inspection workers, the tasks of other workers include set up, loading and unloading, in-line gauging, short time of repair, material transportation, and so on.

## 3. SIMULATION MODELING

Three-dimensional simulation is a kind of dynamic analysis method allowing the determination of the current and future behaviors of the process [6], which has proved to be highly effective for rapid prototyping, visualization and testing 'what-if' scenarios in the manufacturing engineering domain [9].

The design of large scale manufacturing systems often utilizes various discrete-event simulation tools for layout design, bottleneck analysis, throughput analysis, etc. [1]. In this paper, the simulation models were developed with QUEST® (see Figure 5), which is a simulation tool with 3D digital factory environment for process flow simulation and analysis, accuracy, and profitability [8]. Furthermore, a great number of user-defined programs were also developed using Simulation Control Language (SCL) that can be set into the model to achieve the complex function for simulating the real product line likewise.

By intercalating the information data (e.g. cycle time) into the 3D simulation model, discrete event simulation will be implemented so that the performance data of product line can be gained and analyzed.

## 4. EXPERIMENTS AND RESULTS

The simulation run time was set at a period of 6 months, while the warm-up period was set to 2 months. Most of the simulation experiments generally included two phases, labeled "As-is" and "What-if." For each scenario, five replications were conducted. The As-is analysis was carried out to validate the simulation model and investigate the performance of the initial layout of the line. With the results obtained from the As-is analysis, some improvements were suggested and then verified in a What-if simulation.

### 4.1 Performance Measures

Generally, for a complex manufacturing system, several measures should be integrated for one or more targets in order to provide a comprehensive analysis among numerous involuted factors. The performance measures used in the simulation are as follows:

- Machine utilization;
- Labor utilization;
- Throughput;
- Work In Process (WIP);
- Manufacturing lead time; and
- Percentages of product mix.

### 4.2 As-is Analysis

The objective of the As-is analysis is to confirm the correctness of the simulation model. Using the data collected from the existing line, the simulation results of the As-is analysis should correspond to the real system.

In this existing line, only type A (one layer) products were produced. There were four product groups which were grouped based on the different sizes, shapes of package substrate and production routings. In other worlds, type A products were divided into four groups (A-1 to A-4) as shown in Table 1.

According to the data gathered, the real production

**Table 1.** Simulation results of as-is analysis

| Group | Real System | Simulation | Difference |
|---|---|---|---|
| A-1 | 56.1% | 58.2% | 1.6% |
| A-2 | 26.7% | 27.3% | 0.6% |
| A-3 | 11.1% | 9.6% | 1.5% |
| A-4 | 6.0% | 4.9% | 1.1% |

quantity in October 2007 was 77 million and the simulation result was 78 million. Moreover, the proportions of four groups were similar as shown in Table 1. From the comparison, we convinced that the simulation model was valid for representing the real production system. Upon ensuring the validity of the model, the experiments for the new layout with two types of products will then be carried out in the What-if analysis.

Several bottleneck processes were identified after analyzing the utilization of machines and labors. Figure 6 shows the utilization of bottleneck processes in the existing line. In this analysis of results, we categorized the whole simulation time related to machines into four categories, and they were processing time, blocking time, failure time and idle time (including starving time). Processing time included loading/unloading time and operation time. There were eight components in the failure time including setup change, major failure, minor failure, preventive maintenance and so on. Blocking time was caused by the problems (like failures) of the direct succeeding processes. Therefore, if the portion of blocking time is high, then the buffer size next to the process and the succeeding processes should be investigated (see processes 13 and 27 in Figure 6). Obviously, Most of these machines' level of utilization reached a value of about 80%. The proportions of failure time for operations 11, 17, 21 and 29, took up almost 10%. That means it would be difficult to increase the throughput without adding a new machined to the process because of the failure time and blocking time. On the other hand, the levels of utilization of labors units of the 26 and 27 processes were almost 90%, which were values evidently higher than the others (this graph does not presented in this paper).

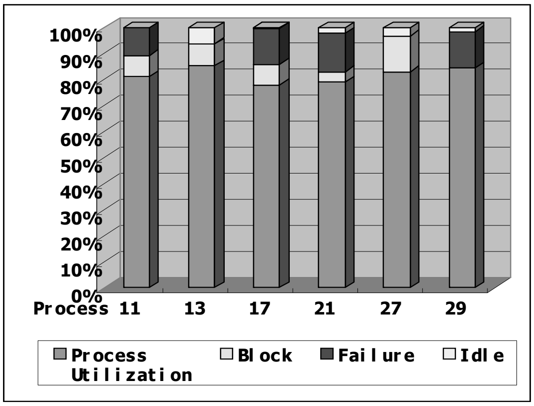


**Fig. 6.** Machine utilization in as-is analysis

### 4.3 What-if Experiments

The what-if experiments of this system had two main objectives: one was to improve the performance of the machines and increase the throughput, and the other was to explore the possibility of changing the product mix with the new product (two-layers). The new throughout target was set at 120 million pieces/month. The strategies suggested by the company included the increasing of the number of machines, labor units, and working hours.

- **Scenario 1**

In Scenario 1, two groups of two-layer products (B-1, B-2) were introduced and two groups of one layer products (A-2 and A-4) were allowed to cease production. This resulted in altered proportion of quantities. Seven machines were purchased due to the new processes and 17 machines including inspection were added to the existing system. Six labor units were also added to the existing system according to the plan.

The Simulation results in Table 2 indicate that Scenario 1 failed to achieve the target. We thus conclude that there are many problems involved in line balancing.

- **Scenario 2**

From the simulation result of Scenario 1, we modified the number of machines and labor units in some processes. The cycle time of some processes were reduced after improving the manufacturing technology involved.

**Table 2.** Comparison Between Scenario 1 and 2

| Product | Plan | Simulation Result | |
|---|---|---|---|
| | | Scenario 1 | Scenario 2 |
| A-1 | 24.7% | 21.8% | 22.0% |
| A-3 | 68.0% | 73.3% | 73.6% |
| B-1 | 4.1% | 2.8% | 2.7% |
| B-2 | 3.1% | 2.2% | 1.8% |
| Throughput | 120million | 79million | 121million |
| WIP | - | 2.5million | 2.3million |
| Lead Time (day) | Type A | 14.0 | 7.6 |
| | Type B | 19.1 | 12.1 |

Furthermore, 3 machines and 6 labor units were added to those employed in Scenario 1. The existing shifts within process 2 and process 8 to process 34 changed from two shifts/day to three shifts/day.

The simulation results of Scenarios 1 and 2 are shown in Table 2. We can see from the results in Scenario 2 that the 120 million pieces/month target is actually achievable. Meanwhile, the WIP (work in process) and manufacturing lead time decreased.

- **Scenario 3**

The purpose of this scenario was to reduce the working days in one week from 7 to 5, and to keep the Throughput within 120million/month. However, after reducing the working days to 5, the Throughput remained at 84million/month (Scenario 3-1). Therefore, several solutions were suggested in some processes: (1) change the machines to new ones with shorter cycle time; (2) reduce loading and unloading time; and (3) reduce setup time. In fact, all three solutions are difficult to achieve in a real factory, but since this is a design of a new product line and the objective of the simulation test is to identify more feasible solutions, therefore, we assumed that some new technology can be applied and some new machines could be purchased (Scenario 3-2).

Table 3 shows the results of Scenarios 3-1 and 3-2. Unfortunately, although all of the above suggestions were carried out, it was still impossible to achieve the target of 120million/month because of the fixed capacity of buffers and restrictions posed by the substrate line.

**Table 3.** Simulation result of scenario 3-1 and 3-2

| | Plan | Simulation | |
|---|---|---|---|
| | | Scenario3-1 | Scenario3-2 |
| Throughput | 120million | 84million | 104million |
| WIP | - | 1.4million | 2.2million |
| Lead Time (day) | Type A | 8.9 | 7.7 |
| | Type B | 12.4 | 11.0 |

**Table 4.** Alteration item of scenario 4

| Scenario | 6 days working process | 1 labor added process |
|---|---|---|
| S4-1 | 21,26,30 | |
| S4-2 | 17,21,26,30 | |
| S4-3 | 9,11,14,16, 17,21,26,30 | |
| S4-4 | 21,26,30 | 30 |
| S4-5 | 21,26 | 30 |
| S4-6 | 21,26,30 | 34 |

**Table 5.** Simulation results of scenario 4

| | Throughput (million) | WIP (million) | Lead Time (day) | |
|---|---|---|---|---|
| S4-1 | 116.08 | 2.9 | 9.10 | 13.03 |
| S4-2 | 116.48 | 3.0 | 9.99 | 13.95 |
| S4-3 | 118.69 | 10.7 | 21.49 | 25.44 |
| S4-4 | 118.72 | 2.3 | 7.84 | 11.99 |
| S4-5 | 118.05 | 2.3 | 7.94 | 12.11 |
| S4-6 | 116.59 | 2.9 | 8.86 | 12.37 |

Until now, 104 million per month is considered as the best Throughput. Therefore, the idea of increasing working days, labor units, and number of some machines must be considered.

- **Scenario 4**

The alteration item of Scenario 4 is shown in Table 4. Most of the changes focus on the bottleneck processes, such as processes 21, 26,and 30. Especially for processes 30 and 34, one more labor unit is added respectively in Scenarios 4-4, 4-5, and 4-6.

Based on the simulation results shown in Table 5, the lead time of Scenario 4-3 has greatly increased, which could be attributed to the different working days of the machines, meaning that if the upstream process works in the 6th day of a week, but the downstream process does not, the products produced by the upstream process should wait in buffers until the downstream process begins to work. Therefore, the more machines are operated 6 days a week, the more products should wait in the buffer areas.

If we only consider the measurement of Throughput, Scenarios 4-3 and 4-4 seem to be better solutions than the others. However, after considering the WIP, Lead Time, Labor Number and different working days of machines, Scenario 4-5 also seems to be an acceptable solution. Therefore, it is difficult to get the conclusion directly just by simple observation. This is the reason why AHP method has been applied in this paper. Since that Scenario 4-3 is not a reasonable solution because of its higher WIP, Lead Time, and inconsequential Shifts, only the other five other scenarios will be discussed.

## 4.4 AHP Application

### 4.4.1 AHP Structure

The establishment of the AHP structure requires extensive information collection and investigation. In fact, in the simulation experiments phase, several performance measures have already been applied for the scenario analysis. Thus, when establishing the criteria layer of the AHP structure, the focus is to translate these into criteria measures. After gathering advice from managers and engineers, Throughput, WIP, Lead time, Labor Number, and Shift are regarded as the important factors affecting the performance of the substrate line. The AHP structure is framed like the configuration shown in Figure 7. The objective is to select the best solution based on the five criteria presented among five alternatives.

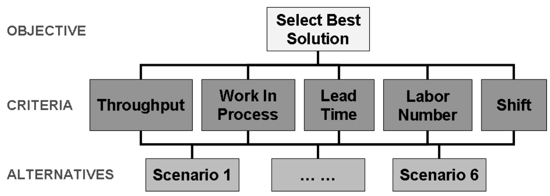


**Fig. 7.** The AHP structure

### 4.4.2 Comparison Matrix of Criteria

In the AHP approach, there are two kinds of matrixes that should be calculated: one is the comparison matrix of criteria, and the other is the comparison matrix of alternatives. Table 6 shows the scale of importance by which both kinds of comparison matrixes can be gained. In most cases, several matrixes should be collected from different managers or engineers as references to help identify the appropriate one.

The importance of these comparison matrixes is that they serve as the criteria for judging various alternatives. This means that the final ideal solution is to be established by these matrixes. Therefore, the calculations of matrixes must be conducted accurately.

Table 7 shows three sample comparison matrixes suggested by different constitutor for this AHP structure. Since AHP method is brought out to solve the decision making problem among alternatives with faintness relationship, the strong relative situation of criteria such like A>B>C (A, B and C are the criteria) should be avoided. Therefore, the value of CI (Consistency Index) and CR (Consistency Ratio) should be calculated in order to prove the consistency of the matrix. Only when this matrix equal or is close to a consistency matrix, the yield priorities for criteria that calculated from above matrix is regarded as creditable.

$$CI = (\lambda_{\max}(A) - n)/(n-1),$$

where $A$ is the comparison matrix, $\lambda_{\max}(A)$ is the maximum eigenvector of matrix, and n represents the rank number of matrix. Then,

**Table 6.** Scale of importance

| intensity of importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Weak importance |
| 5 | Strong importance |
| 7 | Demonstrated importance |
| 9 | Extreme importance |
| 2, 4, 6, 8 | For compromise between the above values |

**Table 7.** Comparison matrixes reference

| Matrix 1 | Throughput | WIP | Lead Time | Labor Number | Shift |
|---|---|---|---|---|---|
| Throughput | 1 | 7 | 5 | 1/3 | 2 |
| WIP | 1/7 | 1 | 1/3 | 1/9 | 1/5 |
| Lead Time | 1/5 | 3 | 1 | 1/5 | 1/2 |
| Labor Number | 3 | 9 | 5 | 1 | 5 |
| Shift | 1/2 | 5 | 2 | 1/5 | 1 |

| Matrix 2 | Throughput | WIP | Lead Time | Labor Number | Shift |
|---|---|---|---|---|---|
| Throughput | 1 | 5 | 3 | 9 | 6 |
| WIP | 1/5 | 1 | 1/2 | 5 | 3 |
| Lead Time | 1/3 | 2 | 1 | 5 | 4 |
| Labor Number | 1/9 | 1/5 | 1/5 | 1 | 1/3 |
| Shift | 1/6 | 1/3 | 1/5 | 3 | 1 |

| Matrix 3 | Throughput | WIP | Lead Time | Labor Number | Shift |
|---|---|---|---|---|---|
| Throughput | 1 | 6 | 5 | 1 | 3 |
| WIP | 1/6 | 1 | 1/2 | 1/7 | 1/5 |
| Lead Time | 1/5 | 2 | 1 | 1/5 | 1/2 |
| Labor Number | 1 | 7 | 5 | 1 | 3 |
| Shift | 1/3 | 5 | 2 | 1/3 | 1 |

$CR = CI/RI,$

Where $RI$ (Random Index)is just related with the dimension of matrix. Once CR value less than 0.1, the comparison matrix is close to a consistency matrix.

Fortunately, all CR values of these three matrixes were less than 0.1. However, the second constitutor, who placed more priority on “Throughput” than “Labor Number” and “Shift”, had quite a different opinion from the other two. Although it would not affect on the matrix consistency when we combined three matrixes together, it would make the decision incorrect because of the poles apart of criteria weightiness between Matrix with the other two. After inquiring with managers about actual situations in the factory, we concluded that adding labor units or changing shifts are difficult to achieve than the other criteria. Therefore, the second matrix was ignored and a new comparison matrix of criteria could be established by synthesizing the last two matrixes shown in Table 8. The values of matrix in Table 8 is the mean values of matrix 1 and matrix 3 in Table 7.

**Table 8.** Comparison matrix of criteria

| Matrix | Throughput | WIP | Lead Time | Labor Number | Shift |
|---|---|---|---|---|---|
| Throughput | 1 | 6 | 5 | 1 | 3 |
| WIP | 1/6 | 1 | 1/2 | 1/8 | 1/5 |
| Lead Time | 1/5 | 2 | 1 | 1/5 | 1/2 |
| Labor Number | 1 | 8 | 5 | 1 | 4 |
| Shift | 1/3 | 5 | 2 | 1/4 | 1 |

**Table 9.** Comparison matrix of throughput

| Throughput | S4-1 | S4-2 | S4-4 | S4-5 | S4-6 |
|---|---|---|---|---|---|
| S4-1 | 1 | 1/2 | 1/5 | 1/5 | 1/3 |
| S4-2 | 2 | 1 | 1/4 | 1/4 | 1/2 |
| S4-4 | 5 | 4 | 1 | 2 | 4 |
| S4-5 | 5 | 4 | 1/2 | 1 | 3 |
| S4-6 | 3 | 2 | 1/4 | 1/3 | 1 |

#### 4.4.3 Priorities of Criteria and Alternatives

Through calculation, the maximum Eigenvalue of matrix was found as $\lambda_{\max}(A) = 5.0999$, with $RI = 1.12$, and $U = (0.6343, 0.0762, 0.1339, 0.7139, 0.2534)$. Therefore, $CI = 0.0250$, with $CR = 0.0223 < 0.1$. That means that matrix $A$ is close to a consistency matrix, and that the priorities for criteria calculated by this matrix are practicable. However, we find that the eigenvector $U$ we obtained can not applied directly and that the normalization should be achieved first in order to make each value of eigenvector bigger than 0 and their sum equal to 1 at the same time. Thus, $U = (0.3514, 0.0415, 0.0751, 0.3942, 0.1378)^T$. If the value $CR$ is greater than 0.1, the comparison matrix should be adjusted and above process of above should be achieved continually until the consistency matrix is gained.

In the next step, we conduct a comparison among each of the alternatives considered. Table 9 shows the comparison matrix of the Throughput for each scenario.

After calculating, $\lambda_{\max}(A)=5.1376$, $CI=0.0344$, therefore, $CR=0.0307 < 0.1$. By analogy, another 4 matrixes of comparison among WIP, Lead Time, Labor Number and Shift can be gained. At the same time, the eigenvector of each matrix also can be calculated. The following matrix is the comparison of WIP, Lead Time, Labor Number and Shift in turn.

$$\begin{bmatrix} 1 & 2 & 1/3 & 1/3 & 1 \\ 1/2 & 1 & 1/3 & 1/3 & 1/2 \\ 3 & 3 & 1 & 1 & 3 \\ 3 & 3 & 1 & 1 & 3 \\ 1 & 2 & 1/3 & 1/3 & 1 \end{bmatrix} \begin{bmatrix} 1 & 3 & 1/5 & 1/5 & 1/2 \\ 1/3 & 1 & 1/5 & 1/5 & 1/3 \\ 5 & 5 & 1 & 2 & 3 \\ 5 & 5 & 1/2 & 1 & 3 \\ 2 & 3 & 1/3 & 1/3 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 1 & 3 & 3 & 3 \\ 1 & 1 & 3 & 3 & 3 \\ 1/3 & 1/3 & 1 & 1 & 1 \\ 1/3 & 1/3 & 1 & 1 & 1 \\ 1/3 & 1/3 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 1 & 3 & 1 & 1/3 & 1 \\ 1/3 & 1 & 1/3 & 1/5 & 1/3 \\ 1 & 3 & 1 & 1/3 & 1 \\ 3 & 5 & 3 & 1 & 3 \\ 1 & 3 & 1 & 1/3 & 1 \end{bmatrix}$$

As can be seen, the consistency of 4 matrixes has been validated, with all CRs having a value of less than 0.1. Therefore, they are practicable. Moreover, the eigenvector values of the 5 criteria are:

$w_{Throughput}=(0.0561, 0.0877, 0.4216, 0.3016, 0.1330)$;
$w_{WIP}=(0.1269, 0.0837, 0.3313, 0.3313, 0.1268)$;
$w_{LeadTime}=(0.0861, 0.0511, 0.4116, 0.3119, 0.1393)$;
$w_{Labor}=(0.3333, 0.3333, 0.1111, 0.1111, 0.1111)$; and
$w_{Shift}=(0.1655, 0.0621, 0.1655, 0.4414, 0.1655)$.

#### 4.4.4 Synthesizing Priorities

As shown in the previous section, each eigenvector value represents the priority of every scenario for each criterion. For example, 0.0561 is the priority of Scenario 4-1 for the Throughput criteria. Therefore, by taking the correspondence value for each scenario from the eigenvector matrixes, the priority of scenarios can be coordinated as follows:

$P_{S4-1}=(0.0561, 0.1269, 0.0861, 0.3333, 0.1655)$;
$P_{S4-2}=(0.0877, 0.0837, 0.0511, 0.3333, 0.0621)$;
$P_{S4-4}=(0.4216, 0.3313, 0.4116, 0.1111, 0.1655)$;
$P_{S4-5}=(0.3016, 0.3313, 0.3119, 0.1111, 0.4414)$;
$P_{S4-6}=(0.1330, 0.1268, 0.1393, 0.1111, 0.1655)$.

Then, by using the $U$ gained before, the value $\sum u_i \times p_i$ can be obtained, which is the weight of each scenario. For instance:

$$\begin{aligned} w_{S4-1} &= 0.3514\times0.0561+0.0415\times0.1269+ \\ &\quad 0.0751\times0.0861+0.3942\times0.3333+ \\ &\quad 0.1378\times0.1655=0.1857 \end{aligned}$$

In the same way, $w_{S4-2}=0.1781$, $w_{S4-4}=0.2594$, $w_{S4-5}=0.2478$, $w_{S4-6}=0.1291$. Therefore, synthesizing all the effective factors, we find that Scenario 4-4 is the best solution based on the comparison matrix given by the managers and engineers in this paper. Certainly, Scenario 4-5 can also be an alternative solution, since it has a similar priority with Scenario 4-4. However, if the comparison matrix is quite different from the one we chose, the result may be another scenario. Therefore, the best solution selected to achieve the main objective depends on the criteria we suggested and the importance of the comparison we established, in reference to the requirement we have posed.

## 5. CONCLUSION

Simulation has become a very powerful tool for the planning, design, and control of systems. It helps engineers to understand the behavior of the system and evaluate the various strategies involved in forecasting. However, most of the simulation tools do not offer analysis methods or algorithms. At the same time, it is difficult to make a standard formula for a complex manufacturing system using these tools, especially when influencing factors are in a fuzzy relationship. Therefore, this poses a need for the integration of simulation technology with analysis algorithms. Toward this end, AHP is considered a useful method in solving the MCDM problem as it helps engineers gain a clearer cognizance of the influencing factors within a manufacturing system.

Therefore, in this paper, a case study of a Korean company which produces the BOC-type of packaging substrate is discussed. We aimed to develop a two-layer type model and increase production quantity. In this study, we used QUEST® for simulation modeling as well as evaluated various other strategies for corresponding environmental changes. We likewise applied the AHP approach to establish the relationship of effect factors and chose the best solution among several similar simulation scenarios.

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