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Analysis on the Effect of Shop Floor Parameters on the Effectiveness of Preventive Maintenance through Discrete Event Simulation

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ABSTRACT

Preventive maintenance (PM) is a predetermined task that constitutes any maintenance actions performed before the quantity or quality of product equipment deteriorates. PM is primarily aimed at protecting assets, improving system reliability, and decreasing system downtime. Recently, the implementation of PM is becoming more challenging due to the increase in complexity of manufacturing systems. A case study on the effect of different parameters from a maintenance perspective on industrial shop floor performance is presented. The parameters include number of technicians, number of operations in each machine before maintenance actions, and volume of parts ordered by customers. This present research demonstrates the application of WITNESS simulation software to develop shop floor simulation model and the use of analysis of variance (ANOVA) to measure the significance of such parameters on performance.

Keywords: Analysis of Variance (ANOVA), models, parameters, performance measure, Preventive Maintenance (PM), WITNESS simulation software

INTRODUCTION

Preventive maintenance (PM) plays an important role in keeping equipment in excellent condition. The prevention of sudden malfunction and downtime during production, especially in the manufacturing industry, will improve productivity and reduce loss. PM involves various activities such as inspection, servicing, and repairing or replacing component after a specified service life. Apart from preventing equipment or machine from malfunctioning, PM improves reliability and reduces maintenance costs (Oyedepo & Fagbenle, 2011). Moreover, enhanced PM planning can lead to a globally competitive production system by reducing malfunctions and hence, downtime. This scenario can be

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achieved by knowing the optimal period and frequency in carrying out PM (Eti et al., 2006). Discrete Event Simulation (DES) is a computational technique to analyse, design and operates complex systems for better understanding without affecting the real system (Alabdulkarim et al., 2013). It is an indispensable problem solving tool for addressing real-time problems (Banks, 1998). With the development of highly-advanced model, simulations are widely used in engineering, production, medical, and economic systems. It enables designers to obtain a thorough perspective of the shop floor behaviour system, especially in production (Ghasemi et al., 2012).

In the early years of this research, Eloranta and Raisanen (1987) proposed simulation models to characterise the shop floor buffer size requirement. Wallace and Mills (1988) investigated the effects of manufacturing strategy through a simulation and proved the importance of simulation in the field of manufacturing. Furthermore, O'Kane (2000) stated that simulation can be applied to justify and design production technology programmes. Viharos and Monostori (2002) conducted optimisation of production systems. By linking simulation model and the concept of key performance indicator, Bataineh et al. (2010) were able to measure the performance of public departments. Its applicability was also extended to network modelling as explained by Sukhroop et al. (2012) in wired and wireless network performance. The wide range of application shows the versatility of the DES.

In PM perspective, various methods have been proposed to determine the optimal frequency of performing the PM planning. As stated by Ab-Samat et al. (2012), developing the PM planning includes preparing for PM activities, prioritising spare parts, setting up systems and components, and preparing time estimation for maintenance operations in order to aid the decision making for actions to be taken. In addition, the documentation of the system that provides valuable information such as maintenance recommendation on the system from the manufacturer, production operations, maintenance personnel, breakdown record, and maintenance costs are important to be considered in order to properly maintain the system. Knapp and Mahajan (1998) optimised a manpower model which aims to reduce the cost of the maintenance resources by optimising the allocation of the cost of manpower based on the workload demand. The optimisation model was implemented by using a simulation analysis (SIMAN). The model provides statistical information such as the utilisation of the workers and queue length of failed systems in each area and for each craft-type. The results showed the improvement of the overall performance due to the allocation of workers, worker utilisation and queue length, which can help in making decisions for PM planning in regard of the workers' assignments. Caldeira and Guedes (2007) designed an algorithm that calculates the optimisation of PM planning through Weibull hazard function. On the other hand, Su and Tsai (2010) proposed a flexible PM planning analytical model for two parallel machines. In a more recent study, Abogrean and Latif (2012) presented a new approach using Witness simulation in combating issues related to maintenance in a cement industry. The study developed a simulation model and demonstrated on a single-unit system by focusing on the spare parts and maintenance personnel, with reference to the time-effective aspect. Thus, a better PM planning can be implemented in the actual operation based on the result of a simulation by improving the stock control system and ensuring efficient communication and teamwork throughout the facility. However, there are significant knowledge gap in the optimisation of PM planning (Almomani et al., 2012).

This present research outlines an approach that uses simulation to measure shop floor performances toward the effectiveness of PM. WITNESS simulation software is applied in conducting a case study on various variables on the shop floor with different parameters from the PM perspective. This study aims to analyse the significance of throughput rate, machine utilisation and technician utilisation towards the effectiveness of PM.

DEVELOPMENT AND ANALYSIS OF SIMULATION MODEL

The shop floor maintenance performance model approach utilised in this research is aimed at analysing the impact of conducting PM on the shop floor. WITNESS simulation software is used for the model development, verification and validation. WITNESS is a DES software that includes the visual interactive simulation. This software offers a visual display and a statistical report of the replication results and thus, ascertains errors in the flow logic during model building. The shop floor parameters can be amended at any interval throughout the simulation runs, which are prominent for an easy model-building platform. WITNESS also allows models to be built and tested in small incremental stages. Therefore, by adopting the conceptual model development (Banks, 1998), a comprehensive shop floor maintenance performance model methodology is developed. The adopted methodology is shown in Figure 1. The methodology consists of five phases. In phase 1, shop floor analysis is executed to obtain a good understanding of the shop floor environment. In phase 2, shop floor data are collected to develop the simulation model. Computations of the data, incorporated in the development and verification of the developed simulation model, are included in this phase. Performance measures are then identified and selected. Next, the experiment is designed to study the effects of performance measures. In phase 5, ANOVA is used to analyse the significant effects of the different shop floor models on performance measures. The framework is discussed in detail in the subsequent section.

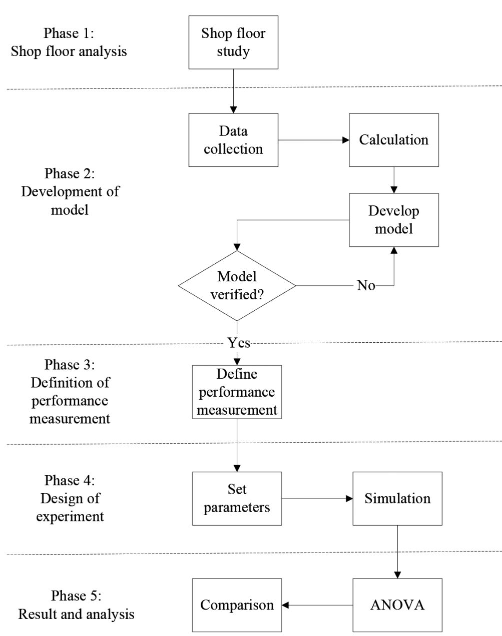

Figure 1. Development and analysis of the simulation model

Phase 1: Shop floor analysis

Shop floor analysis is a preliminary step prior to the development of the simulation model. In this phase, the product, process and layout of the department are studied. A good understanding of various variables and elements such as the flow of materials, products, human interaction and processes ensures the development of realistic simulation model to represent the real world scenario.

Phase 2: Development of the simulation model

Data are collected to develop the simulation model. The data include machine cycle time, output per shift, machine setup time and breakdown time. The collected data are then analysed to determine the parts demand ratio, output per shift, working time per shift, and average breakdown time that are crucial in the model architecture. The simulation model is developed using WITNESS. Next, the computed data are structured into the numerical elements to mimic the real-world environment. The simulation model is verified before proceeding to the stage in which the parameters are set. This step is vital in ensuring that the developed simulation model can be used in the design of experiment phase.

Phase 3: Identifying performance measures

Several authors defined performance measurement in different ways. Magretta and Stone (2002) defined performance measurement as the critical elements in translating missions or strategies of an organisation into reality. On the other hand, Tagen (2004) stated that performance measurement is a complex issue that incorporates four disciplines, namely, economics, management, accounting, and information technology. Performance measurement is also essential for an organisation to gauge its progress towards its predetermined objectives (Purbey et al., 2007). Hence, a significant performance measure must be identified and used.

Phase 4: Design of experiment

In this phase, different parameters are determined and several different models are constructed to investigate the effects of shop floor parameters on the identified performance measures. The experiments are designed by incorporating elements from the data and the determined performance measures. Three systematic experimental setups are identified to obtain a clear depiction of the problem to be analysed. Given the problem to be analysed, a good, apparent solution can be obtained, especially those related to PM. The experimental setup will be discussed in detail in the following section.

Phase 5: Result and analysis

In this phase, statistical reports obtained from the WITNESS simulation are tabulated. Based on the simulation results from each experiment, the model that performs better is selected. Next, the chosen models are analysed by using ANOVA to identify the effects of varying parameters to the shop floor performance.

CASE STUDY

The case study was conducted in a printed circuit board (PCB) manufacturing company, which is referred as Company A. Company provides a full range support and services, from circuit design, prototype fabrication and mass production up to full board assembly. This case study focuses on the punching department of Company A. The punching department generally handles single-sided printed circuit board and double-sided printed circuit board. The printed circuit board undergoes punching process to create holes for further processes or to fulfil customers' requirements. As mentioned previously, this paper focuses on the imperative effects of different shop floor parameters such as throughput rate, machine utilisation and technician utilisation on the effectiveness of PM.

Phase 1: Shop floor analysis

Shop floor observation and check are the first steps in the shop floor analysis. Observation and check is one of the qualitative means for accruing data in order to identify unlooked-for, but latent issues and variables related to the actual shop floor environment. The observation and scrutiny are performed to gain information and understand the whole shop floor processes and procedure. In this phase, the observation and scrutiny is important in the attainment of the real production operations, culture and working procedure of both the management and production point of views for this research. Therefore, before initiating the maintenance performance analysis phase, this research is directed by looking at the analysis of the shop floor a case company. This analysis is conducted on a shop floor that has multifaceted manufacturing processes and a large number of systems to perform the production operations. Observation of the actual production operations of a related manufacturing environment is the main step in this phase. The observation normally refers to the Toyota terms such as Gemba, where observers are required to go and find out the actual production floor in order to gain a better understanding of the problem and perspective. Gemba can be carried out in various ways, such as interviewing related personnel, reviewing the documentation and understanding the whole production operations in detail. Thus, the information acquired can assist in defining the problems that arise in the related study. From the observation in the simple case study, the breakdown of the system is a major problem that occurs in the manufacturing plant.

In this research, the punching department is essential for the case study prior to the development of the simulation model. Therefore, a detailed analysis was carried out on the aforementioned department. The punching department currently uses a total of 17 machines, which consist of three SWA machines, four CF machines and 10 LC machines. As indicated, the processes consign to the each machine are related to punching a through hole or a chamfer hole on the PCB. Each machine is operated by one operator. There are two dedicated technicians that are responsible for breakdown and PM. The layout of the punching department is divided into two sections, namely, the incoming line and the looping line, as shown in Figure 2. The incoming and looping lines involve different punching processes, including panel trim, subpanel, outline, and piercing. Another difference is that the looping line is used for parts that need to be processed in the punching department for the second time. Some parts usually need to undergo other punching processes in between the incoming line and looping line. The following are examples of the processes involved in the incoming line and the looping line based on machines:

- **Incoming line:** Other processes → Incoming line punching process (SWA3→CF1→ LC12) → Other processes
- **Looping line:** Incoming line punching process (SWA2 → LC14 → LC13) → Other processes → Looping line punching process (LC8 → LC1) → Other processes

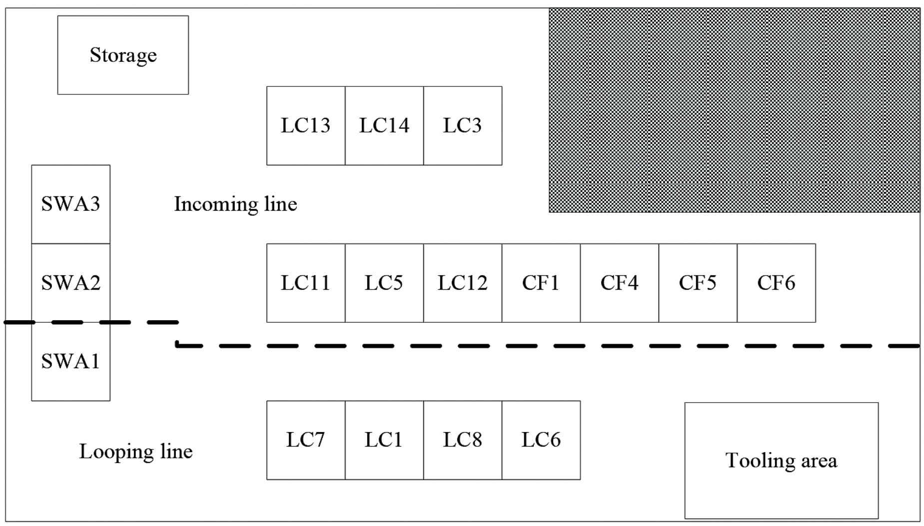

Figure 2. Shop floor layout of the punching department

Phase 2: Development of the simulation model

The initial development of the model development before it is translated into the WITNESS simulation software begins with the hand simulation. This is to ensure that the structure of the model has been well designed. A model was initially built on paper and used to analyse with WITNESS later. In creating a model through the WITNESS simulation software, the primary step was to establish the elements and variables to be included. Then, the elements and variables were detailed with their individual characteristics such as the cycle time and set-up time for each machine. The elements and variables were linked with rules and action. For example, as depicted in Figure 2, part inputted to machine LC7 was either pushed to or pulled from another machine. Then, labour (operator and technician) element was incorporated into the machine with details, such as assigning the labour to operate or set-up the workstation. As mentioned previously, there are two types of parts; single-sided part and double-sided part. The lot sizes for the single-sided part and double-sided part are 300 pieces and 80 pieces, respectively. Both parts have the same processing time of 14.4 seconds per piece in the SWA machines and 40.8 seconds per piece in the CF or LC machines. In this stage, a base model of the shop floor is constructed by using WITNESS simulation software. The path of each part processed through different machines is set by using the PUSH and PULL rules. IF rules are applied when conditional flow is needed. PM activities are set as the setup of machines. Labour rules are programmed to ensure that specified operators are responsible for traveling and processing the parts on specified machines. Labour rules are also integrated to ensure that technicians are involved in PM activities and repair during breakdown. The verification of this model is evaluated by comparing the output per shift that resulted from the simulation and manual calculation. The following assumptions are made during the development of the simulation model:

1. The ratio of part arrivals from previous processes is constant.
2. The processing flow is continuous.
3. Changeover of tool at each machine takes place with every change in part number.
4. The production runs 24 hours a day, seven days a week, in two shifts.
5. No scrap and rejected parts are produced.
6. Operators and technicians have similar working experiences and efficiencies.

A warm-up period is likely to start empty in the simulation. However, in reality, the punching department does not start each shift without any work-in-progress. Hence, the warm-up period is set as 1440 minutes, which is equivalent to two shifts of production runs.

Phase 3: Identifying performance measures

In this study, the simulation is used to measure shop floor performances by varying shop floor parameters from the maintenance perspective. Three performance measures are chosen; throughput rate of the department, machine utilisation and technician utilisation.

Throughput rate. In this experiment, throughput rate is the number of output units per unit time going through the punching process. The throughput rate is as in equation [1]:

$$\text{Throughput rate} = \sum_{i=1}^{T} \frac{Pi}{T} \quad [1]$$

Where,
Pi : the number of parts completed in a unit time i
T : the total completion time

Machine utilisation. Machine utilisation is the occupied percentage of a machine throughout the entire run of the simulation model. In this case study, the machine utilisation per shift can be obtained from the WITNESS simulation report, and average machine utilisation can be calculated by using the summation of machine utilisation divided by the number of machines. The machine utilisation is expressed as equation [2]:

$$\text{Average machine utilisation} = \frac{\sum machine\ utilization}{number\ of\ machines} \quad [2]$$

Technician utilisation. Technician utilisation is the occupied percentage of a technician throughout the entire run of the simulation model. Similar to machine utilisation, the technician utilisation per shift can be obtained from the WITNESS simulation report, and the average technician utilisation can be calculated by using the summation of technician utilisation divided by the number of technicians. The technician utilisation is expressed as equation [3]:

$$\text{Average technician utilisation} = \frac{\sum technician\ utilization}{number\ of\ technicians} \quad [3]$$

Phase 4: Design of the experiment

Three experiments were conducted. The first experiment was conducted to study the effects of the number of technicians who were responsible for maintenance activities on the shop floor performance. The second experiment was conducted to study the effects of the number of machine operations before maintenance is performed on the shop floor performance. The last experiment was conducted to study the effects of different volumes of parts on the shop floor performance. A total of seven different models were used in this study. The first model is the base model, applied for comparison purposes, while the other six models were used for experimental purposes. All the models used the same layout, number of machines and number of operators. Each model consists of different parameters, namely, the number of technicians, maintenance schedule, and demand of volume of parts as tabulated in Table 1.

Table 1
Simulation models with specified parameters

Model	Number of technicians	Number of operations before maintenance	Volume of parts
Base model	2	100	Low
Model 1	1	100	Low
Model 2	3	100	Low
Model 3	2	80	Low
Model 4	2	120	Low
Model 5	2	100	Medium
Model 6	2	100	High

The number of maintenance technicians in the punching production area varied from one to three. The maintenance schedule is another variable considered in this experiment. The experiments are designed in which maintenance activities are carried out by one to three technicians at different time intervals considering the number of operations on each machine. The parameters varied between 80, 100 and 120 operations before maintenance the activities were carried out. Moreover, the experiments were conducted based on the volume of parts in the punching department. The part volume varied from low (1050 lots), medium (4200 lots) and high (7350 lots), respectively.

Experiment 1: *Test on significance of number of technicians on shop floor performance*
In experiment 1, base model 1 and model 2 were selected to test the significance of the number of technicians on the shop floor performance. In model 1, the number of technicians is one and in model 2, the number of technicians is three. It is assumed that 100 operations are run prior to PM activities and low volume production.

Experiment 2: *Test on significance of operation number before PM activities are conducted on shop floor performance*
In experiment 2, base model, model 3 and model 4 were selected to test the significance of the operation number on the shop floor performance before PM activities were conducted. In model 3, PM was conducted after 80 operations, whereas in model 4, PM was conducted after 120 operations. In this experiment, two technicians were used with low volume production.

Experiment 3: *Test on significance of the demand of volume parts on the shop floor performance*
In experiment 3, base model, model 5 and model 6 were selected to test the significance of the volume of parts on the shop floor performance. The volume was set to 1050, 4200 and 7350 parts for model 1, model 5 and model 6, correspondingly. In this simulation, it is assumed that 100 operations are required with two maintenance technicians.

Phase 5: Results and analysis

Once the simulation had been carried out, the WITNESS software was used to compute the statistical data from each model. Specific performance data are tabulated for further analysis. The results of the simulation runs, ANOVA, and model comparisons are shown in the following sections.

Simulation Results for Experiment 1. Table 2 outlines the results of three performance measures based on the models involved in experiment 1.

Table 2
Results of experiment 1

Model	Throughput rate (lot/minute)	Machine utilisation (%)	Technician utilisation (%)
Base model	0.023	44.35	11.59
Model 1	0.023	44.22	23.29
Model 2	0.023	44.45	3.92

The throughput rate in the base model, model 1, and model 2 are similar at 0.023 lots per minute. Slight difference was observed in terms of machine utilisation, in which base model obtained 44.35%, model 1 obtained 44.22%, and model 2 obtained 44.45%. The technician utilisation in each model varies significantly. Model 1 achieves the highest technician utilisation among all the models in this experiment (23.29%), followed by the base model (11.59%) and finally, model 2 (3.92%). ANOVA was used to test the impacts of the number of technicians on the shop floor on performance measures to decide whether to reject the null hypothesis, h_0, or to accept the alternative hypothesis, h_1, or vice versa. In this section, although the machine utilisation in model 1 is not the highest, model 1 was selected because it achieved the highest technician utilisation. Model 1 was further analysed by using ANOVA.

Simulation Results for Experiment 2. Table 3 shows the results of three performance measures based on the models involved in experiment 2.

Table 3
Results of experiment 2

Model	Throughput rate (lot/minute)	Machine utilisation (%)	Technician utilisation (%)
Base model	0.023	44.35	11.59
Model 3	0.023	53.53	15.99
Model 4	0.023	44.42	10.99

In contrast to experiment 1, the throughput rate in base model, model 3 and model 4 are similar at 0.023 lots per minute. In order to determine the influence of operation number before PM activities were conducted on shop floor performance, ANOVA was used. It is to decide whether to reject the null hypothesis, h_0, or to accept the alternative hypothesis, h_1, or vice versa. Model 3 has the highest machine utilisation at 53.53%, compared with machine utilisation of the base model at 44.35%, and model 4 at 44.42%. Moreover, model 3 achieves the highest technician utilisation, which is 15.99%, and is 4.4% and 5% higher than the technician utilisation of the base model and model 4, respectively. Obviously, model 3 performed the best among all the models in experiment 2. Hence, model 3 was selected for further analysis by using ANOVA.

Simulation Results for Experiment 3. Table 4 shows the results of three performance measures based on the models involved in experiment 3.

Table 4
Results of experiment 3

Model	Throughput rate (lot/minute)	Machine utilisation (%)	Technician utilisation (%)
Base model	0.023	44.35	11.59
Model 5	0.027	69.67	19.63
Model 6	0.024	68.46	18.41

Differences in throughput rate, machine utilisation and technician utilisation among the models were observed in experiment 3. Model 5 has the highest throughput rate at 0.027 lots per minute, followed by the throughput rate in the base model and model 6 at 0.023 lots per minute and 0.024 lots per minute, respectively. Furthermore, the machine utilisation in model

5 is optimum among the three models in experiment 3 at 69.67%. In model 6, the machine utilisation was slightly lower than model 5 at 68.46%, whereas the base model obtained the lowest utilisation at 44.35%.

In terms of technician utilisation, model 5 achieved the highest utilisation with 19.63%, which is 1.22% higher than that of model 6 and 8.04% higher than that of the base model. ANOVA is adopted to define the impacts of demand of volume parts on shop floor performance. It is to establish whether to reject the null hypothesis, h_0, or to accept the alternative hypothesis, h_1. Overall, model 5 achieved the best performance compared with the other models in this experiment. Hence, model 5 was chosen for the ANOVA analysis.

ANALYSIS OF VARIANCE (ANOVA)

ANOVA is used to test the effects of the different models with specified parameters on the performance measures. In this phase, base model, model 1, model 3, and model 5 were chosen for ANOVA based on their significant performances in the previous experiments. One-way ANOVA at 95% confidence level is used to test the null hypothesis (h_0) in which the different models have no significant effects on performance measures and the alternative hypothesis (h_1) in which the different models significantly affect performance measures. The null hypothesis (h_0) is rejected and the alternative hypothesis (h_1) is accepted when the *F* value computed from ANOVA is higher than the *F* critical value, and vice versa.

ANOVA for throughput rate

In this section, ANOVA is used to test the following hypotheses:

h_0: The different models have no significant effects on the throughput rate.

h_1: The different models have significant effects on the throughput rate.

After ANOVA has been carried out, the result is tabulated in Table 5.

Table 5
ANOVA results for throughput rate

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	0.000727	3	0.000242	1.186224	0.315666	2.642851
Within groups	0.048238	236	0.000204			
Total	0.048966	239				

The obtained *F* value is 1.186224. This value is lower than the *F* critical value, 2.642851. In this scenario, the hypothesis h_1 is rejected, while hypothesis h_0 is accepted. The result indicates that different shop floor models have no significant effects on the throughput rate.

ANOVA for Machine Utilisation

In this section, ANOVA is used to test the following hypotheses:

h_0: The different models have no significant effects on machine utilisation.

h_1: The different models have significant effects on machine utilisation.

After ANOVA has been completed, the results are shown in Table 6.

Table 6
Results of ANOVA on machine utilisation

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	25807.85	3	8602.618	4.496066	0.004334	2.642851
Within groups	451554.2	236	1913.365			
Total	477362.1	239				

The obtained *F* value, 4.496066, is greater than the *F* critical value, 2.642851. Thus, the hypothesis h_0 is rejected, but hypothesis h_1 is accepted. The result indicates that different shop floor models significantly affect machine utilisation.

ANOVA for Technician utilisation

In this section, ANOVA is used to test the following hypotheses:

h_0: The different models have no significant effects on technician utilisation.

h_1: The different models have significant effects on technician utilisation.

After the ANOVA test has been carried out, the results are tabulated in Table 7 below.

Table 7
Results of ANOVA on technician utilisation

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	4509.809	3	1503.27	2.71367	0.045587	2.642851
Within groups	130735	236	553.9618			
Total	135244.8	239				

In this analysis, the obtained *F* value, 2.71367, is greater than the *F* critical value of 2.642851. The hypothesis h_0 is rejected, but hypothesis h_1 is accepted. The results indicate that the different shop floor models significantly affect technician utilisation.

MODEL COMPARISON

In this section, the performance measures of the chosen models are plotted in the column chart for comparison purpose. Based on the ANOVA test performed previously, the different models were found to significantly affect machine utilisation and technician utilisation without any significant effect on the throughput rate. Thus, the comparison is only based on machine utilisation and technician utilisation.

Comparison of machine utilisation

Figure 3 shows a comparison of machine utilisation between the base model, model 1, model 3, and model 5. The comparison was done to determine the effects of different parameters, including the number of technicians, number of operations at each machine before PM was conducted, and volume of parts on the machine utilisation of the shop floor. Each model of 1, 3 and 5 represents certain parameters with reference to machine utilisation. In Figure 3, it can be seen that model 3 and 5 have better performances compared to the other models.

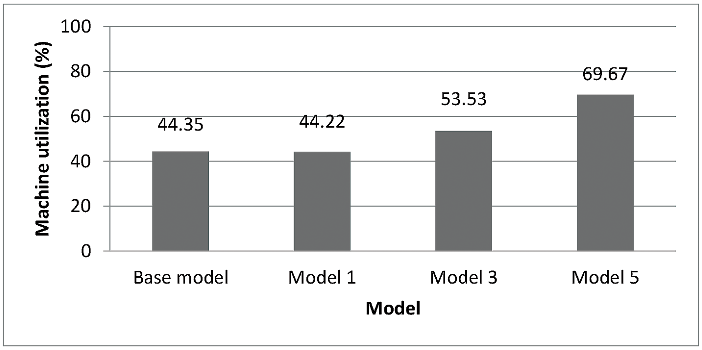

Figure 3. Graph of models against machine utilisation

Model 5 shows the highest machine utilisation, followed by model 3, base model, and model 1, with machine utilisation readings of 69.67%, 53.53%, 44.35%, and 44.22%, respectively. A higher machine utilisation percentage can eliminate more wastage during production. Hence, model 5 is selected among the models.

For a system that is highly dependent on manpower for maintenance, machine reliability is an important factor to ensure the resilience of maintenance systems should opposing scenarios occur for PM. It is vital that PM is planned precisely for optimal result. Machine reliability can be quantified by computing the probability of a technician to successfully complete a maintenance task without any mistakes or errors.

Comparison of technician utilisation

Figure 4 shows a comparison of technician utilisation among base model, model 1, model 3, and model 5. The comparison was done to determine the effects of different parameters, including the number of technicians, number of operations at each machine before PM was conducted, and volume of parts, on the technician utilisation of the shop floor.

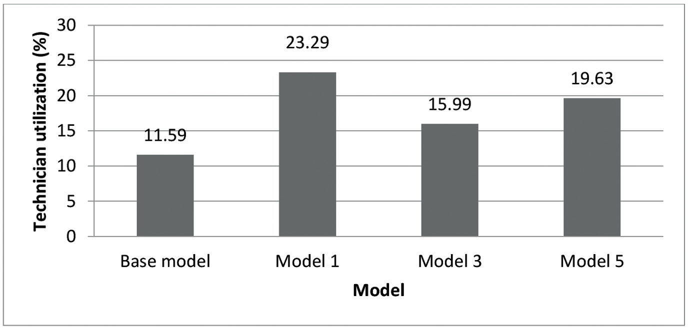

Figure 4. Graph of models against technician utilisation

Based on the chart, model 1 has the highest technician utilisation at 23.29%. Although the maintenance takes place after 80 operations for each machine in model 3 compared with 100 operations for model 1, the technician utilisation of model 1 is still 7.33% higher than that in model 3. The result could be due to the difference in the number of technicians; model 1 has only one, and model 3 has two. In model 1, the technician performs all the maintenance work, whereas in model 3, two technicians share the task.

The utilisation of technicians is highly dependent on their skills and job scope. It can be translated to working-hour productivity. A highly skilled technician may reduce the machine downtime and improve machine availability. The number of tasks the personnel performed in a week can be compared to others in determining the efficiency of a technician.

The results of this case study can be used by Company A to make informed decisions about improving the performances of the punching department. This study creates the shop floor design alternatives for Company A, which could then enable the company to deal with PM issues in enhancing machine or technician utilisations. Model 5 can be adopted to improve machine utilisation performance, in which machines undergo PM after every 100 lots of operations with two technicians at 4200 lots volume. Model 1 can be used to improve technician utilisation performance. In this case, a single technician is employed and PM takes place after every 100 lots of operations at 1050 lots production volume.

CONCLUSION

This study demonstrates the employment of DES as a tool to measure shop floor performance, especially when the shop floor parameters need to be changed due to maintenance issues. The simulation can be used by companies to obtain cost saving designs in predicting future shop floor performance rather than implementing a new design of maintenance parameters and measuring performances through trial and error. Thus, a systematic approach can be employed to address unforeseen issues. Based on the case study in the punching department of Company A, shop floor parameters have no significant effects towards its throughput rate. However, machine and technician utilisations are highly dependent on shop floor parameters. In the punching shop floor, model 5 can be used to obtain a higher machine utilisation percentage, while model 1 can be considered to obtain a higher technician utilisation percentage. The methodology developed in this research is simple and easy for implementation, and suited for applications in actual industries. The five phases in the plan can be adopted in various shop floors. Emphasis should be given on understanding the current situation of the company and translating the situation into a replicated scenario, with a list of employees responsible for each task in the system model. Improvement is then implemented by including as much as possible information for each task to achieve overall shop floor effectiveness. Thus, the maintenance planning protocol is continuously revised to detect imperfections. This study can be further improved by including different shop floor layouts and inspection operations. These variables can enhance the simulation model, which can lead to the advancement of performance measures in a shop floor.

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