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Research Article

Analysis of Shop Floor Performance through Discrete Event Simulation: A Case Study

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Shop floor performance management is a method to ensure the effective utilization of people, processes, and equipment. Changes in the shop floor might have a positive or negative effect on production performance. Therefore, optimal shop floor operation is required to enhance shop floor performance and to ensure the long-term efficiency of the production process. This work presents a case study of a semiconductor industry. The punching department is modeled to investigate the effect of changes in the shop floor on production performance through discrete event simulation. The effects on the throughput rate, machine utilization, and labor utilization are studied by adjusting the volume of parts, number of operators, and flow pattern of parts in a series of models. Simulation results are tested and analyzed by using analysis of variance (ANOVA). The best model under changes in the shop floor is identified during the exploration of alternative scenarios.

1. Introduction

The fierce competition in the manufacturing industry has become an important issue in developing an effective and efficient shop floor. However, most companies in this industry are challenged by shop floor changes, such as unstable customer demand, alteration of part flow routing, and different numbers of operators assigned. Soh et al. [1] showed that the shop floor is focused on providing a suitable location for existing machines, resource planning, and production planning from the manufacturing system perspective. Changes in the shop floor might have a positive or negative effect on production performance. According to Fredendall and Melnyk [2], variations in the shop floor negatively affect shop floor performance. Therefore, an optimal operating shop floor is important for continuous production improvement.

To investigate the positive or negative effect of changes in the shop floor, a company has to assess shop floor performance. As reported by Panjehfouladgaran et al. [3], performance measurement is defined as a managerial key that integrates the tasks for the controlling event, which guides an organization to be within acceptable and desirable parameters. Gunasekaran et al. [4] stated that production performance has to be assessed to develop an efficient and effective shop floor. Performance measurement provides a means to capture performance data, which can be used to evaluate organizational performance. Thus, performance measurement and metrics are essential for objective setting, performance evaluation, and future work identification [3]. Numerous approaches, including thorough mathematical modeling and simulation, can be used to assess shop floor performance. However, the success of measuring and managing operational performance lies in simulating the desired shop floor behavior [5]. Simulation techniques are appropriate due to the growing need to address the complexities of real-world applications [6]. Thus, simulation results can be used to examine how changes affect shop floor performance.

Simulation is defined as the emulation of real-world processes or system operations over time [7]. Numerous benefits, such as the optimization of system performance and the reduction of failure instances to meet certain specifications, have facilitated the adoption of simulation to assess shop floor performance [8]. Simulation can be classified into discrete event simulation (DES) and continuous simulation. Lin [9] stated that DES consists of a series of events that occur over time. This type of simulation is used when a variable changes in discrete time and discrete steps [10]. Meanwhile, continuous simulation involves continuous dynamic system tracking

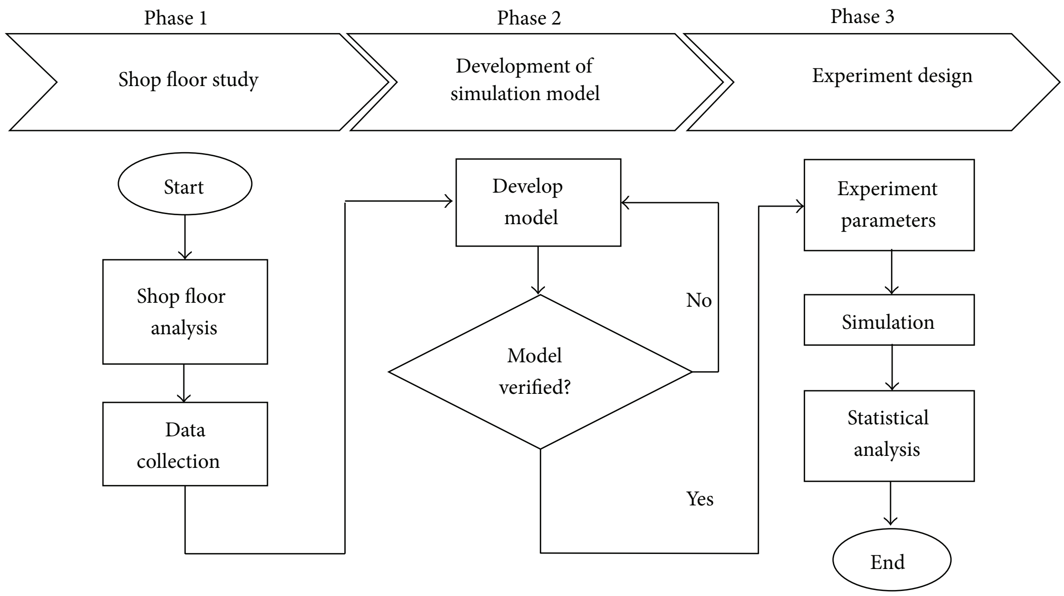

Figure 1: Systematic procedure for DES model development.

over time [11]. Continuous simulation is activity based and is suitable for a system in which variables continuously change. Nevertheless, DES is adopted by most manufacturers for its capability to analyze complex manufacturing systems even under uncertainty and dynamicity. Hence, it enables manufacturers to evaluate different alternatives of system configurations to support decision making in the manufacturing context [12, 13]. A number of simulation software programs, such as Automod, Arena, Simul8, WITNESS, and Factor, are commercially available.

Shop floor changes are unavoidable in the manufacturing industry. Thus, the effect of these changes on shop floor performance should be studied before implementing any appropriate solution. DES can be used to measure shop floor performance. In most studies, DES outperforms continuous simulation [6]. Previous works showed that DES can be mainly used for decision making in logistics and supply chain management. Tako and Robinson [14] applied DES as a decision support tool in logistics and supply chain management for its capability to produce realistic representations of real systems. However, limited research has been conducted on the evaluation of performance measurement by using DES. One study employed DES to evaluate overall production capability on the basis of different failure components [15].

Owing to the limited use of DES in shop floor performance measurement [6, 12], this approach is used in this study to evaluate production performance with respect to different changes in the shop floor. This study investigates the effects of the changes in shop floor. These changes include those relating to the volume of parts, number of operators, and flow pattern of the parts toward the throughput rate, machine utilization, and operator utilization. The effects on throughput rate, machine utilization, and operator utilization (measurement criteria) can be studied by altering the flow pattern of parts, number of operators, and volume of parts in a series of models. By exploring alternative scenarios in the simulation, the best models can be chosen under different changes in the shop floor. Moreover, by adopting DES, particularly from a real-world perspective, the company will reap more benefits. Such process is important to simulate the operation of real-world processes before implementation to avoid interrupting the real system and to prevent failures caused by misjudgment, which may result in a loss of time and money. The remainder of this paper is organized as follows. Section 2 discusses the procedure used to develop the DES model. Section 3 presents a case study of a manufacturing company. Section 4 compares the experimental results from Section 3. Section 5 draws the conclusion and proposes directions for future studies.

2. Systematic Procedure of Developing the DES Model

A systematic procedure will be used to study the effect of changes in the shop floor on performance measurement through the application of DES. Figure 1 illustrates the procedure adopted, which consists of four phases. Phase 1 begins a systematic procedure for shop floor analysis, in which the shop floor condition is examined. Through comprehensive shop floor analysis, useful data, including machine cycle time, setup time, and customer demand, are collected to develop a simulation model in the next phase. In Phase 2, a base model is developed by incorporating the data collected in Phase 1 into the simulation modeling phase. A verification process is then conducted on the basis of the theoretical calculation of the output per shift. In Phase 3, we determine how the identified performance measures are affected by the changes in shop floor through an experimental run. The results obtained in Phase 3 are then employed in Phase 4 for the analysis of variance (ANOVA) and for determining the sample-data relationship. The base model and the alternative models will be compared to make an informed decision on the preeminent solutions before implementation. The details on each phase will be discussed in the following sections.

2.1. Shop Floor Analysis. Shop floor analysis is the primary and essential step in the whole DES procedure. A detailed shop analysis has to be completed to gain a better understanding of the working environment before developing the simulation model. The collected data will be applied in the simulation to emulate real-world operation processes without disrupting the system. Thus, the required data that should be collected from the shop floor include machine cycle time, setup time, customer demand, types of parts, and part routing.

2.2. Development of the Simulation Model. A model is developed by using WITNESS simulation software. It is a computerized simulation system designed for modelling manufacturing operations [16]. The collected data are entered into the software to build the model. Once the model is completely designed and developed, verification is conducted on the basis of theoretical calculation. The model is verified by comparing the simulation and theoretical outputs. Verification is necessary to determine whether the obtained simulated output results are within the acceptable range before proceeding to the next phase, which is experimental design.

2.3. Experimental Design. Before proceeding to the experimental design phase, an accurate model that emulates the real-world system is crucial because the results obtained from the simulation should represent real-world scenarios. Therefore, experimental runs are systematically designed to study the effects of changes in the shop floor on the identified performance measures. By incorporating various experimental parameters, simulation runs can be conducted to emulate real-world operations. Performance measurement is a quantifiable indicator used to assess system performance, whereby the measurement criteria can be obtained from the statistical report generated from the simulation. The shop floor performance results obtained from the simulation are tested and analyzed through one-way ANOVA. ANOVA is applied in this study to test and analyze the effect of changes in the shop floor on its performance by rejecting the null hypothesis (H_0) or accepting the alternative hypothesis (H_1). A graph can be plotted to verify whether the sample-data relationship is significant. The base model can be compared with the alternative models on the basis of the graph. Managers can decide on the best solution from the experiment in accordance with the different measurement criteria.

3. Case Study

The case study is mainly focused on the punching department of a circuit board manufacturing company that produces single-sided and double-sided printed circuit boards. The machines are divided into process-based groups, namely, the incoming and looping section groups. Given the complexity of the flow of operator, materials, and parts, the performance

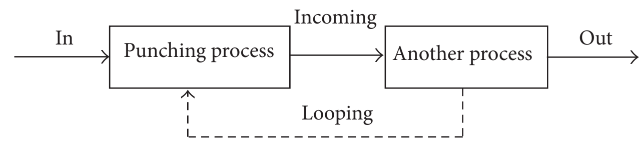

Figure 2: Process flow of the incoming and looping sections.

of these identified variables should be assessed regularly. Changes in the shop floor might affect production performance positively or negatively. Thus, the optimality of shop floor performance should be aligned with dynamic day-to-day changes. In this case study, DES is used to measure the effect of the changes in the shop floor on shop performance. Upon completion of DES, the previously discussed systematic procedure for DES model development will be adopted and further elaborated in the subsequent sections.

3.1. Shop Floor Analysis. Understanding the shop floor is important, especially during data collection. As previously stated, the machines in the punching department are classified according to the process grouping structure. The proposed shop floor has 17 machines, which are divided into the incoming and looping sections. Each machine is manned by an operator. The incoming section is referred to as the process flow, in which a part enters the department in "one time" to undergo the punching process. The part then proceeds to the adjacent department for further processing or is sent to the customer as a completed part. For the looping section, the part will be sent to the testing department. Once testing is completed, the part will again enter the punching department. The remaining processes will be completed. Similar to the incoming, completed looping is sent to the adjacent department for further processing or to the customer as a complete part. Figure 2 demonstrates the incoming and looping process flows. Incoming and looping have five subprocess lines (A, B, C, D, and E) and three subprocess lines (A, B, and C).

During the shop floor operation, the part will either pass through the machine in the incoming section and then proceed to the looping section or will pass through the incoming section only. This indication implies that all parts will go through the incoming section, but not all parts will go through the looping section. All parts will arrive at the storage area of the punching department simultaneously. Subsequently, the parts will be distributed to the available machines in the incoming section according to the process and type of machine used. The part will flow from right to left; for instance, the parts that have undergone Line 1 in the incoming section will pass from E1 to E2. In addition to conducting the flow analysis, data will be collected to obtain such information as machine cycle time, setup time, customer demand, type of part, part routing, and working time per shift. The collected data will be used for developing simulation models and manual computation. Working time per shift, demand ratio, and output per shift are manually computed. This manual computation aims to ensure that the output reflects the outcome for the daily basis of running the shop floor.

3.2. Simulation Model Development. Once all the required data and the shop floor are identified, the details are entered into WITNESS simulation software. A number of assumptions are made during the development of the simulation model.

(1) The process flow for the simulation is continuous.

(2) Production is in an ideal situation, in which no breakdown occurs and no product quality problem exists.

(3) An equal ratio of volume exists for each part.

(4) All the parts arrive randomly, and the parts will go into a certain machine when available.

(5) The operator moving time between workstations is assumed to be constant.

(6) The machine cycle times are assumed to be the same for both single-sided and double-sided parts.

(7) The production plant runs six days a week with two shifts per day.

After simulation model development, verification is conducted to determine whether the developed shop floor reflects the real-world scenario. The model is verified by evaluating whether the simulated output is within the acceptable range of the calculated output. The changes in the shop floor included alterations in the volume of parts, number of operators, and flow pattern of parts. The volume of parts is based on the customer demand. The purpose of different flows is to examine whether the flow patterns behave in a manner similar to those in the real world. In addition, the effect of the reduction in the number of operators on shop floor performance is also considered as a parameter to verify the developed simulation model. Once verification is completed, the number of performance criteria and experimental parameters will be identified. The measurements for the performance criteria and experimental parameters selected in this study are used as the gauging mechanisms during the experimental setup. The experimental parameters used in this study include the volume of parts, number of operators, and flow pattern of parts. Three measurement criteria were considered: throughput rate, machine utilization, and operator utilization. The three performance measurement criteria are discussed in detail in the following sections.

Throughput Rate. Throughput rate is defined as the rate of production in a process over a specific amount of time. It is a measure of the number of parts completed per unit time and is expressed as

$$\text{Throughput rate} = \sum_{i=1}^{T} \frac{P_i}{T}, \tag{1}$$

where P_i is the number of parts completed in unit time i and T is the completion time.

Machine Utilization. Machine utilization measures the machine usage intensity and is computed as the percentage of busy hours that a machine runs to complete the given tasks. The data can be acquired from the statistical report generated by the WITNESS simulation software. Average machine utilization can be expressed as the sum of all the machine busy times divided by the total number of machines, which is represented as

$$\text{Average machine utilization} = \frac{\sum \text{machine busy time } (\%)}{\text{total number of machines}}. \tag{2}$$

Operator Utilization. Operator utilization reflects the overall performance or productivity of the process and refers to the percentage of busy hours that an operator requires to complete given tasks. The data can be obtained from the statistical report generated by the WITNESS simulation software. The average operator utilization can be computed as the sum of all the operator busy times divided by the total number of operators, which is represented as

$$\text{Average operator utilization} = \frac{\sum \text{operator busy time } (\%)}{\text{total number of operators}}. \tag{3}$$

3.3. Experimental Design. Experiments were conducted to study the effect of changes in the shop floor on the shop floor performance. Seven models were developed by considering different conditions, as indicated in the Simulation Model Development section. All models have the same number of machines with a base model set as a benchmark for comparison. The differences of the models were based on the volume of parts, number of operators, and types of flow pattern. Table 1 tabulates the models used during the experiment.

As shown in Table 1, three experimental parameters are set in the simulation: the flow pattern of parts, number of operators, and volume of parts. In this case study, three types of flow patterns are designated as flow 1, flow 2, and flow 3. The distinction among the flows is mainly on the machine arrangement for each line in the incoming and looping sections. In flows 1 and 2, the machines are separated into the up and down positions for incoming and looping, as shown in Figures 3 and 4. Meanwhile, the machines in incoming and looping are separated into the left and right sides for flow 3, as shown in Figure 5. This experiment tests the effect of different flow patterns on production performance. The base model, Model 1, and Model 2 in Table 1 are chosen for this experiment. Different flow patterns can be attributed to different machine arrangements. For base model and Model 1, machines in incoming and looping are separated into up and down positions. The difference between the base model and Model 1 is that the machine arrangements of the subprocess lines in both incoming and looping are slightly different, whereas, for Model 2, the machines in both incoming and looping are separated into the left and right sides.

Shop floor performance is also affected by the number of operators. In this case study, the ratios of the number of operators to the machine are set as 1 : 1 and 1 : 2. A total of 17, 10, and 9 operators are tested to examine the effect of the reduction in the number of operators on the production performance. In the case of an operator-to-machine ratio of

Table 1: Information on the different models used in the experiment.

Model	Parameters			Remark	With respect to
	Flow pattern	Number of operators	Volume of parts		
Base model	F1	17	Low	Benchmark	
Model 1	F2	17	Low	Experiment 1	Flow pattern
Model 2	F3	17	Low		
Model 3	F1	10	Low	Experiment 2	Number of operators
Model 4	F1	9	Low		
Model 5	F1	17	Medium	Experiment 3	Volume of parts
Model 6	F1	17	High		

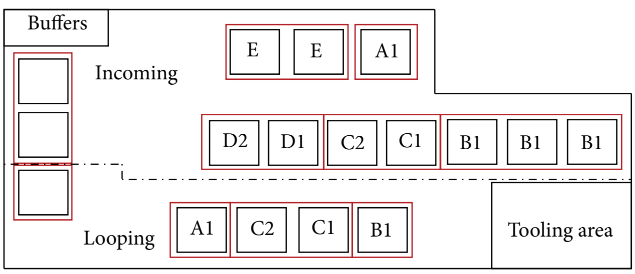

Figure 3: Flow 1.

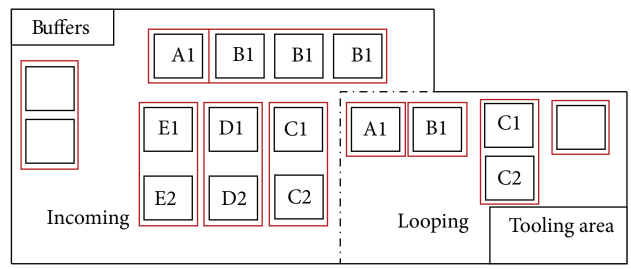

Figure 5: Flow 3.

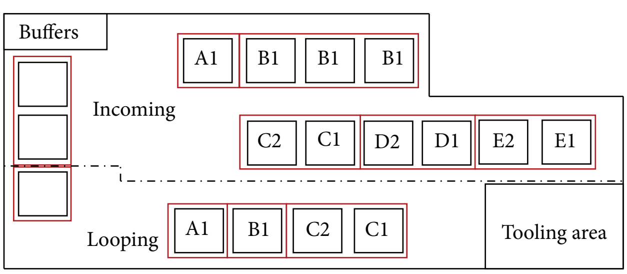

Figure 4: Flow 2.

1 : 2, 10 and 9 operators are used. The allocation of 10 operators is based on the line, whereas the assignment of the 9 operators is based on the nearest machine. This experiment describes the significance of reducing the number of operators relative to production performance by using the base model, Model 3, and Model 4, where the ratios of the number of operators to the machine are 1 : 1 and 1 : 2. In Model 3, the number of operators is reduced to 10, and operator allocation is based on the line. For example, an operator is assigned to Line E, which consists of two machines in the incoming section. By contrast, the operators in Model 4 are allocated to the nearest machine, which means that the two nearest machines are operated by only one operator. Model 4 has nine operators with an operators-to-machine ratio of 1 : 2 (the same as Model 3). For the base model, one operator is assigned to one machine, as proposed.

The preceding experiment considered the volume of parts on the basis of customer demand. The demands are categorized as low, medium, and high. Each demand represents the different volume of parts on the shop floor. The ratio of the volume of parts under low demand with respect to medium and high demands is 1 : 4 : 7. The effect of different volumes of parts on production performance is demonstrated in Experiment 3. Three types of customer demand are given: low, medium, and high. The demands for the base model, Model 5, and Model 6 are low, medium, and high, respectively. The flow pattern of parts and the number of operators remained the same as in the case of the base model. The ranges of the low, medium, and high demands are defined in Table 2.

The simulation runs started subsequent to the determination of experiment parameters. The data and information required for the simulation are the machine cycle time and setup time, volume of parts, type of process and machine involved, number of operators, working time per shift, and part routing. To reduce the gap between the virtual simulation and the actual scenario in the industry, a warm-up period plays an important role. In actual scenarios, factories do not start without initially being a work in progress (WIP). A warm-up period is needed to achieve a steady state condition in the simulation. A warm-up period is the amount of time that a model runs before any results are recorded. The results of the model are unlikely to be typical until the model has warmed up. In this case, the warm-up period is set to 2 shifts (12 hours per shift). The results obtained from the simulation underwent a statistical analysis to determine the relationship between the experiment parameters and the performance measurement.

4. Simulation Results

The results of the simulation runs are analyzed in this section. As mentioned, three experiments were conducted to investigate the significance of the changes in the shop floor.

Table 2: Volume of parts for each demand.

Demand	Volume of parts (lots)
Low	1050
Medium	4200
High	7350

Under each experiment, two alternative models and a base model were compared in terms of the throughput rate, machine utilization, and operator utilization. The model that obtains the best performance is chosen from each experiment for further analysis. The results of each experimental run are discussed and tabulated in Tables 3, 4, and 5.

4.1. Experiment 1: Testing the Significance of the Different Part Flow Patterns on Production Performance. This experiment is to test the significance of the different part flow patterns on production performance. Three types of flow pattern are presented: flow 1, flow 2, and flow 3. Table 3 shows the results of Experiment 1.

The results demonstrate that the base model, Model 1, and Model 2 have equal throughput rates and labor utilizations, while the machine utilizations of the three models are almost comparable. The differences in the machine utilizations of Models 1 and 2 compared to that of the base model are 0.08% and 0.01%, respectively. Thus, differences in the flow pattern of parts do not affect the shop floor performance because all the models have equal throughput rates and operator utilizations, and the differences in the percentages of machine utilization are negligible. The three models have the same performance in terms of the throughput rate, machine utilization, and operator utilization. However, the results show that the machine utilization of Model 1 is slightly better than that of the base model and Model 2, which means that flow 2 performed better in terms of machine utilization. Thus, Model 1 was chosen for further ANOVA based on the results.

4.2. Experiment 2: Testing the Significance of a Reduction in the Number of Operators on Production Performance. Experiment 2 is conducted to determine the effect of a reduction in the number of operators on the production performance. The number of operators varies in each model and is determined by the ratio of the number of operators to machines, which is 1 : 1 and 1 : 2. This experiment used 17, 10, and 9 operators to examine the effect of the operator numbers on the production performance. The results of Experiment 2 are tabulated in Table 4.

The results reveal that the performances of Models 3 and 4 are inferior to that of the base model. The throughput rate and the machine utilization of Models 3 and 4 decreased drastically because of the reduction in the number of operators. However, the operator utilization increases because the operators are busy coping with the impending parts. The obtained data show that if the number of operators is reduced to nine, the throughput rate and machine utilization are reduced to 0.019 lot/min and 35.08%, respectively. By contrast, the operator utilization increased to 66.43%. However, Model 4 is selected for ANOVA because the performance of this model is slightly better than that of Model 3 in terms of the throughput rate and machine utilization. As regards the reduction in the number of operators, the ratio of one operator to one machine possesses the highest throughput rate, which indicates that 17 operators in the shop floor are able to produce a higher throughput rate compared with 10 and 9 operators.

Table 3: Results of Experiment 1.

	Throughput rate (lot/min)	Machine utilization (%)	Operator utilization (%)
Base model	0.0234	44.53	44.63
Model 1	0.0234	44.61	44.63
Model 2	0.0234	44.52	44.63

Table 4: Results of Experiment 2.

	Throughput rate (lot/min)	Machine utilization (%)	Operator utilization (%)
Base model	0.0234	44.53	44.63
Model 3	0.0184	34.77	59.34
Model 4	0.0186	35.08	66.43

Table 5: Results of Experiment 3.

	Throughput rate (lot/min)	Machine utilization (%)	Operator utilization (%)
Base model	0.0234	44.53	44.63
Model 5	0.0298	70.59	70.64
Model 6	0.0251	69.86	70.03

4.3. Experiment 3: Testing the Significance of Different Volumes of Parts on Production Performance. The significance of different volume of parts on production performance was studied in Experiment 3. The volume of parts applied is based on the customer demand, which can be divided into low, medium, and high. Different volume of parts might have either a positive or a negative effect on the production performance. Table 5 shows the results of Experiment 3.

The results indicate that Model 5 has the best performance compared with the base model and Model 6. Model 5, with a medium demand, has the highest throughput rate of 0.0298 lot/min, and the machine and operator utilizations have increased by approximately 26.06% and 26.01%, respectively. For Model 6, the throughput rate increased to 0.0251 lot/min, and the machine utilization apparently increased by 69.86% compared with that of the base model at 44.53%. There is not much difference between Models 5 and 6 in terms of the 3 measurement criteria. The machine and operator utilizations of Model 6, with a high demand, have differences of only 0.73% and 0.61%, respectively, compared with Model 5. This observation implies that the performances of both medium and high demands show not much effect.

Table 6: ANOVA for throughput rate.

Source of variance	SS	df	MS	F
Between groups	0.003784	3	0.000273	6.582222
Within groups	0.045225	236	0.000192	
Total	0.049009	239		

Nevertheless, the difference between the low demand and the medium and high demands is remarkable, which is roughly 26%. Hence, the shop floor performs best with medium demand. Therefore, Model 5 is selected for further ANOVA.

5. Analysis of Variance

Once the three models are resolved, ANOVA is applied to study the sample-data relationship of the selected models. ANOVA is a statistical method used to test the significant difference among means. ANOVA is also a hypothesis test that consists of a null hypothesis (H_0) and an alternative hypothesis (H_1). If the calculated F value is greater than the critical F value, then the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. One-way ANOVA is conducted at 99% and 95% confidence levels in this research to test the effect of different shop floors on the performance measures. The models with better performance in each experiment are selected for further analysis. The base model and Models 1, 3, and 5 are selected for ANOVA because they outperformed other models. ANOVA is applied to analyze the effect of changes in the shop floor on the production performance.

5.1. ANOVA for the Throughput Rate. ANOVA is employed to test the following hypotheses:

H_0: different shop floors have no significant effect on throughput rate;

H_1: different shop floors significantly affect throughput rate.

The critical F value at 99% and 95% confidence levels obtained from the F-table are 3.87 and 2.64, respectively. From Table 6, the calculated F value is evidently greater than the critical F value. Thus, the null hypothesis (H_0) is rejected, which also implies that the effect of a different shop floor on the throughput rate is significant.

5.2. ANOVA for Machine Utilization. For machine utilization, ANOVA is used to test the following hypotheses:

H_0: different shop floors have no significant effect on machine utilization;

H_1: different shop floors have a significant effect on machine utilization.

The results in Table 7 show that the calculated F value of 35.65273 is much greater than the critical F value at 99% (3.87) and 95% (2.64) confidence levels. The null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. This finding implies that there is a significant effect of a different shop floor on the machine utilization.

Table 7: ANOVA for machine utilization.

Source of variance	SS	df	MS	F
Between groups	41929.05	3	13976.35	35.65273
Within groups	92515.18	236	392.0135	
Total	134444.2	239		

Table 8: ANOVA for operator utilization.

Source of variance	SS	df	MS	F
Between groups	34825.3	3	11608.43	24.02253
Within groups	114042.6	236	483.2312	
Total	148867.9	239		

5.3. ANOVA for Operator Utilization. ANOVA is used to test the following hypotheses:

H_0: different shop floors have no significant effect on operator utilization;

H_1: different shop floors have a significant effect on operator utilization.

From the results shown in Table 8, the calculated F value is 24.02253, while the critical F values at 99% and 95% confidence levels are 3.87 and 2.64, respectively. The calculated F value is greater than the critical F value for both confidence levels. Thus, the null hypothesis (H_0) is rejected, and the effect of a different shop floor on the operator utilization is proved to be statistically significant.

6. Comparison Analysis

The base model and the three alternative models are compared with regard to the performance measurement considered to have a better view of the effect of a different shop floor on the performance measurement. The results of the comparison will aid in making an informed decision on the best models to be adopted by the case study company. The comparisons will be based on the three performance criteria, which are the throughput rate, machine utilization, and operator utilization.

6.1. Throughput Rate. Figure 6 shows the throughput rates of the four models through a chart. Model 5, with a medium demand, 17 operators, and flow pattern 1, has the highest throughput rate compared with the base model and the other alternative models. This result connotes that flow 1 functions well under medium demand, with a ratio of 1 operator to 1 machine. Model 4 has the lowest throughput rate among all the models with only 0.0186 lot/min, which could be caused by the adverse effect of reducing the number of operators. However, Model 1 has a throughput rate equal to that of the base model, which is 0.0234 lot/min. This observation indicates that the effect of the flow pattern with a low demand is insignificant.

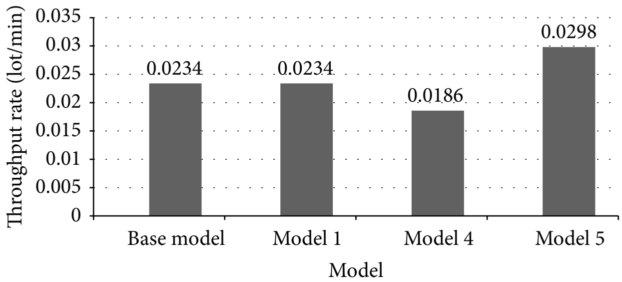

Figure 6: Throughput rate of the four models.

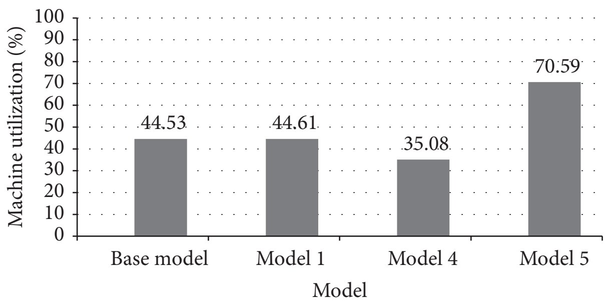

Figure 7: Machine utilization of the four models.

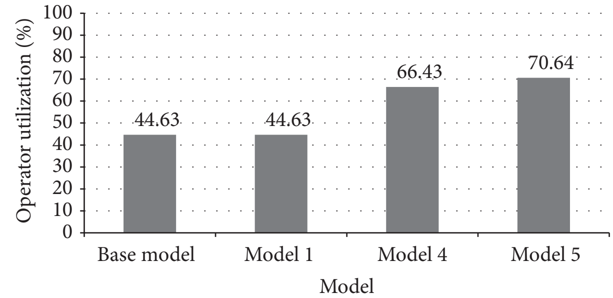

Figure 8: Operator utilization of the four models.

Table 9: Summary of the four models.

	Throughput rate (lot/min)	Machine utilization (%)	Operator utilization (%)
Base model	0.0234	44.53	44.63
Model 1	0.0234	44.61	44.63
Model 4	0.0186	35.08	66.43
Model 5	0.0298	70.59	70.64

6.2. Machine Utilization. Figure 7 illustrates the machine utilization of the four models through a chart. Model 5, which has the highest throughput rate, has the best performance among all the models in terms of machine utilization. Model 5 shows the highest machine utilization with 70.59%. This result proves that the medium demand has the highest effect on machine utilization compared with the base model and Model 1, which have low demands. Model 4 performed the worst once more, with 35.08% machine utilization. The poor performance of Model 4 can be attributed to the 1 : 2 ratio of the number of operators and machines. One of the machines will possibly be idle, while the other machine is fully utilized. Therefore, the machine utilization in Model 4 is the lowest. There is not much difference between the machine utilization of the base model and Model 1, with values of 44.53% and 44.61%, respectively.

6.3. Operator Utilization. Figure 8 shows the graph of the operator utilization of the four models. Model 5, which has been chosen as the best model, shows the highest operator utilization with 70.64%. Model 4 follows with 59.34%, which is the second highest operator utilization resulting from the lower number of operators involved in the operation. All the operators are fully utilized because one operator has to work on two machines. Moreover, the base model and Model 1 both have the same operator utilizations of 44.63%, which shows that different flow patterns do not affect the operator utilization even with low demand and 17 operators.

Table 9 shows a summary of the four models with different changes in the shop floor and with respect to the performance measurement. The model that exhibits the best performance in each experiment is chosen and tabulated for comparison with the base model. Models 1, 4, and 5 are selected from each of the experiments because of their satisfactory performance.

Each model has a different performance in terms of throughput rate, machine utilization, and operator utilization under distinct variables on the shop floor. The base model, which is also the proposed model, is performing normally compared with Model 5, which has an overall significant performance. All the models, except for Model 4, are obviously able to produce more output in a period of time with high machine utilizations. Model 4, which is comprised of nine operators and with flow 1 under a low demand condition, had the poorest overall performance. This poor performance can be attributed to the reduction in the number of operators resulting from the decrease in the machine utilization, thus lowering the throughput rate. Regarding the throughput rate and machine utilization, the higher the percentage of machine utilization is, the higher the throughput rate will be. Model 5, which has the highest machine utilization, evidently has the highest throughput rate among the models as well. Model 5 is the model that operated in flow 1 with 17 operators (one operator to one machine) under medium customer demand. Therefore, the throughput rate is directly proportional to the machine utilization as an increase of 26% in the machine utilization raised approximately 27% in the throughput rate of Model 5 compared to that of the base model. However, high operator utilization does not necessarily mean a high throughput rate, as proven by Model 4. Model 4 is the model that has nine operators (one operator to two machines) and works in flow 1 under low customer demand. The results showed that even Model 4 has high operator utilization, but the throughput rate is the lowest among all models. This finding might be attributed to the fact that one operator is busy handling two machines simultaneously. Hence, a high operator utilization may not lead to a high throughput rate as well. In terms of the three measurement criteria, Model 5 performed well compared with the other models. In the midst of the intensive analysis, the simulation outcome allows the case study company to make an informed decision on the best alternative available when the company is required to make a crucial decision. The DES enables the applicability and performance of various variables to be examined and tested before these variables are changed and implemented in the production. As discussed earlier, the changes in the shop floor can cause a positive or negative effect on the shop floor performance. Examining the changes in the shop floor is important to prevent adverse effects. Choosing the suitable solution makes a difference in the shop floor performance because a bad decision on this matter can be disastrous, and a suitable solution can lead to an optimal production operation. From the managerial perspective, finding the optimal operating shop floor is important for the case study company. Throughout this study, the primary benefit to the company is that changes in production operation can be made at the lowest cost and without interruption through simulation. In this way, the management team is able to choose the appropriate and optimal operating shop floor through proper analysis and planning.

7. Conclusions

This study investigated the application of DES in identifying the effect of different number of operators, volume of parts, and different types of flow pattern of parts on the shop floor performance through the case study company. DES is able to measure the performance, and the simulation results can be used to examine the shop floor performance via statistical analysis. The results obtained from ANOVA proved that the shop floor performance is significantly affected by the three measurement criteria: throughput rate, machine utilization, and operator utilization. The best model is demonstrated under each alteration in the shop floor. Aside from the optimal operating shop floor determined from this study, the manager is also able to choose the appropriate models to be implemented in the shop floor based on different performance measurements. The performance measures that are selected can be used to assess the efficiency of the organization, and the data can be a benchmark for future planning to find ways of improving productivity. In actual scenarios, changes in operating conditions can vary the results obtained. For example, an alteration in the level of buffer capacities, part interarrival time, variety of products, and machine failure rate can cause different outcomes and have different effects. System disruptions, such as material handling system breakdowns and absence of operators, can be included in future studies so that the details considered will be closer to the real-world scenario of the shop floor.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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References

[1] C.-H. Soh, S.-H. Ding, and S. Kamaruddin, "Shop floor performance measurement—a case study in injection moulding industry," *International Journal of Agile Systems and Management*, vol. 5, pp. 103–121, 2012.

[2] L. D. Fredendall and S. A. Melnyk, "Assessing the impact of reducing demand variance through improved planning on the performance of a dual resource constrained job shop," *International Journal of Production Research*, vol. 33, no. 6, pp. 1521–1534, 1995.

[3] H. Panjehfouladgaran, R. Yusuff, T. S. Hong, and S. M. Homayouni, "Qualitative performance measurement of supply chain management using fuzzy logic controller," in *Proceedings of the 11th Asia Pacific Industrial Engineering and Managements System Conference*, 2010.

[4] A. Gunasekaran, C. Patel, and E. Tirtiroglu, "Performance measures and metrics in a supply chain environment," *International Journal of Operations and Production Management*, vol. 21, no. 1-2, pp. 71–87, 2001.

[5] D. Barnes and Z. Radnor, *Performance Measurement and Management: The Operations Management Perspective*, Palgrave Macmillan, London, UK, 2008.

[6] M. Jahangirian, T. Eldabi, A. Naseer, L. K. Stergioulas, and T. Young, "Simulation in manufacturing and business: a review," *European Journal of Operational Research*, vol. 203, no. 1, pp. 1–13, 2010.

[7] J. Banks, J. S. Carson, B. L. Nelson et al., *Discrete-Event System Simulation*, Prentice Hall, New York, NY, USA, 2001.

[8] J. F. O'Kane, J. R. Spenceley, and R. Taylor, "Simulation as an essential tool for advanced manufacturing technology problems," *Journal of Materials Processing Technology*, vol. 107, no. 1–3, pp. 412–424, 2000.

[9] Y.-B. Lin, "Design issues for optimistic distributed discrete event simulation," *Journal of Information Science and Engineering*, vol. 16, no. 2, pp. 243–269, 2000.

[10] O. Özgün and Y. Barlas, "Discrete versus continuous simulation: when does it matter?" in *Proceedings of the 27th International Conference of The System Dynamics Society*, Albuquerque, NM, USA, 2009.

[11] W. D. Kelton, R. P. Sadowski, and D. A. Sadowski, *Simulation with Arena*, McGraw Hill, New York, NY, USA, 2nd edition, 1998.

[12] A. Negahban and J. S. Smith, "Simulation for manufacturing system design and operation: literature review and analysis," *Journal of Manufacturing Systems*, vol. 33, no. 2, pp. 241–261, 2014.

[13] M. Jägstam and P. Klingstam, "A handbook for integrating Discrete Event Simulation as an aid in conceptual design of manufacturing systems," in *Proceeding of the Winter Simulation Conference*, vol. 2, pp. 1940–1944, December 2002.

[14] A. A. Tako and S. Robinson, "The application of discrete event simulation and system dynamics in the logistics and supply chain context," *Decision Support Systems*, vol. 52, no. 4, pp. 802–815, 2012.

[15] B. Sharda and S. J. Bury, "A discrete event simulation model for reliability modeling of a chemical plant," in *Proceedings of the Winter Simulation Conference (WSC '08)*, pp. 1736–1740, Austin, Tex, USA, December 2008.

[16] C. Murgiano, "A tutorial on WITNESS," in *Proceedings of the Winter Simulation Conference Proceedings*, pp. 177–179, New Orleans, La, USA, December 1990.