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WITNESS simulation of preventive and corrective maintenance for Surface Mounted Technology (SMT) line

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Abstract. This paper shows the application of Discrete Event Simulation to study the effect of proposed maintenance strategies to the availability. The simulation study was conducted on a Surface Mount Technology (SMT) line. The model is built in the Discrete Event Simulation software WITNESS 14 to imitate this selected case study line to test out two proposed maintenance strategies. The first proposed strategy consists of Corrective Maintenance (CM) task only whereas the second proposed strategy is the introduction of Preventive Maintenance (PM) to the line. The effect of the two cases to the availability of each machine and system availability were verified with the simulation model to determine the most optimal solution. Although the simulation testing did not show improvement in availability for all station after the introduction of PM, the increment in system availability indicate that PM is the most optimal maintenance strategy for the SMT line.

1. Introduction

Due to rapid global market changes and evolving technologies, the manufacturing companies are moving toward Industry 4.0, they need to continuously improve their performance to achieve just-in-time production. The industries demand higher quality, lower cost and faster lead time in delivering their products and services to the customer. In term of equipment or machine, breakdown is the common challenge of all the industry due to the losses and drawback it brings to the production. Kiran summarized that the largest cause of production breakdown is due to equipment breakdown [1]. For this aspect, maintenance contributes to the minimize of equipment failure. The objective of the function is to combat the invertible degradation of the assets over time [2]. This function becomes one of the essential part in an industry. Although this function is known as a nonvalue-added component in the manufacturing system, its role cannot be ignored.

1.1. Maintenance Strategies

The two most common maintenance strategies are Corrective Maintenance (CM) and Preventive Maintenance (PM). CM is the maintenance task conducted when the asset degrades until it breakdown unexpectedly. It is an unplanned maintenance task [3]. Therefore, CM is defined as firefighting approach and it requires highest priority during machine breakdown as it may interfere the production. High frequency random breakdown cases have high possibility to halt the production if insufficient of



spare parts and human resource to support them [4]. This strategy is suitable to be used for only some cases. For example, when the hazard rate is constant, there is no serious effect and loss cause by the breakdown and the failed equipment is low in its priority [5].

To compensate with the drawback of stochastic breakdown, PM is introduced to minimize the unscheduled breakdown. PM is the scheduled maintenance task that is conducted routinely. The planning of PM requires the failure distribution data for the assets [6,7]. The planning of PM maybe troublesome, thus another more advanced strategy which is Condition Based Maintenance (CBM) is introduced. In CBM, the maintenance is conducted only when necessary based on the constantly monitoring of condition of the assets. It requires the diagnostic software, sensors and cameras to constantly monitor the condition of the machine include vibration, temperature and so on [6,8].

1.2. Machine Availability

To achieve world class Overall Equipment Effectiveness (OEE), availability plays an important role in achieving this goal. OEE is the product of availability, performance and quality. It is very challenging to achieve world class OEE which is 85%. The system must achieve 90% availability, 95% performance and 99% quality. Every component is very significant and thus losses that cause the drop of OEE is the focus. For availability, the factors that will causes the loss in availability are unplanned stop which is equipment breakdown and planned stop which is setup and changeover [10,11].

The availability is the portion of time that the equipment is capable to operate to the total planned duration that the production run. This can be explained in equation (1). Besides, availability can be also defined by using mean time between failures (MTBF) and mean time to repair (MTTR) as in equation (2) [9].

$$\text{Availability} = \frac{\text{Planned Production Time} - \text{Stop Time}}{\text{Planned Production Time}} \quad (1)$$

$$\text{Availability} = \frac{MTBF - MTTR}{MTBF} \quad (2)$$

1.3. Discrete Event Simulation

For the industry to sustain their global market, they must have the advantage in flexibility, responsive, cost efficiency, quality, reliability and service even in the maintenance function [12]. The growth of technology has enable the use of Discrete Event Simulation(DES) to test the proposed solution before it exists. DES is a dynamic simulation technique as the changes of system are represented over time. The state of variables changes only at the discrete-point of the model when certain event happens [13]. In addition, the changes of system states which are shown animated enable better visualizing and understanding, interactive experimentation and also better communication to all the stakeholders [14].

DES gains its popularity in many business and manufacturing application. For example, Yan and Wang had utilized DES to evaluate the performance of scheduling schemes for job shop scheduling [15]. Review done by Jahangirian et al. had shown the application of DES in assembly line balancing, capacity planning, transportation management, inventory management, production planning and inventory control, purchasing, resource allocation, scheduling and supply chain management. According to this review, the application of DES is more than 40% and thus is the most widely used technique in manufacturing and business [16].

The maintenance modelling and scheduling with DES is an interesting application part of this study. However, the utilization of this technique in maintenance is lesser compared to other application field as shown in the review by Jahangirian et al. [16]. Among the 114 papers that use DES technique, only one paper is from maintenance field. Nevertheless, there is no doubt that DES is helpful for the maintenance planning for an organization. DES has the ability to represent the system in animation, hence enable the user to have overall view on how the process operates and the process flow. This technique is also more suitable in analysing a well-defined system such as a production line [17]. In response to this problem, this study uses DES to simulate the effect of different maintenance strategy to the performance.

There are still some researches that use DES into their maintenance planning. From past studies, Abogrean and Latif had used WITNESS simulation to develop maintenance model and cost

optimization of a cement factory [18]. Meanwhile, Algrabghi and Tiwari used the same software in optimisation in maintenance planning [18]. Later in 2016, the researchers further improved their studies by considering more factors in their model. They planned the maintenance for multi-unit production line under the constrain of spare part with WITNESS simulation [14].

ARENA which is one of the DES software was used by Altugur and Chassapis in studying multi criteria decision approach of preventive maintenance [19]. Similar to Kevin whom developed simulation studies with ARENA to compare predictive maintenance policies with traditional time-based policies [20]. On the other hand, Enco and Lucas developed a simulation model in Anylogic software to evaluate cost reduction of the integration of intelligent maintenance system and spare parts supply chain [13]. All these past studies show the potential of DES in maintenance planning.

There is still gaps from the past studies. The utilization of DES in maintenance planning is a new era to be explore. Maintenance field should adopt this technique into the planning work in order to be more efficient and low risk in the decision made. This effort is one of the keys for the industrial in their evolution into Industry 4.0. The researchers need to eliminate oversimplified assumption in the model so that the decision made is more convincing. For example, maintenance planning is made without ignoring the labour and production factor in the model. Most of the research that did research on a multi-unit line will treat the line as single-unit system. The same maintenance strategy with the same frequency is introduced to all the units in the system regardless the function, breakdown problem and the breakdown frequency of the machines. The assumptions decrease the accuracy of the simulation result.

Moreover, most of the past result studies the effect of only one type of maintenance strategy in simulation. However, each strategy has their own advantage and limitation. It needs experimentation to determine the most optimal and beneficial maintenance strategy. Therefore, this study creates a maintenance model DES software Witness 14 to evaluate the performance of daily PM and CM in a selected case study Surface-Mount Technology (SMT) line. The simulation result compares the system availability of the two strategies. In the research also, we will see whether the maintenance strategy is beneficial to all the units.

2. Method

2.1 Simulation Framework

A Surface Mounted Technology (SMT) line with multi and different machines was chosen as case study line. SMT is an assembly line to mount the electronic components on the surface if printed circuit boards (PCB) or substrates [21]. The SMT line has five machines which are connected by conveyors. The flow of the parts is shown as in Figure 1. The machines were named M1, M2, M3, M4 and M5 for confidentiality and easier documentation in the following steps. The machine breakdown is the disaster for this continuous line as any stoppage due to breakdown will stop the whole production line. Therefore, it is significant to minimize the unscheduled breakdown of machines.

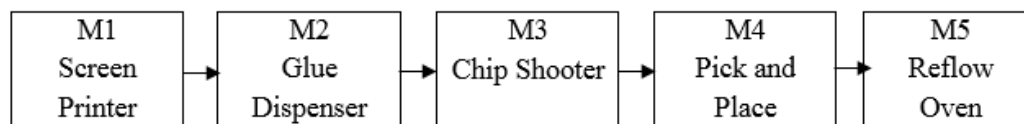


Figure 1. Machines and process flow of SMT line.

2.2 Data Collection

The data in Figure 2 was collected using time studies, from records and interview. The inputs for the process included the materials and man were determined. The lead time of each process was collected by time studies as well as the travel time for the conveyor. The number of operator and maintenance crews were determined for the input of simulation model. The duration for machine breakdown, time to repair, setup and changeover were also collected by time study in the production line.

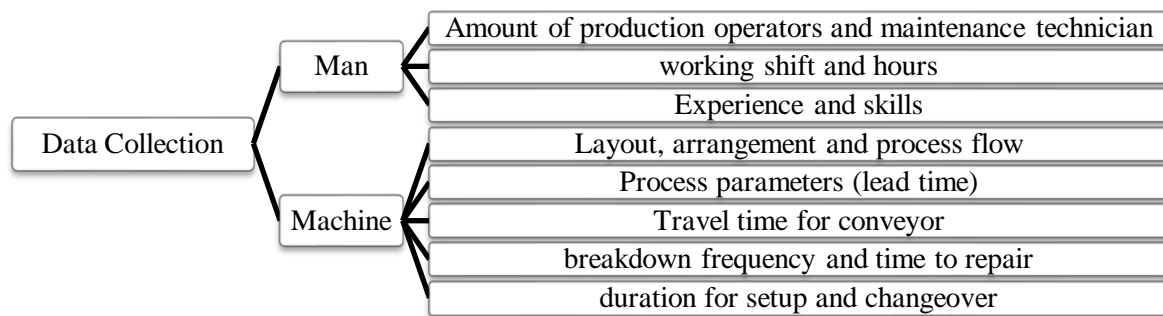


Figure 2. Information and data to collect.

2.3 Data Analysis

The raw data collected must be analysed before simulation model building. For the planning of CM and PM, the machine degradation pattern of M1 to M5 and their respective repairing time were analysed to get the distribution curve. From the analysis, the time between failure for M1 to M5 followed Weibull distribution whereas the repair time followed Uniform distribution. Data collected in Section 2.2 were also analysed.

2.4 Maintenance Strategy Planning

There were two cases to be tested in the DES software WITNESS 14 in which the details are listed in the Table 1. For Case 1, the only maintenance strategy used is CM. Hence, the maintenance is performed only when the machine breakdown. The breakdown of machine will cause stoppage to whole production line.

As for case 2, PM is introduced to all five machines. The maintenance task that should be done during PM and its frequency were decided qualitatively after discussion with the stakeholders. The PM was scheduled to be done daily. The time for adjustment and setup task during PM is 15 minutes.

Table 1. Maintenance strategies

	Correction Maintenance (CM)	Preventive Maintenance (PM)	Setup and Changeover
Case 1	Yes	No	Yes (Before a new batch of production)
Case 2	Yes	Yes (Daily)	Yes (During PM and before a new batch of production)

2.5 Simulation

The maintenance model was constructed in DES software WITNESS 14. The building of model was done by dragging and placing the elements related on including Part, Machine, Conveyor and Labour on the working screen as shown in Figure 3. The process parameters include the lead time, failure distribution data and repair time were used as inputs in the simulation model. The input rules and output rules of the element were programmed to run as desired. There are some assumptions made to build the model. The assumptions are as follows:

- The maintenance task is conduction according to First Come First Serve (FCFS) law under the constraint of labours and spare parts.
- CM is given higher priority than PM.
- The PM frequency is the same for all the machines
- The machines are assumed to be as good as new after the maintenance task. The age of the machines is not the concern of the study

Then, the model went through validation and verification so that it can really represent the real condition of the SMT line. The performance measure used in availability and system availability. For this aspect, equation (1) in section 1.2 was applied and modified as in Equation (3). Note that the total planned production time is 103680 minutes. The details for total planned production time will be explained in next section. The mathematical Equation (3) and Equation (4) was inserted into the model for calculation and comparison. The variable was used to store the result for calculation as in Figure 4.

$$\text{Availability} = \frac{103680 - \text{Schedule Down Time} - \text{Unschedule Down Time} - \text{Duration for setup and Changeover}}{103680} \quad (3)$$

$$\text{System Availability} = \text{Availability}_{M1} * \text{Availability}_{M2} * \dots * \text{Availability}_{M5} \quad (4)$$

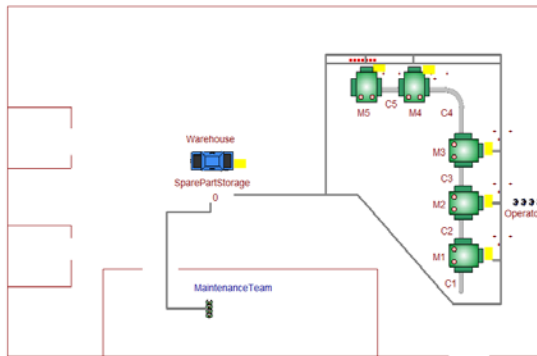


Figure 3. Simulation model in WITNESS 14

Performance Indicator					SystemAvailability
	M1	M2	M3	M4	M5
Availability	0.00	0.00	0.00	0.00	0.00
Unscheduled Breakdown	0.00	0.00	0.00	0.00	0.00
Scheduled Breakdown	0.00	0.00	0.00	0.00	0.00

Figure 4. Variable to store the value for availability

2.6 Performance Measurement

After the verification and validation of model, the model is ready for simulation testing. The simulation testing was run for 132480 minutes which is equivalent to three months including the warm up period. The actual production run for six days per week and there are three shifts every day. Hence, the total run time is 103680 minutes.

3. Result and Discussion

The availability of machine M1, M2, M3, M4 and M5 were collected after the simulation testing of Case 1 and Case 2. The graph was plotted and is shown in Figure 5. Also, the system availability in two cases were plotted in the graph in Figure 6.

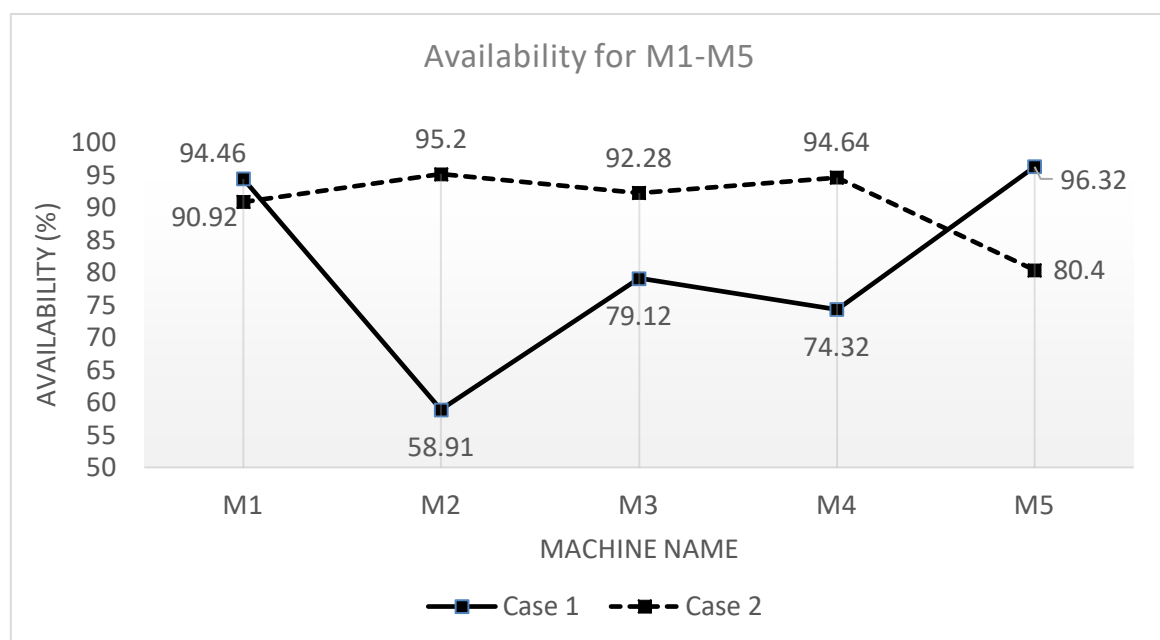


Figure 5. Availability for machines for case 1 and 2.

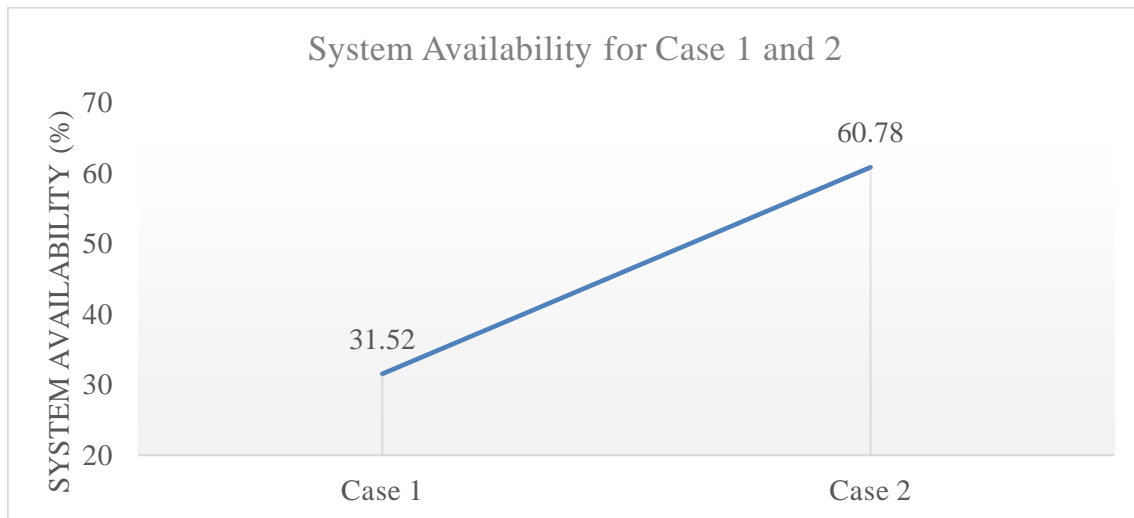


Figure 6. System availability for case 1 and 2

Looking into Figure 5, for Case 1 when there is only CM is conducted only during the machine failure, M5 has the highest availability which is 96.32%. This is followed by machine M1 in which its availability is 94.46%. The availability of the rest of the machines comparatively lower than M5 and M1. The third highest availability is M3 which is 79.12% then M4 which has 74.32% availability is the forth highest. Lastly, M2 which has 58.91% availability is the lowest. This indicates that machine M2 has the most breakdown problem as it is only operating for 58.91% of total planned production time. Only M1 and M2 have the availability more than 90% which is what required to achieve world class OEE. The result shows that the CM strategy is good enough to increase the availability of M1 and M2. However, the result for M3, M4 and M5 are not satisfy if the company target for world class OEE. M2 has the highest priority because it has lowest availability.

For Case 2 when PM task is done daily according to the schedule, most of the machine improve in their availability. The availability of all machines is higher than 80%. M2 which has the lowest availability in case 1 creates the highest score in case 2. Its availability is 95.2%. This is followed by M4 which has 94.64% availability, M3 which has 92.28% in availability and M1 which has 90.92% in availability. The lowest availability is M5 which is 80.4%. Four out of five machines have more than 90% availability which is the requirement to achieve 85% world class OEE. Only M5 does not full-fill the requirement.

Based on the result obtained using simulation in Figure 5, it can be observed that most of the machine increases in its availability. Three out of five machines increase in its availability after introduction of PM into the system. The highest improvement is M2 which increases from 58.91% to 95.20%. The increment is 36.29%. This prove that the proposed PM really reduce the unplanned breakdown problem significantly for M2. Although there is planned stop time for PM and setup, the reduction of unplanned breakdown is more significant. Hence, the total downtime reduces and this leads to increment of availability. The availability of M4 also increases from 74.32% to 94.64%, which is 20.32% improvement. Lastly, machine M3 has the least improvement in availability which is 13.16%. The availability of M3 increases from 79.12% to 92.28%. In short, the introduction of PM is beneficial for availability of M2, M3 and M5. Further improvement can be done on revise the frequency of PM to maximize the availability.

Unfortunately, from Figure 5 also, two machines decrease in their availability from the simulation. The availability of M5 decrease from 96.32% to 80.40% which is 15.92% reduction. M1 reduces slightly in availability which is from 94.46% to 90.92%, equivalent to 3.54% reduction. The reduction in availability is due to the increased in downtime after PM is introduced. This is because the increment of scheduled downtime is more than the reduction of unscheduled downtime. The scheduled downtime includes duration for PM, setup and changeover. Hence, it is advisable to revise

the planning of maintenance strategy whether to remove the PM task for M1 and M5, re-plan the task for PM or revise the frequency of PM. There is possibility that PM is not the correct solution for the breakdown problem. The root cause analysis strategy should be done and countermeasures are planned in order to improve the availability.

However, from Figure 6, there is no doubt that the overall system availability is improved when PM is introduced. The improvement is 29.26% from 31.52% in Case 1 to 60.78% in Case 2. Although M1 and M5 decrease in availability in Case 2, the effect is balanced. Therefore, the increment proof that the introduction of PM is still beneficial to the system availability for the SMT line. At the same time, root cause analysis of the breakdown problem of each machine should be done simultaneously to identify the real problem of the machines to improve the breakdown problem.

For further improvement of the system availability, further work can be done to identify the most optimized maintenance planning for different machines. For example, CM is enough to solve the breakdown problem for M1 and M5. As the introduction of PM with same frequency does not help to increase the availability of these two machines, the maintenance planning should be revised. For M2, M3 and M4, PM is definitely the key for the organization to achieve world class availability. Hence, PM can be implemented for these three machines in the system.

4. Conclusion

The simulation model and testing conducted in this research shows how the suggested model helps in visualizing the effects of maintenance strategy planned to the production and how it affects the availability of each station and the whole production line. A simulation model had been created in WITNESS 14 to model a SMT line which has multiunit but different in their function and properties.

The model is user friendly and creative, thus enable the replication to majority industries. It enables experimentation on production line easier by developing “what if” scenarios to see the effect of the proposal to the production line. For this study, the aim is to test out the effect of maintenance strategies to the system availability. Besides maintenance, this simulation model can be utilized in the planning of production, scheduling, supply chain management, inventory planning, workforce planning and so on. The model is definitely an intelligent decision-making tool to help the management to decide the most optimal solution for the industry.

For the two cases tested, not all machines show increment in availability after implementation of PM. Only M2, M3 and M4 increase in availability but M1 and M5 show reduction in availability. This is due to the increment in schedule downtime is more than the reduction in unscheduled downtime. To further improve this problem, the PM task and its frequency should be revised to get an optimum planning. Even though there are two stations that reduce in their availability, the increment of system availability is satisfied. The system availability creates 29.26% increment in availability from Case 1 to Case 2. The system availability increases from 31.52% for Case 1 to 60.77% system availability in Case 2. Therefore, it can conclude that the PM task is beneficial to increase the system availability of the SMT line.

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