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# PRACTICAL PRODUCTION LAYOUT DESIGN FOR MULTI-PRODUCT AND SMALL-LOT-SIZE PRODUCTION: A CASE STUDY

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## Abstract

Facility layout design has an important function in manufacturing systems because it affects manufacturing costs, work in progress, lead times, and production output. This study presents facility layout designs for multi-product and small-lot-sized production lines. This research focuses on the development and analysis of layout alternatives on the basis of performance measures and aims to improve production efficiency. Thus, the tools and techniques available for the layout designed were investigated. Related data were collected, and alternative layouts were developed using the WITNESS simulation software. Finally, the alternative layouts were ana1yzed and evaluated using the analytic hierarchy process to identify the best possible layout. Two important parameters observed in the alternative layouts: the ability to produce a desired output and the flexibility of each layout coherent with the fluctuation of product demands in the industry. Results from analysis shows that suggested Model 3 with the combination of flow line and job shop configurations is the most suitable layout. This model has the highest machine utilization rate and the highest labour utilization rate yet requires only 21 operators, the lowest number of workers. For future work, this type of layout should be tested with different variation in lot sizes.

*Keywords*: Layout design, multi-product, small-lot-sized, Analysis of Variance (ANOVA), Analytical Hierarchy Process (AHP)

## Abstrak

Reka bentuk susun atur kemudahan mempunyai fungsi penting dalam sistem pembuatan kerana ia memberi kesan kepada kos pengeluaran, kerja dalam kemajuan, tempoh masa pengeluaran, dan jumlah pengeluaran. Kajian ini membentangkan reka bentuk susun atur kemudahan untuk pelbagai produk dan barisan pengeluaran lot bersaiz kecil. Kajian ini memberi tumpuan kepada pembangunan dan analisis alternatif susun atur berdasarkan pengiraan prestasi dan matlamat untuk meningkatkan kecekapan pengeluaran. Oleh itu, cara-cara dan teknik yang terdapat bagi susun atur yang direka telah dikaji. Data yang berkaitan telah dikumpulkan, dan susun atur alternatif telah dibangunkan menggunakan perisian simulasi WITNESS. Akhir sekali, susun atur alternatif dianalisis dan dinilai menggunakan proses hierarki analisis untuk mengenal pasti susun atur yang terbaik. Dua parameter penting diperhatikan dalam susun atur alternatif: keupayaan untuk menghasilkan pengeluaran yang dikehendaki dan fleksibiliti setiap susun atur selari dengan turun naik permintaan produk dalam industri. Keputusan daripada analisis menunjukkan Model 3 yang di cadangkang iaitu dengan kombinasi susun atur garis aliran dan kumpulan adalah susun atur yang paling sesuai. Model ini mempunyai kadar penggunaaan mesin yang paling tinggi, kadar pengunaan pekerja yang paling tinggi walaupun hanya memerlukan 21 operator iaitu jumlah pekerja yang paling rendah. Untuk penyelidikan di masa hadapan, jenis susun atur ini perlu dikaji dengan variasi saiz los yang berbeza.

*Kata kunci*: Rekabentuk susun atur, pelbagai produk, lot saiz kecil, analisis varian (ANOVA), proses analisis hierarki (AHP)

## 1.0 INTRODUCTION

In manufacturing, the production line is an important aspect requiring detailed analysis and research. The production line is where all products are produced, comprising various processes and factors necessary for effective production. The area in this operation that draws significant interest in the manufacturing industry relates to production layout. Production layouts provide information such as flexibility, production flow, and process characteristics in the production line [1]. Different layout configurations significantly affect the performance of a production line. A satisfactory layout design helps improve the use of resources such as equipment, materials, space, and labour as well as the reduction of inventory and setup time [2]. A good layout design also helps maximize productivity, improve the flow of materials, and eliminate unnecessary steps in the manufacturing process.

However, changing a layout design is a costly, long-term proposition. Any modification or rearrangement of an existing layout represents a large expense in terms of both relocation and processing time. Thus, changing a layout design cannot be accomplished directly. For example, rearranging the layout after piping and wiring had been accomplished would be difficult. In addition, planners need to calculate the material flow costs and rearrangement costs in evaluating the effectiveness of facility arrangement [3]. Thus, the performance and benefits of each alternative layout must be thoroughly analysed before a final layout is selected. Moreover, modification of an existing layout for the production line does not ensure improved productivity. To achieve high productivity on the shop floor, an efficient layout arrangement and material flow path design are important because of the large percentage of product costs related to resources and material handling processes. A number of companies recognize the importance of developing systematic guidelines for modifying an existing production layouts or designing a new layout to increase productivity. An increasing number of studies on methods and approaches for production layout design have been conducted in recent years. The purpose of layout design is to improve productivity and eliminate all unnecessary steps in the production line.

Many researchers have investigated the benefits of using simulations to assist in production layout design. Eloranta and Raisanen [4] proposed a simulation-based planning tool to help with decisions related to plant's capacity requirement, buffer size requirement, and effects of changes in plant design on throughput time. While for [5], the research used computer simulation to improve shop floor performance. The study aimed to redesign an entire shop floor and improve the material flow and the output level of the existing production line. The performance of the production line was evaluated using ARENA before the layout was developed using rank-order clustering (ROC) and the computerized relative allocation of facilities technique. Finally, the best production layout alternative was selected based on evaluation of new production layouts and comparison with the existing production line. Another research [6] addressed layout design by using computer simulation and the analytic hierarchy process (AHP). The AHP offer process improvement prioritization decisions when involve both tangible and intangible strategic options. The study described the processes of design and the development of a cellular layout. Models were generated and evaluated using the simulation software SIMFACTORY II, and a model was selected based on the layout using the AHP technique.

Okane *et al*. [7] redesigned the functional layout by using DES simulation software. In the study, bottleneck in the production line was solved, output was increased by about 75% to 80% and lead time was reduced by 40%. Differently [8] used the AWESIM software to build and evaluate a production layout by a computer simulation model. They successfully relocated the existing production layout to two separate plants (production and assembly), thereby increasing the throughput rate by 11% and the plant capacity by 13%. In other case, a simulation model of an existing motor production line with a multi-product and small-lot-sized type of line was developed [9]. The SIMAN simulation language was used to identify system parameters such as dispatching rules, setup time reduction, overwork, demand increase, and productivity improvement to improve several aspects of system performance, such as facility utilization, flow time, and buffer sizes (work-in-process inventories). The simulation results were then analysed and compared using the factor weighting and a quantitative approach to select the best layout with maximum space utilization, minimum moving expenses, and maximum lead time reduction. The result was applied in the development of a new layout for a production line.

Computer simulation is generally performed before analysis and changes in the layout are implemented. Computer simulation and modelling has been widely used in the analysis of complex manufacturing systems [10]. Reference [6] indicated that computer capabilities can be combined with the versatility of simulation techniques to develop a powerful tool in manufacturing system design. This method has also been widely adopted as an advanced approach to problem solving, allowing users to mimic the behaviour of real-life systems. By using computer models, details regarding internal interactions and the interactive effects of the individual variables and components of a system can be obtained, thereby determining the key elements of the system and evaluate system performance [11].

Yang and Kuo [12] emphasized that layout design significantly affects the performance of a manufacturing industry and is usually involved in a multiple-objective problem. As indicated by Chakravorty and Hales [13] layout design is a multi-step process consisting of multiple decision-making processes related to the implementation and arrangement of resources and materials handling. However, neither an algorithmic nor a procedural layout design methodology can effectively solve a practical design problem. Knowledge about the process must also be extracted from multiple sources by using various elicitation techniques, which include questionnaires, interviews, workshops, and role playing involving expert judgement from workers [14]. Thus, an extensive approach to studying the design and analysis of production layout alternatives according to various performance measures must be developed. This study reports on the processes involved in developing different layout configurations.

The present study focuses on the development of different layout configurations for production lines with multi-products (about 100 items) and small-lot-sized (from several tens to hundreds) production characteristics by computer simulation and then design experiments to test whether these layouts can meet the targeted output. A simulation-based layout design is applied, and the AHP approach is adopted for selecting the best production layout for implementation in a case study. The remainder of this paper is organized as follows. Section 2 presents the research methodology and the experiments conducted. Section 3 provides the results and empirical illustrations. Section 4 further discusses the results. Section 5 concludes the paper.

## 2.0 LAYOUT MODELING AND SIMULATION

To evaluate the performance of the most suitable layout for a multi-product, small-lot-sized production line, layout designs are analysed in a case study involving an electric company. This project involves the design of alternative layout configurations to improve the productivity of electrical board (EB) production plant of the company. EB is built in a factory on an assembly line. An assembly system is described as “dedicated type manufacturing” in which workstations are arranged sequentially and products moving from one station to the other are processed [15]. The design of an assembly line involves multiple steps to achieve an effective layout arrangement of different resources such machines, equipment, raw materials, and labour [16 & 17]. The EB assembly line of the company consists of feeder stations, a cover assembly station, a main assembly station, and the packing area. Layout modelling in the present study includes three major phases: examination of the overall EB assembly process, analysis of process cycle time, and development of simulation models. The process is further explained in subsequent subsections.

### 2.1 Phase I: Understanding the Overall EB Assembly Process

Prior to layout design, the existing flow line is thoroughly examined to elucidate the overall assembly process and ensure accuracy in the data collected. Existing problems such as bottleneck stations and stations with high work-in-process (WIP) are identified. These data are useful in the planning and design stage of new layout configuration. EBs manufactured at the case-study company are divided into several components, usually including a main switch and one or more residual-current devices or residual current breakers with over current protection. The boards are assembled in an assembly line, with stations from the feeder station to the main assembly, subassembly for the cover, and finally to packing stations. The assembled products are then transported to the warehouse and prepared for shipping.

The existing manufacturing system for the EB assembly had been established and operating for several years. The two production shifts produce only about 1200 boards of different models per day. The assembly line was found to have bottleneck problems as well as high WIP, especially at the cover assembly area and the main assembly area. Thus, conversion to another layout configuration could help improve the productivity and eliminate these problems. The EB assembly line is multi-product and small-lot-sized and consists of four main assembly stations: the cover assembly, feeder station, main assembly, and packing station. The cover assembly station consists of the secondary cover assembly and main cover assembly processes. In a line, four operators are needed at this sub-assembly station. The main assembly process for EBs starts at the feeder station in which boards from the paint plant undergo several processes. These processes include riveting and labelling, M4 tapping, M6 tapping, and Busbar pressing before the EBs are pushed to the next assembly process. Similarly, four operators are needed at this station. At the main assembly station, several assembly processes occur. The boards then integrate with the full-cover assembly process and the packing station at the end of the assembly line. The targeted productivity is more than 1500 EBs a day.

### 2.2 Phase II: Cycle Time Analysis

Before a layout is planned and designed, all processes involved in the assembly line are examined, and the data gathered are analysed. Phase II consists of four steps.

#### 2.2.1 *Step 1: Analysis of EB Assembly Processes and Cycle Time for Each Task*

All tasks and processes need to be recorded to understand the assembly line. Precedence tables and detailed work instructions are among the best tools used to record the tasks involved. Table 1 tabulated the standard cycle time to assembly an EB, including painting of the plant, assembly of parts, final assembly, and packaging of the finished product. The data shown are slightly modified to adhere to the confidentiality agreement with the case-study company. The precedence diagram presented in

Figure 1 is the activities and the immediately preceding tasks.

### 2.2.2 Step 2: Identification of the Desired Output and Calculation of the Desired Cycle Time

The ability to achieve the desired output of the production plant is the most critical issue in production layout design. In this case study, the desired output of EB ranges between 1500 and 1800 units per day for the multi-product mix, as listed in Table 2. The cycle time is calculated using Equation (1).

**Table 1** EB assembly line activity and process flow

| Task No. | Activity | Immediate Predecessor |
|---|---|---|
| 1 | Prepare SCV (From Paint Plant) | - |
| 2 | Place PG on SCV | 1 |
| 3 | Fix SC and WA | 1 |
| 4 | Place PK Gasket on SCV | 1 |
| 5 | Put label on the SCV | 1 |
| 6 | Put the SCV aside | 2,3,4,5 |
| 7 | Prepare MCV (From Paint Plant) | - |
| 8 | Assemble Screws & Washers | 7 |
| 9 | Put label on MCV | 7 |
| 10 | Assemble Cover | 6,8 |
| 11 | Prepare OBP | - |
| 12 | Place rivet to the OBP | 11 |
| 13 | Tapping M4 | 12 |
| 14 | Put label on OBP | 12 |
| 15 | Tapping M6 | 13 |
| 16 | WA assembly & Busbar Pressing | 15 |
| 17 | Assemble Earth bolt | 16 |
| 18 | Assemble EBS | 16 |
| 19 | Assemble ETM | 16 |
| 20 | Stick labels onto OBP | 17,18,19 |
| 21 | Apply Grease | 20 |
| 22 | Assemble Isolator | 21 |
| 23 | Assemble RCDs | 22 |
| 24 | Fix and Align cables to RCDs | 23 |
| 25 | Assemble with cover | 10,24 |
| 26 | Cop ID Operator | 25 |
| 27 | Preparation for the Packing Case | 26 |
| 28 | Seal the bottom of the Case With Tape | 27 |
| 29 | Insert the Polystyrene foam | 28 |
| 30 | Seal the top of the case with tape | 29 |
| 31 | Stick Product label | 30 |
| 32 | Stamp the date code | 31 |
| 33 | Put the Box on Pallet | 32 |

**Table 2** Production data

| | |
|---|---|
| Desired output per day | 1800 unit |
| Working hours per day | 960 minute (8 hours per shift) |
| Downtime per shift | 1 hour (breaks, clean-up, etc.) |
| Working hours available at 100% | 840 minute per shift (7 hours/shift) |
| Outputs that need to produce per day | 1800 units per day |

$$\text{Cycle time, C} = \frac{Operating\ time}{Desired\ output} \qquad (1)$$

$$\text{C} = \frac{840\ minutes\ per\ line\ per\ day}{1800\ units\ per\ line\ per\ day} = 0.4667\ \text{min/unit}$$

### 2.2.3 Step 3: Balancing Of the Line and Assigned Tasks to Workstations

The next step is balancing the tasks of the workstations. Table 3 presents the cycle time for each workstation in each cell. Tasks are assigned to each workstation according to cycle time and the requirements of immediate precedence. Given several obstacles such as product constraints, process constraints, or machine cycle time, some tasks must be assigned to a single machine or station, and the process cannot be combined with or separated from other processes. However, this problem can be solved by adding more machines or creating multi-stations to perform the same process simultaneously.

**Table 3** Cycle time for each cell according to tasks assigned to workstations

| Cell | Workstation | Task | Cycle Time (min) |
|---|---|---|---|
| 1 | 1 | 1-6 | 1.1967 |
| | 2 | 7-10 | 1.3900 |
| 2 | 3 | 11,12,14 | 0.9633 |
| | 4 | 13 | 0.4700 |
| | 5 | 15 | 0.4400 |
| | 6 | 16 | 0.4633 |
| 3 | 7 | 17-19 | 0.9567 |
| | 8 | 20,21 | 0.4800 |
| | 9 | 22-24 | 1.400 |
| | 10 | 25,26 | 0.4300 |
| 4 | 11 | 27-33 | 1.0300 |
| | | | ∑ = 9.2200 |

### 2.2.4 Step 4: Calculation of the Theoretical Minimum Number of Each Station

To achieve the desired output rate, tasks are assigned to stations according to cycle time, ensuring that the smallest numbers of stations *n* are formed. This process helps solve bottleneck problems at certain stations. Minimizing *n* also maximizes productivity. Table 4 shows the minimum number of stations required for each cell.

The theoretical minimum number of stations is given by

$$N = \frac{\sum t}{c} \qquad (2)$$

where **Σ** t **=** the total cycle time of each station (min)

c = the ideal cycle time (min) per unit = 0.4667 min/unit

**Table 4** Theoretical minimum number of stations for each workstation

| Cell | Workstation | Task | Cycle Time (min) | *n* |
|---|---|---|---|---|
| 1 | 1 | 1-6 | 1.1967 | 3 |
| | 2 | 7-10 | 1.3900 | 3 |
| 2 | 3 | 11,12,14 | 0.9633 | 2 |
| | 4 | 13 | 0.4700 | 1 |
| | 5 | 15 | 0.4400 | 1 |
| | 6 | 16 | 0.4633 | 1 |
| 3 | 7 | 17-19 | 0.9567 | 2 |
| | 8 | 20,21 | 0.4800 | 1 |
| | 9 | 22-24 | 1.400 | 3 |
| | 10 | 25,26 | 0.4300 | 1 |
| 4 | 11 | 27-33 | 1.0300 | 3 |
| | | | ∑ = 9.2200 | |

## 2.3 Phase III: Development of the Simulation Model

Computer simulation is performed after the basic structure of models is designed based on manual calculation and assumption. Layout models based on the data obtained in Phases I and II are developed using the WITNESS simulation software. Three models are developed in the present study. Model 1, the existing layout, is used as the base model for validation and verification purposes. Historical data collected over a period of three months were used to compare the layouts. Model 2, which is based on Model 1, has its feeder station removed as an individual cell, whereas the cover assembly cell is integrated into the main assembly line. Model 3 is a newly constructed layout with each station having tasks either combined or separated in accordance with the data in Table 4.

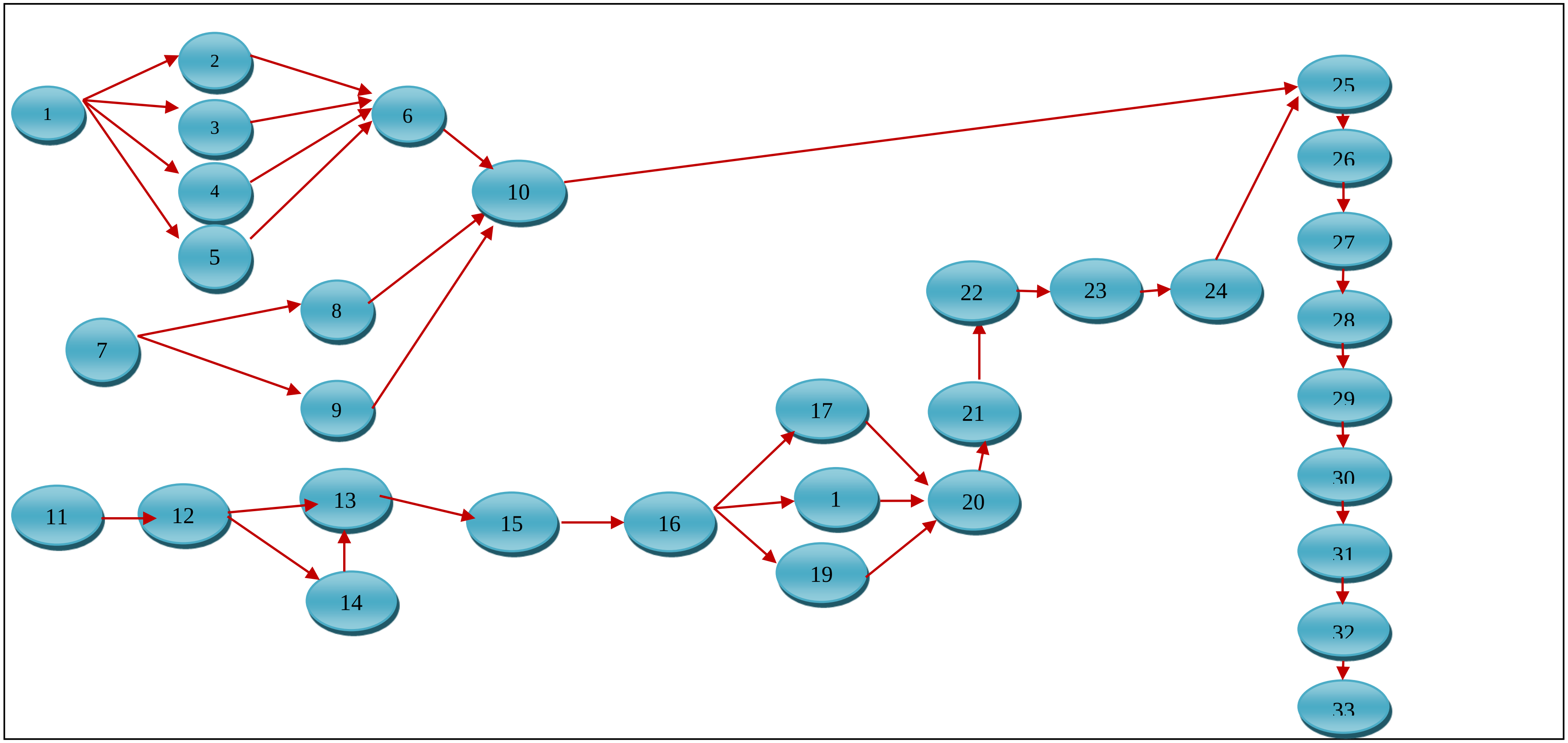

**Figure 1** Precedence diagram for EB assembly line

### *Simulation Models*

#### *a) Model 1*

Model 1, the existing layout of the current EB assembly line, is used as the base model for validation and verification purposes. Historical data collected over a period of three months are used to compare the layouts generated by the WITNESS simulation software. Figure 2 shows the layout of Model 1 generated by the WITNESS simulation software. The layout consists of two cover assembly cells, two feeder stations, four main assembly stations, and four packing stations. A total of 28 operators are required, with 14 operators for each line. For this model, two product models can be generated at one time.

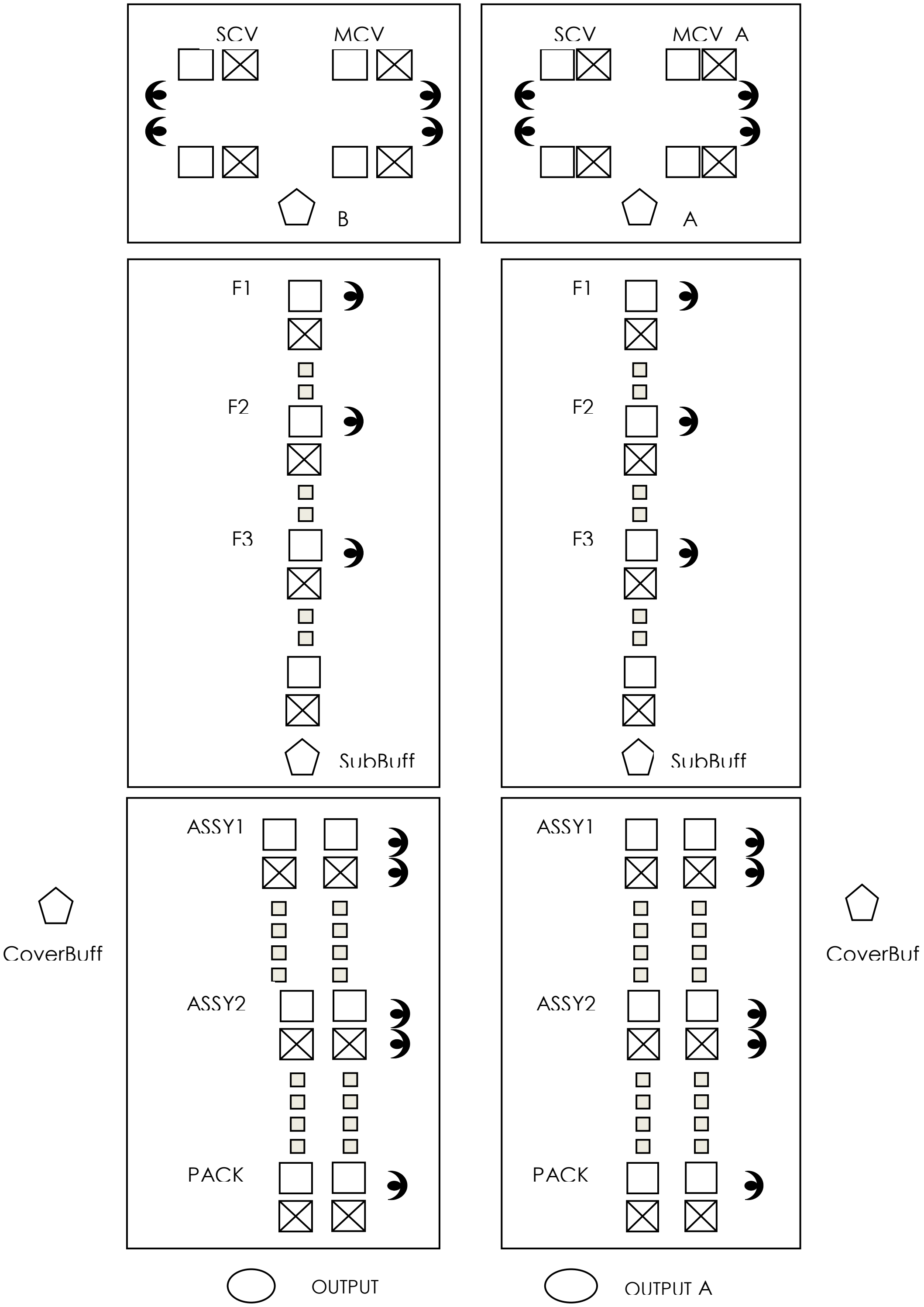

**Figure 2** Layout of Model 1

*b) Model 2*

Model 2, designed differently from the layout of Model 1, have its feeder station removed as an individual cell, whereas the cover assembly cells are integrated into the main assembly line. The number of operators required in this layout is the same as that in the Model 1 layout. Figure 3 shows the layout of Model 2, generated using the WITNESS simulation software. The advantage of this design is that four models (one in each cell) can run at one time, as shown in Figure 3. Each cell has a secondary cover assembly station, a main cover assembly station, a main assembly station, and a packing station with five operators in each cell. The feeder station at the beginning of the main assembly line is removed and treated as an individual cell consisting of four operators at each line. The tasks assigned to each operator are the same for both Models 1 and 2.

*c) Model 3*

Model 3, a newly-constructed layout, has tasks assigned to each station either combined or separate, in accordance with the data in Table 3. The layout of this model differs from the layouts of the first two layouts because the tasks assigned to each operator also vary. Figure 4 shows the layout of Model 3, generated using the WITNESS simulation software. A total of 21 operators are required for this layout configuration. Three secondary and main cover assembly stations are needed to accomplish tasks 1 to 10 for the cover assembly cell. Only one line with two operators is required for tasks 11, 12, and 14. Seven and three operators are needed at the main assembly station and the packing station, respectively.

The models are built in incremental steps; thus, each stage can be verified and validated before subsequent changes are made. The models are initially built with the existing layout configuration, gradually becoming more complex. A specific change is planned for each model, and then the program is updated. Therefore, every element is checked as the models are updated. Typical verification is performed based on machines and associated buffers, routing and cycle time of parts, and correct labour assignments. Validation is required to ensure that the models are realistic before experiments can begin. Validation is the process of establishing the desired accuracy or correspondence between the simulation model and the system being simulated [18]. The process involves the comparison of these models with the real system by using historical data and demonstrating the models to the company (thereby obtaining expert opinion on the comparison).

## 3.0 EVALUATION THROUGH SIMULATION

To evaluate the performance of each model layout, experimentation by running the models and observation of the behaviour of the models are conducted. Prior to experimentation, factors such as the required warm-up period and the number of replications and experiments required must be determined. Normal distribution is applied to vary the data such that the real-world setting in which conditions are unpredictable and changing is simulated.

The warm-up period refers to the amount of time required for a model to run to achieve a steady state before statistical data are collected. Starting conditions constitute the warm-up period. In this study, the simulation model is assumed to start from empty (i.e., with no parts) and work-in-progress. Replication is defined as the number of times a model is run, which varies in each run. In this study, each simulation model is run for 960 minutes, which is the total working time per day, with five replications per simulation model.

The first experiment is conducted to test whether the specific layouts can produce 1500 units to 1800 units per day. The second experiment is performed to test and compare the flexibility of each layout in coping with three types of production orders to run per day: low-variety (6 models to 9 models), medium-variety (12 models to 15 models), and high-variety (19 models to 22 models).

### 3.1 Experiment 1: Testing the Ability of the Layouts to Produce the Desired Output

As mentioned, this study primarily aims to develop alternative layouts that can increase the output from 1200 units per day between 1500 and 1800 units per day. Thus, if the layouts developed fail at this stage, the second experiment cannot be conducted. The outcome of this experiment demonstrates the ability of the layouts designed to achieve the target output for this study. Performance measures such as output, throughput rate, labour utilization rate, machine utilization rate, and average WIP are compared with the productivity on the shop floor.

### 3.2 Experiment 2: Testing the Flexibility of the Layouts

The second experiment focuses on the flexibility of each layout in coping with three types of production orders to run per day: low-variety (6 models to 9 models), medium-variety (12 models to 15 models), and high-variety (19 models to 22 models). Twenty-two product models are randomly chosen for this experiment. All models are tested with three types of production orders, and the total output produced by these models ranges from 1500 units per day to 1800 units per day. The best layout is then selected and recommended to the company, as evaluated using six performance measures. Data collected from simulation runs are used for the analysis.

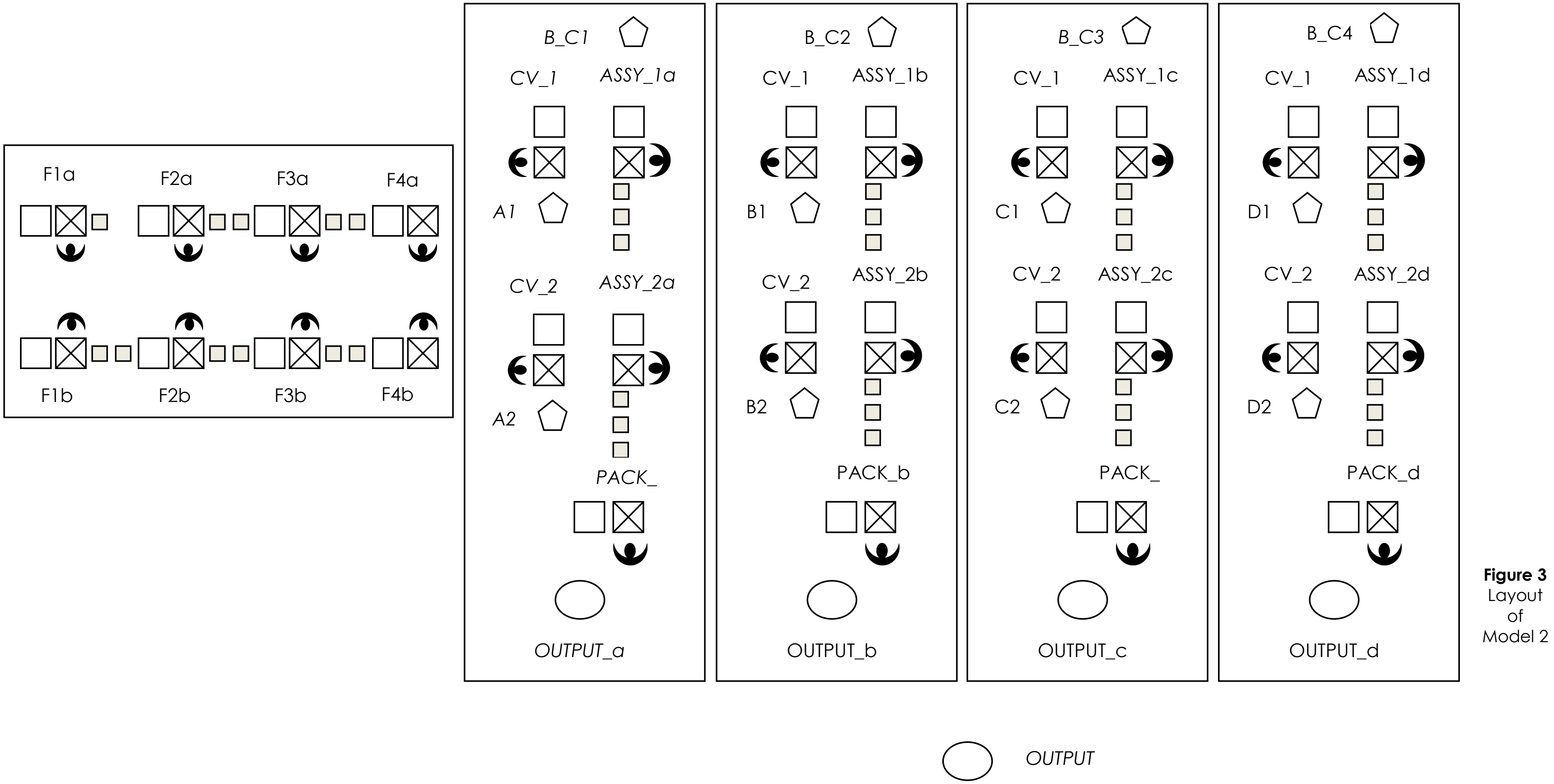

**Figure 3** Layout of Model 2

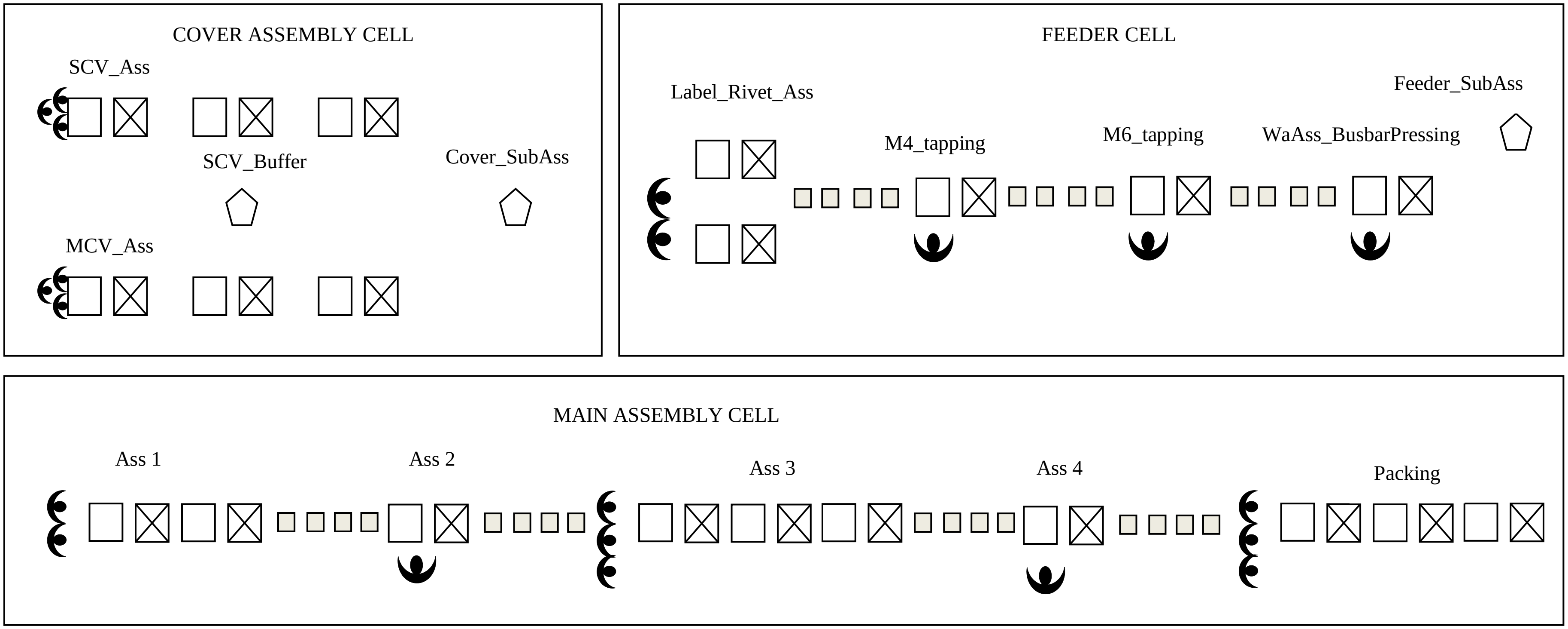

**Figure 4** Layout of Model 3

# 4.0 RESULT AND DISCUSSION

## 4.1 Experiment 1: Testing the Ability of the Layouts to Produce the Desired Output

Performance measures such as average throughput rate, labour utilization rate, machine utilization rate, output, and the average WIP of Models 1, 2, and 3 are obtained from the simulation experiment. To verify the advantages of the layout designed, the performance measures of Model 1 (base model) are compared with those of Models 2 and 3. Table 5 presents the comparison and average results of five replications for each model.

**Table 5** Results of each layout configurations in term of six performance measures

| No. | Performance Measure | Model 1 (Base Model) | Model 2 | Model 3 |
|---|---|---|---|---|
| 1. | Average Output (units) | 1053 | 2337 | 2010 |
| 2. | Labour Utilization (%) | 42.0678 | 56.6536 | 90.6271 |
| 3. | Machine Utilization (%) | 48.5657 | 50.1621 | 92.2773 |
| 4. | Average WIP (units) | 400 | 255 | 10 |
| 5. | Throughput Rate(units/min) | 1.0969 | 2.4344 | 2.0938 |
| 6. | Number of Labour (person) | 28 | 28 | 21 |

Model 1 is the base model. Historical data show that the layout currently used by the company can produce 1104 units of boards per day. The simulation run also indicates that the layout can achieve an output of 1053 units of boards per day. Therefore, the model achieves the desired accuracy, with a variance of less than 5%. The labour utilization rate and the machine utilization rates for Model 1 are 42% and 49%, respectively, which is low, given that each is below 50%. The average WIP is 400 units, which is considered high.

Model 2 is a layout designed as an improvement of Model 1; the feeder station as an individual cell is removed, whereas the cover assembly cell is integrated into the main assembly line. Similar to Model 1, Model 2 is operated by 28 people. Table 5 indicates that Model 2 exhibits an improvement of more than 100% in average output. The labour utilization rate and the machines utilization rate of Model 2 are increased by 14.6% and 1.6%, respectively. Compared with Model 1, Model 2 shows a decrease in average WIP from 400 units to 255 units, representing a reduction of 64%. Model 2 also achieves the objective of Experiment 1, which is to increase the output to more than 1500 units per day. Thus, Model 2 performs more efficiently than the existing layout.

Table 5 also shows that Model 3 generates the desired result: its average output of 2010 units per day is 91% better than that of Model 1, which produces only 1053 units per day. However, the average output of Model 3 is 14% lower than that of Model 2, which shows the highest output of 2337 units per day. The average throughput rate for Model 3 also exhibits significant increments of more than 100%, which is slightly lower than that of Model 2. Among the models, Model 3 requires the smallest number of labourers, that is, 21. This number is only 75% of the number required for Models 1 and 2. A reduction of 7 labourers is thus achieved by Model 3. The most significant improvement for Model 3 is the average WIP, which is reduced to 10 units. This reduction represents 97.5% and 96% of the average WIPS achieved by Models 1 and 2 (400 and 255 units, respectively).

## 4.2 Experiment 2: Testing the Flexibility of the Layouts

A further experiment is conducted to examine the flexibility of the layouts designed to cope with three types of production orders to run per day: low-variety (6 product models to 9 product models), medium-variety (12 product models to 15 product models), and high-variety (19 product models to 22 product models). For this case study, multi-models of EBs with different complexities are used. Twenty-two product models are randomly selected for this experiment. All product models follow the basic structure of the assembly line, except that the setup time varies for each model. The performance measures in this experiment include the labour utilization rate and the machine utilization rate. ANOVA is used to test the significance of these performance measures. Table 6 tabulated the data collected from simulation runs with five replications.

**Table 6** Results for Experiment 2

| **Product Model Variability** | | **Performance Measures** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Model 1 | | Model 2 | | Model 3 | |
| | | Labour Utilization | Machine Utilization | Labour Utilization | Machine Utilization | Labour Utilization | Machine Utilization |
| Low Variety | 6 models | 42.0478 | 48.6657 | 50.1683 | 56.6315 | 92.1515 | 90.5512 |
| | 7 models | 42.1879 | 48.5615 | 50.2135 | 56.5651 | 92.1815 | 90.5641 |
| | 8 models | 42.0549 | 48.5970 | 50.2327 | 56.6461 | 92.2545 | 90.6613 |
| | 9 models | 42.0678 | 48.5657 | 50.1621 | 56.6536 | 92.2773 | 90.6271 |
| Medium Variety | 12 models | 42.3597 | 48.6565 | 50.2648 | 56.7516 | 92.1482 | 90.2321 |
| | 13 models | 42.3654 | 48.6613 | 50.3574 | 56.6846 | 92.0761 | 90.2545 |
| | 14 models | 42.2154 | 48.7265 | 50.2482 | 56.7613 | 92.1315 | 90.1562 |
| | 15 models | 42.3417 | 48.7421 | 50.2408 | 56.7418 | 92.0146 | 90.2919 |
| High Variety | 19 models | 42.2345 | 48.7467 | 50.3458 | 56.7665 | 92.0879 | 90.3512 |
| | 20 models | 42.2976 | 48.8464 | 50.4615 | 56.7516 | 92.0816 | 90.3141 |
| | 21 models | 42.2265 | 48.7845 | 50.4559 | 56.8811 | 92.0613 | 90.2945 |
| | 22 models | 42.2150 | 48.8946 | 50.4561 | 56.8453 | 92.0709 | 90.3795 |

As shown in Table 6, the increase in model varieties (from 6 models to 22 models) increases the labour utilization rate and the machine utilization rate. For Model 1, the labour utilization rate under the medium-variety model exhibits the highest labour utilization rate and the machine utilization rate. However, the utilization rate decreased when tested with the high-variety model. For Model 2, the labour utilization rate under the low-variety model is lower than the labour utilization rate under the medium-variety and the high-variety models. The high-variety models demonstrate the highest labour utilization rate. However, Model 3 slightly decreases in utilization rate under the medium-variety model compared with the low-variety model. By contrast, a slight increase in the utilization rate occurs under the medium-variety model compared with the high-variety model.

## 4.3 Analysis of Variance (ANOVA)

The results are further analysed using ANOVA. One-way ANOVA is used to test the effects of layout configuration on performance measures in deciding whether to reject the null hypothesis, $H_0$, and accept the alternative hypothesis, $H_1$, or vice versa.

The critical values of *F* at 95% and 99% confidence levels obtained from the standard F table are 3.49 and 5.95, respectively. If the calculated F-ratio is greater than the critical value, $H_0$ is rejected and $H_1$ is accepted. This condition suggests that the effect of the layout on the performance measure based on various data is statistically significant. Table 7 and Table 8 summarize the ANOVA results of the three layout models with different orders of variety for the labour utilization rate and the machine utilization rate, respectively.

**Table 7** Summary for test of significant of three layout models for machine utilization

| **Performance Measures** | **Model Variety** | **F-test Value** | **Conclusion** |
|---|---|---|---|
| Model 1 | Low | 169.5825 | Significant |
| | Medium | 33.9569 | Significant |
| | High | 2.6584 | Insignificant |
| Model 2 | Low | 0.3416 | Insignificant |
| | Medium | 58.0549 | Significant |
| | High | 852.2924 | Significant |
| Model 3 | Low | 802.4282 | Significant |
| | Medium | 2242.1423 | Significant |
| | High | 21.2022 | Significant |

**Table 8** Summary for test of significant of three layout models for labour utilization

| **Performance Measures** | **Model Variety** | **F-test Value** | **Conclusion** |
|---|---|---|---|
| Model 1 | Low | 3488.8112 | Significant |
| | Medium | 40.9702 | Significant |
| | High | 2.0685 | Insignificant |
| Model 2 | Low | 0.9911 | Insignificant |
| | Medium | 290.6554 | Significant |
| | High | 1165.3607 | Significant |
| Model 3 | Low | 1575.6624 | Significant |
| | Medium | 131.7181 | Significant |
| | High | 107.5567 | Significant |

A flow line is most suitable for producing low-variety products, whereas a cellular layout is best suited for producing high-variety products [19]. The cellular layout design is targeted for a maximum capacity of 1800 units of boards per day. The model variety from 6 models to 22 models highly affects the layout performance because of the increase in setup time that accompanies the change in model variety. Although both Models 2 and 3 can produce the targeted output of 1500 units to 1800 units of boards per day, Model 2 poorly copes with low-variety conditions because the model is designed for high-variety boards in the cell.

Finally, four types of boards can be assembled simultaneously. Thus, the machine utilization rate and the labour utilization rate are low and insignificant especially in repetitive operation [20].

## 4.4 Comparison Matrix of AHP

The AHP is employed to rank the three layout models with respect to six performance measures and then select the best layout for assembling EBs. Pairwise comparisons between the preferable performance measure levels of alternative models in developing the relative priority weights are conducted. Table 9 shows the results of the local and priority AHP analyses for the three layout configurations. Table 10 ranks the alternatives according to global priority.

**Table 9** Local and Global Priorities of the AHP Analysis for selecting the Alternative Layout

| Parameters /Alternative Layouts | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Throughput Rate (0.0712) | 0.1196 | 0.5740 | 0.3063 |
| Output (0.3599) | 0.2015 | 0.4891 | 0.3109 |
| Machine Utilization (0.1347) | 0.0553 | 0.2622 | 0.5650 |
| Labour Utilization (0.1347) | 0.0892 | 0.2549 | 0.4744 |
| Average WIP (0.3599) | 0.0692 | 0.1196 | 0.5740 |
| Number of workers (0.1347) | 0.0479 | 0.0479 | 0.0975 |
| **Global Priorities** | **0.2859** | **0.3360** | **0.4934** |

Note: The calculation for global priority is:

$$
\begin{aligned}
& w_i^l = \sum_{i=1}^{n_{l-1}} w_{ij}^l w_j^{l-1} \\
& = \sum \left(0.0712 * 0.1196 + \ 0.3599 * 0.2015 + \cdots\cdots + 0.1347 * 0.0479\right) \\
& = 0.2859
\end{aligned}
$$

**Table 10** Ranking of Alternatives

| Alternatives Layout | Global Priorities | Ranking |
|---|---|---|
| Model 1 | 0.2859 | 3 |
| Model 2 | 0.3360 | 2 |
| Model 3 | 0.4934 | 1 |

The alternative layouts are ranked according to global priority, as shown in Table 10. The highest global priority is the most preferable alternative. AHP analysis indicates that Model 3 is the most preferable choice and should thus be selected. Model 3, which is designed based on the combination of the line and job shop layout configurations, is the optimal layout for assembling EBs. This layout requires 10 WIP buffers and 21 workers. This model also exhibits the highest machine utilization rate and highest labour utilization rate, lowest number of required workers, as well as average throughput rate and total output.

## 4.5 Comparison of Alternative Layouts

Two alternative layouts have been designed and proposed based on different layout configurations. Table 11 lists the tasks assigned to each station for these three models and the number of operators required for each workstation.

Model 1 is the base model for the EB assembly line, a flow line that is structured and run using the WITNESS simulation software in accordance with the current actual layout of the production line. Model 1 is also the least preferable layout as determined based on AHP analysis with six performance measures comparing the 3 models. This line layout has the lowest machine utilization rate and the lowest labour utilization rate. In addition, this layout is used to achieve high production rates and can be used for low-variety models. This layout is not the most preferable layout for EB assembly because the average output of this layout is 1800 units only and more than 100 different models have to be produced in this layout, suggesting high product variety.

Model 2 is the second most preferable choice among the three alternative layouts on the basis of the AHP analysis results. This layout groups processes into cells. A sequence of processes is identified and then assigned to a specific area on the shop floor to produce different product models. Four main assembly cells are grouped and placed close to one another. Each cell consists of a secondary cover assembly, a main cover assembly, a main assembly, and a packing area. Each cell requires five operators. Moreover, the feeder station as an individual cell is removed. The results prove that the cellular layout can provide higher machine and labour utilization rates compared with the original flow line; however, Model 3 remains preferable to Model 2.

Model 3 is the most preferable choice and should be selected on the basis of the AHP analysis results. This model is designed based on the combination of flow line and job shop layout configurations; thus, it is known as a hybrid layout. This model achieves the highest machine utilization rate and the highest labour utilization rate and requires the lowest number of workers, that is, 21. This layout shows average throughput rate and output of this layout and exhibits the advantage of a hybrid layout. Model 3 can be used for EB assembly, which shows both high and product varieties.

**Table 11** Different between three layout models

| Workstation | Tasks Assigned | | | Operators needed | | |
|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| **Cover Assembly**<br>Secondary cover assembly | 1-6 | 1-6 | 1-6 | 4 | 4 | 3 |
| Main cover assembly | 7-10 | 7-10 | 7-10 | 4 | 4 | 3 |
| **Feeder Station**<br>Feeder 1 | 11,12,14 | 11,12,14 | 11,12,14 | 2 | 2 | 2 |
| Feeder 2 | 13 | 13 | 13 | 2 | 2 | 1 |
| Feeder 3 | 15 | 15 | 15 | 2 | 2 | 1 |
| Feeder 4 | 16 | 16 | 16 | 2 | 2 | 1 |
| **Main Assembly**<br>Assembly 1 | 17-21 | 17-21 | 17-19 | 4 | 4 | 2 |
| Assembly 2 | 22-26 | 22-26 | 20,21 | 4 | 4 | 1 |
| Assembly 3 | - | - | 22-24 | - | - | 3 |
| Assembly 4 | - | - | 25,26 | - | - | 1 |
| **Packing Station**<br>Packing 1 | 27-33 | 27-33 | 27-33 | 4 | 4 | 3 |
| | | | Total | 28 | 28 | 21 |

## 5.0 CONCLUSION

The layout design of EB production areas is investigated by integrating simulation, ANOVA, and the AHP decision-making approach. Two different models of layout configurations based on a cellular manufacturing layout and a hybrid layout are developed. Model 1 is based on the existing layout of the EB assembly line and used for validation and verification purposes. The layout models are structured with the WITNESS simulation program to evaluate performance measures such as the throughput rate, machine utilization rate, output, and average WIP. The numbers of workers assigned are based on the machine requirements.

After data collection by simulation experiments, ANOVA is used to analyse the effects of experimental layout configurations on the performance measures at 95% and 99% confidence levels. The result shows that different layout configurations with three different product models variability significantly affects the performance measures such as the machine utilization rate and the labour utilization rate. These variability are characterized as low-variety (6 to 9 models), medium-variety (12 to 15 models), and high-variety (19 to 22 models). AHP analysis indicates that with respect to the six performance measures, Model 3 is the best layout for EB assembly. Model 2 is the second most preferable choice, and Model 1 is the least preferred model. These results show that both alternative designs were more desirable than the existing flow line layout. In the future research of this topic, the practicality of Model 3 need to be verified by conducting a case study on different lots sizes in the real industry and the impact on throughput.

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