SIMULATION OF PREVENTIVE AND CORRECTIVE MAINTENANCE SCHEDULE IN REDUCING MACHINE STOPPAGE AND DOWNTIME

By:

TAN SZE MING

(Matrix no.: 120820)

Supervisor:

Dr. Hasnida Binti Ab Samat

June 2017

This dissertation is submitted to
Universiti Sains Malaysia
As partial fulfilment of requirement to graduate with honors degree in

BACHELOR OF ENGINEERING
(MANUFACTURING ENGINEERING WITH MANAGEMENT)

School of Mechanical Engineering
Engineering Campus
Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed. .... (TAN SZE MING)
Date ....

Statement 1

This journal paper is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed. .... (TAN SZE MING)
Date ....

Statement 2

I hereby give consent for my journal paper, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available outside organizations.

Signed. .... (TAN SZE MING)
Date ....

ACKNOWLEDGEMENT

Upon completion of this study and research, I would like to express my greatest gratitude to my supervisor, Dr.Hasnida Binti Ab Samat who gave me all the guidance, explanation, motivation and sharing her knowledge of expertise with patience throughout the past one year. Her precious suggestion helped me to develop and complete the simulation modelling.

Special thanks to all my friends who helped me throughout the research especially those who provide me with a rough data for the related production system as reference. I would like to grasp the opportunity to thank School of Mechanical Engineering as the simulation model was taken from the real Surface Mounted Technology system which was just installed in Business Unit Innovation Centre.

Last but not least, I am also indebted to University Sains Malaysia (USM) for providing a complete syllabus to this course so that we have enough engineering knowledge to complete the required study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

DES	-	Discrete Event Simulation
PM	-	Preventive Maintenance
CM	-	Corrective Maintenance
CBM	-	Condition Based Maintenance
TPM	-	Total Productive Maintenance
FCFS	-	First Come First Serve
SMT	-	Surface Mount Technology
WIP	-	Work in Progress
M	-	Machine
C	-	Conveyor
P	-	Part
PCB	-	Printed Circuit Board
OEE	-	Overall Equipment Efficiency
MTBF	-	Mean Time Between Failure
MTTR	-	Mean Time to Repair
MTTF	-	Mean Time to Fail
EOQ	-	Economic Order Quantity
ROP	-	Reorder Point
MS	-	Maintenance Strategy
ME	-	Maintenance Engineer

ABSTRAK

Kaedah-kaedah dan strategik penyelenggaraan telah diselidik sejak beberapa dekad yang lalu mulai dengan kaedah matematik yang rumit dan telah ditambah baik kaedah yang lebih senang dan efektif iaitu penyelenggaran berdasarkan jadual. Walau bagaimanapun, simulasi dalam bidang strategik penyelenggaran adalah bidang yang jarang diselidik, oleh itu, model simulasi strategik penyelenggaran terkini telah menjadi satu penanda aras untuk aplikasi strategik penyelenggaran dalam sistem pembuatan. Pada masa ini, kelemahan utama antara penyelidik yang telah diterbitkan adalah kegagalan menggambarkan sistem pembuatan yang sebenar sebab simulasi dibuat untuk aplikasi strategik penyelenggaraan dalam satu mesin, hanya satu jenis strategik yang digunakan atau banyak mesin dengan jenis yang sama difungsi secara selari sahaja. Oleh sebab itu, kajian ini dilaksanakan untuk mencipta satu model penyelenggaran bersepadu dengan sistem pembuatan yang dinamik. Sistem ini terdiri daripada lima jenis mesin yang berbeza dengan kitaran masa berlainan dan timbangan masa kerja kumpulan penyelenggaran dan penyediaan stok latihan. Kajian ini disimulasi menggunakan perisian WITNESS 14 Edisi Pembuatan dan dijalankan untuk simulasi Sistem Permukaan Teknologi Gunung (SMT) termasuk masa pertukaran, kerosakan kecil dan utama, taktik senggeraan kerosakan (CM) dan taktik senggeraan pencegahan (PM). Objektif kajian ini adalah untuk menyelidik kesan kaedah penyelenggaran terhadap masa mesin tidak berfungsi. Keputusan simulasi SMT ini akan diuji dengan ketersedianan setiap mesin secara individu dan ketersediaan keseluruhan sistem. Dengan anggaran setiap mesin mempunyai tahap degradasi yang berbeza tetapi mengikuti taburan Weibull, kaedah penyelenggaran dirancang berdasarkan masa iaitu penyelenggaran akan dijalankan pada mesin yang rosak pertama dan ikut urutan seterusnya (FCFS) tetapi memberi keutamaan kepada senggaraan kerosakan. Hasil kajian ini mendapati kesediaan sistem telah meningkat sebanyak 30% manakala ketersediaan mesin individu telah ditingkatkan sampai 90% dengan melaksanakan senggeraan pencegahan harian.

ABSTRACT

Maintenance approaches or strategies has been studied since many decades ago and nowadays it varies from the complex mathematical approach to improved and simplified yet effective time-based strategies. However, simulation of maintenance strategies is an intermittent field of research thus current maintenance strategies simulation model created a benchmark to imitate the methodology of implement maintenance strategies in real production. Currently, the major drawback of most of the published researchers is in the application of only single machine, single maintenance strategies or multiple machines of the same type working in parallel which does not reflect the real and complex manufacturing system. Thus, this project is conducted to create a model of maintenance strategies integrated with a dynamic manufacturing system. The system consists of five different machines and each cycle time of machines differ considering the shift time of maintenance team and spare part availability. The work has been conducted using WITNESS 14 Manufacturing Performance Edition software. The model was developed to imitate a Surface Mounted Technology (SMT) production system by considering the changeover time, minor and major breakdown, corrective maintenance (CM) as well as preventive maintenance (PM) scheduling. The aim is to study the effect of maintenance strategies towards the machine downtime. The SMT line was simulated and evaluated based on the availability of individual machines via discrete event simulation system. Presuming that each machine has different degradation level, which follows a Weibull distribution, the maintenance scheduling strategies were planned based on First Come First Serve (FCFS) basis if the same type of maintenance strategies is due on different machines but prior to CM. The findings of this project demonstrated that a daily PM schedule can improve the system availability by 30% while increasing the availability of machine up to 90%.

CHAPTER 1

INTRODUCTION

Maintenance is an activity that is vital to retain asset normally is a machine in their normal operating mode and it aimed to combat the inevitable degradation of the assets over time [1]. The major drawback of machine failure always leads to significant loss of productivity of manufacturing system [2]. Thus, maintenance strategies and techniques are becoming more important to increase the availability of manufacturing system which in turn reduce the machine stoppage. The most common and basic maintenance strategies which should apply on the machine are Corrective Maintenance (CM) and Preventive Maintenance (PM).

CM is a maintenance task carried out to restore the machine back to operating condition when the machine degrades until breakdown occurs unexpectedly [3]. Thus, CM is performed when there is a stochastic machine break down. Stochastic means unplanned, randomly and without any signal of which this is the phenomenon usually happen in a sudden machine breakdown.

In order to reduce the serious impact caused by CM in production, PM is another maintenance policy that introduced to minimise the chance of unscheduled breakdown and performed on a machine in a planned manner [4]. Maintenance task refers to a series of activities vital to repair or replace machine's components which are subjected to failure or wear [5]. The maintenance task for PM can just as simple as tasks stated below:

(i) Cleaning filters
(ii) Lubricating and changing oil
(iii) Repair and replacement of parts and components
(iv) Adjustment such as alignment between critical parts and tightening nuts

In fact, in an ideal case, if PM is done perfectly, there should be no CM is required and it is called perfect maintenance. However, the shortcoming of PM may sometimes result in unnecessary maintenance which is a waste, thus, Condition Based Maintenance (CBM) is introduced as it ensures maintenance is only carried out based on the condition of the machine according to a set parameter such as vibration or any diagnostic software. Nevertheless, due to the limitation of the diagnostic software available and advanced sensor may be costly, CM and PM become the main focus in planning maintenance strategies.

Machine breakdown seems to be a matter of repeated occurrence but a time bomb for production, researchers and expertise are rushing to come out with an ideal machine maintenance management system. Their hard work starts from generating analytic modelling until simulation and optimisation approaches. Unsurprisingly, discrete event simulation dominated the research and case study on maintenance scheduling strategy. Discrete event simulation utilised process-based specialised simulation software which refers to a modelling technique where only changes in system states are represented.

As a result, simulation became a tool for the research to imitate and predicting the effect of implementing the maintenance strategies on machine performance in term of machine availability and machine downtime.

1.1 Problem Statement

Lack of maintenance schedule in production may lead to machine run to failure and halt the production which in turn causes a lot of losses in time, production downtime and planned product quantity. Poor maintenance schedule without considering the availability of resources such as spare part and maintenance team is a waste of time. Thus, simulation is needed to illustrate the condition and reliability of machine to schedule the PM in order to reduce the effect caused by CM.

1.2 Objective

(i) To create a simulation model of corrective maintenance and preventive maintenance in a manufacturing system.

(ii) To study the effect of maintenance strategies towards machine breakdown.

1.3 Scope of Work

Machine stoppage and downtime is a normal yet intolerant phenomenon that happened in production, laboratory and workshop. It may due to human error, misalignment of tools, tool wear, overheat of a machine and all these causes are the result of unplanned maintenance. With the focus on poor maintenance which causes a frequent machine downtime, a reliable schedule of PM is necessary to cope with this problem. Witness simulation software is used to compare the performance of machines in a manufacturing system with and without the maintenance strategies as it is more practical in manufacturing planning and scheduling.

CHAPTER 2

LITERATURE REVIEW

Manufacturing companies are becoming an increasing focus in their performance of production line and setting the goal of achieving just-in-time performance while moving towards to Industry 4.0 where all the production is highly automated. Since all the production is often embodied with machines regardless the size and type of manufacturing process, thus, maintenance definitely is a no trivial part for the production to remain productive and competitive. Let's imagine the side effect and consequences of even one machine breaks down in a 24/7 production which halts the whole production line.

The impact of machine downtime is emphasised when analysis showed that one minute of production stoppage can result of 140 pieces of products wasted in a manufacturing company [6]. By identifying the root cause of machine downtime, equipment breakdown ranked the highest frequency followed by minor stoppages, changeover, labour issues, insufficient material supply and other miscellaneous reason [6, 7]. Therefore, many manufacturing companies are trying to reduce and eliminate the unplanned breakdown of equipment through various maintenance policy.

With the importance of maintenance highlighted, maintenance originated in 1951 with an innovative Japanese concept of Total Productive Maintenance (TPM) when PM idea from USA is introduced in Japan [8]. PM is one of the most commonly accepted maintenance policy as PM is scheduled based on the failure characteristics of a machine which is normally a fixed time maintenance service to detect and prevent potential failures yet extend the life of equipment [9, 10]. There are two tactics to carry out PM which is either periodic maintenance (time-based maintenance) or predictive maintenance (CBM). Since CBM is carried out based on the condition of the machine which is measured by a set of parameters such as vibration, noise, temperature, pressure using a diagnostic software. When a certain threshold is reached, it will trigger a CBM to be carried out. Nevertheless, CBM requires a technically feasible monitoring system or a diagnosis software with an advanced sensor to get the real time information. Thus, PM is preferred since it is easier to plan and more economical without any costly investment yet competitively effective [11].

Due to the limitation of PM that there is no warranty for the machine to retain 100% productive, here comes to the CM which defined as the remedial action carried out due to catastrophic failure, or deficiencies discovered during PM, to repair an equipment to its operational mode [12].

The failure characteristics of a machine or the degradation level or the reliability of a machine and even the lifespan of a unit are always assumed to follow a Weibull distribution. Weibull distribution had been studied and commonly used to model the reliability of machines which reflect the real characteristics and failure behaviour of the machine [7, 11, 13].

Currently, there is no standard terminology to show and teach the management on how to carry out the maintenance or the way to do maintenance schedule in right time without or with the least effect to disturb the production. In the early stage of the research on modelling maintenance strategy, analytical or mathematical modelling was commonly used as the methodology [14, 15]. In years later, maintenance optimisation model is developed by leaps and bound [16, 17]. Meanwhile, the manufacturing system, as well as the maintenance system is developing and becoming more complex significantly by which machines are interdependent and batch production is preferred. As a result, either conventional analytical modelling or maintenance optimisation model becomes more complicated and cannot reflect the complexity of the real production.

With the advanced of technology nowadays, simulation is another focused area in manufacturing companies. Simulation is an imitation or dynamic representation of some part of the real world which is sufficient enough to demonstrate and illustrate it using a model in the software with certain adequate accuracy [18]. An integration of simulation with the maintenance schedule is an interesting yet applicable part of the study by which the condition of a machine such as its reliability can be illustrated or simulated via simulation software. From the simulation result, maintenance team is able to know the predicted condition of the machine and thus arrange and schedule the time to do maintenance.

Thus, the use of simulation to model maintenance system is gradually replacing previous analytical and mathematical modelling [17]. As many maintenance strategies are not analytically traceable, simulation delivers an advantage over analytical approaches [19]. Simulation is well-established for manufacturing system purpose which is able to imitate the real manufacturing environment. Simulation has been traditionally used as a tool to understand and experiment with a system.

A real case study of developing a maintenance model building using Witness Simulation had been done in a cement factory which became a reference for the later model building. Spare part inventory was taken into the consideration for maintenance model but one of the drawbacks of this model was when the stock level was dropped to a certain level, it will automatically replenish without time taken. The model was also limited to one separator machine but divided into many parts to show the details of maintenance task [20]. On the other hand, Alrabghi and Tiwari were the first to present their work with the combination uses of simulation and optimisation in maintenance operation [21].

However, out of plenty of research on maintenance modelling, there are some limitation and oversimplified assumptions which lead to inaccurate of modelling.

(a) Modelling is done for a specific system comprising a single unit only or several identical components and the machine is identical in term of function [22]. This is not applicable to the complex production system to date.
(b) After CM or PM is carried out, the machine is assumed to be as good as a new one condition without considering the machine age as well. In real, the condition of a machine should be degraded and the maintenance schedule should be updated as the mean time between failure may become shorter.
(c) Many research assumes that once the machine breaks down or when it is the time to do PM, it can be done immediately without considering the resources available such as spare part and maintenance vendor. In fact, the maintenance vendor may not be able to come at the right time to do maintenance.

(d) Simulation is done by considering only one maintenance strategy which is either PM, CM or CBM. A combination of strategies is rare.

(e) Most of the simulation modelling research assumes that there is no human error or maintenance mistake when maintenance is done.

In the latest and recent research done by Alrabghi and Tiwari had set a benchmark and foundation for future work on maintenance strategies modelling. Their modelling using Witness Simulation and optimised using Witness Optimizer had considering several factors such as multi-unit manufacturing system, non-identical units, several maintenance strategies (PM and CM), maintenance integrated with inter-related systems such as production and spare part management and yet visual animation was displayed [22]. They had greatly improved the weakness of previous literature.

Nevertheless, there is still some gaps made in the research as there is no detail description and actual imitation model of simulation shown, the objective of the research is to minimise overall maintenance cost instead of availability of the manufacturing system and the unit used in the simulation is not mentioned. Cost, the number of output, number of work in progress (WIP) are the most common performance measure when maintenance strategies are introduced into the system. Availability has been used in few previous research and it is normally related to one machine availability only instead of the whole manufacturing system availability.

Thus, the present study creates a maintenance model simulation to illustrate the daily PM, CM by taking into consideration of the present of the maintenance team, minor stoppage, setup time, availability of spare part inventory in order to reduce machine downtime yet increase the system availability.

CHAPTER 3

METHODOLOGY

In conjunction with the objective of the research, a framework has to be done to create the maintenance model by using simulation. Thus, a flow chart was generated as shown in Figure 3.1. The details description of each step was explained later.

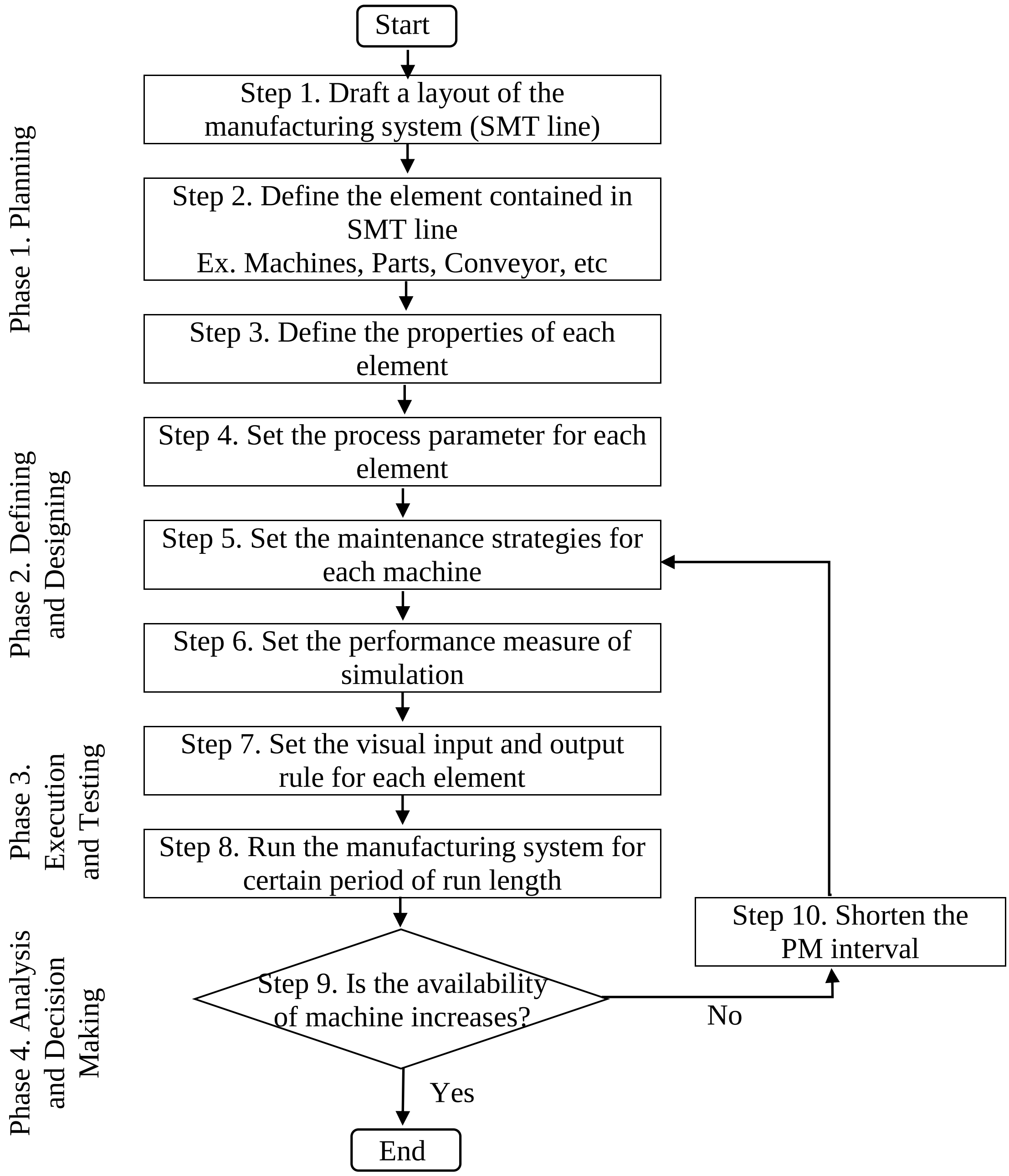


Figure 3.1. Simulation framework

Throughout this research, Witness Simulation Educational Version Release 14 (Build 2124) software by Lanner Group was used to generate the framework of maintenance system due to its advantage of rapid modelling, visual interactive simulation, dynamic graphical user interface, manufacturing system oriented software as well as its additional features of visual experimentations.

3.1 Phase 1: Planning

3.1.1 Step 1: Draft a layout of Manufacturing System

The simulation of maintenance system was done on a Surface Mounted Technology (SMT) production line which was located in Business Unit Innovation Centre, School of Mechanical Engineering, University Science Malaysia.

Surface Mounted Technology (SMT) is an assembly process that mounted surface mount device (SMD) or surface mount component on the surface of a Printed Circuit Board (PCB) instead of inserting them through holes of the board [23].

The SMT line consists of five non-identical machines which are connected to each other by conveyors and it is a continuous process as shown in Figure 3.2 and Figure 3.3 by which either one machine breakdown will halt the whole production line and causing the rest of the machines in idle condition.

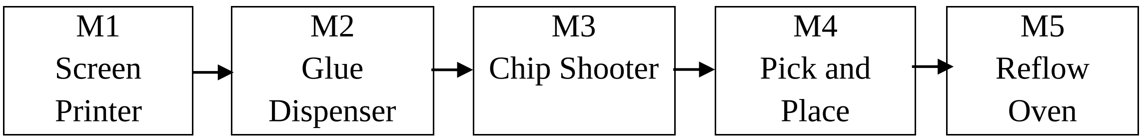


Figure 3.2. Process Flow of SMT line

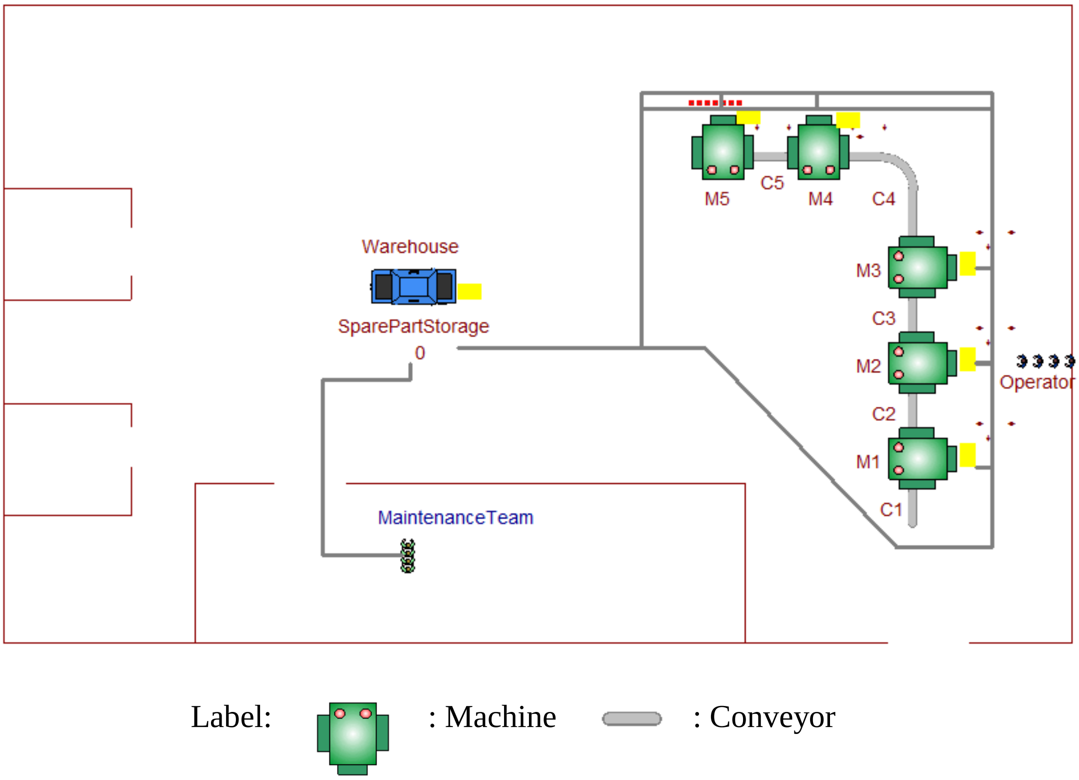


Figure 3.3. Machine Layout

Process Description

Machine 1: DEK 265 GSX Solder Paste Screen Printer

As shown in Figure 3.2 and Figure 3.3, the motherboard of PCB has first entered the first machine (M1) which was Solder Paste Screen Printer. This process was needed to screen (with artwork to match the PCB) solder paste into PCB before placement of surface mount components to ensure the solder paste was deposited accurately onto the solder pads [24]. Alignment of solder paste, the correct amount of solder paste and constantly replace of squeegee became the issues of a screen printer [25].

Machine 2: Fuji GL V-5000 Glue Dispenser

Next, the PCB moved through a 100 cm inspection conveyor before entering the second machine (M2) which was Fuji GL V-5000 Glue Dispenser. This machine allowed deposition of glue within the placement machine without losing any feeder capacity or placement performance [26]. This dispenser provided consistent adhesive dots of glue to the substrate prior to component placement.

Machine 3: Fuji CP-65 Chip Shooter

In chip shooter machine, small components were placed at the different position of PCB by turret head which contained different suction nozzle sizes. During this process, the PCB board was secured on a moving table and the total process time was dependent on the feeder arrangement and placement sequence of the chip shooter machine [27].

Machine 4: Fuji QP-341 E-MM Pick and Place Machine

For pick and place machine, its functionality was similar to chip shooter by which its principle was picking, holding, transport, placement and release. It was responsible for the nozzle to place the SMT components from feeder to PCB [28]. Usually, there were more than one pick and place machine or similar function machine like chip shooter and pick and place due to the different machine may in charge of different size of the SMT components.

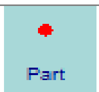
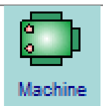
Machine 5: BTU-Paragon 150 Reflow Oven

After all the components were mounted onto PCB, the PCB was transported by a linking conveyor into a reflow oven which was the last process of SMT. Reflow oven caused the solder paste became liquidus and thus make sure the components were settled into the paste and make electrical contact with SMT pads [29]. Once the PCB left the reflow oven, the PCB should have both mechanical and electrical bond between components and PCB.

3.1.2 Step 2: Define element contained in SMT line

Machines, Conveyors and Parts are the three main elements that make up the whole SMT production line. The type of elements used in the simulation was stated in Table 3.1.

Table 3.1. List of designer elements used in Witness Simulation

Designer Element	Description
	Part represented product, in this research, the product produced was Printed Circuit Board (PCB). Besides the product formed, spare part for maintenance also represented in term of the part element.
	There were total five machines in SMT line which included DEK 265 GSX, Fuji GL V-5000, Fuji CP-65, Fuji QP-341E-MM and BTU-Paragon 150. Spare part inventory was also represented by machine element with cycle time symbolised the lead time for the supplier to deliver the spare part.
	Conveyor was used in connecting all the machines together to form the SMT line. This was also the place where parts were moving continuously.
	There were two types of labour in this simulation which were normal operator and maintenance team. Operator was in charge of fixing machine problems such as machine stop due to stuck tape, feeder problem and other minor issues that can fix directly on the spot. Maintenance team was usually maintenance engineer who was responsible for performing regular PM and a catastrophic failure of the machine (CM).

From the maintenance point of view, the operator was present to fix some minor problems such as pick up problem of the machine while the actual CM and PM job will be done by Maintenance Team. In order to imitate the real manufacturing system, a warehouse for storing spare part was also included in the simulation. A spare part was the component needed when carrying out maintenance task which was normally kept as inventory in a warehouse.

3.1.3 Step 3: Define the properties of each element

The properties of elements are dependent on the type of manufacturing system. For instance, an assembly manufacturing system may need an assembly type of machine with two input of parts but only one finished good is produced. In this SMT production line, most of the machines are a single type machine with one input of part and one output of part except for the special characteristics of the reflow oven. When PCB entered the reflow oven, it passes through 10 heating zones (top or bottom) and followed by two cooling zones (top or bottom), thus, when the first PCB is reaching the second heating zone, the next PCB can enter the reflow oven [30]. Therefore, in simulation, this type of machine can be imitate using multiple station machine.

The properties and type of each element were listed in Table 3.2.

Table 3.2. Properties and type of each element

Element	Properties	Description
Printed Circuit Board	Passive type Length: 0.25m Width: 0.15 m	The part was pulled from the first machine according to customer demand. SEQUENCE/NEXT function was used for the Screen Printer to pull the part according to a randomly generated customer demand and after one batch of an order was shipped, it will pull the NEXT batch of PCB. An active type of part properties can also be used if the exact data of part arrival time was available.

Screen Printer Glue Dispenser Chip Shooter Pick and Place	Single type machine	Once the PCB entered the machine, it had to wait for PCB to come out only the next unit can move on.
Reflow Oven	Multiple station machine	When the first unit of PCB was reaching the second heating zone, the next unit can enter the machine. Multiple units inside the machine were possible.
Warehouse (Spare Part Inventory)	Batch type machine	The warehouse was represented by machine element in this simulation. The batch number is the quantity of part ordered which was 600 spare parts and cycle time symbolised the time spent to get the order from the supplier.
Nutek Linking Conveyor [31] Nutek Inspection Conveyor	Type: Continuous Queuing Length: 1 m Speed: 14 m/min Orientation: Lengthwise Maximum Capacity: 4	The conveyor used was a continuous queuing type which meant the unit was next to each other with a spacing set 0.02 m in between when the conveyor was blocked. When the PCB was passing through the conveyor, it will be in a lengthwise orientation. The maximum capacity of the conveyor was determined by the PCB dimension.

3.2 Phase 2: Defining and Designing

3.2.1 Step 4: Set the process parameter for each element

Before key in and set the input and output parameter of each element, data is the core factor to ensure the simulation is running in the correct manner. Some data was obtained from the machine specification while process parameter and the characteristics of the parts were studied and researched through previously recorded data.

Basically, there are three categories of data as shown in Table 3.3. Each category of data has its special way and techniques of dealing with it [32].

Table 3.3. Categories of data

Category	Data Type
Category A	Available
Category B	Not available but collectable
Category C	Not available and not collectable

Since the SMT line in School of Mechanical Engineering was not yet running and still under research, there was no continuous data can be collected for the cycle time of each machine. Due to the limitation of the data available, there were two standard ways to deal with Category C data which were obtaining a secondary data and another technique was using subject matter experts. However, all the assumption had to be clearly stated.

Secondary Data

Standardisation of data do exist for similar manufacturing system and process, thus, a secondary data may be obtained from an analogous manufacturing system. Secondary data indicated the data collected was done by others in a similar process or another machine with the same properties and functionality and was readily available. In this study, a secondary data was available for certain process and machine as listed in Table 3.4.

Table 3.4. Secondary data

Machine	Data type	Number of data
Screen Printer	Setup time	8
Glue Dispenser	Setup time	8
Chip Shooter	Setup time	8
Pick and Place	Cycle time	25
	Setup time	8
	Minor Breakdown	10
Reflow Oven	Setup time	8

The purpose of the previous researcher to collect the data as stated in Table 3.4 was to identify the bottleneck process of pick and place machine and thus the secondary data obtained was mainly focused on this specific machine yet the setup time was recorded for all the five machines during changeover. However, there was a risk if inserting all the data blindly into the system as the historical data may only represent the historical trend and it may change in the future.

Statistic distributions study showed that each process was normally behaved according to an appropriate distribution. It was reasonable to estimate the behaviour of a process in future was following a certain distribution. For example, the most common case was the inter-arrival time of the customer was follow a negative exponential distribution as the arrival of customer was random. Selecting distribution with known process properties was also a way to cope with the non-collectable data [32].

Subject Matter Expert

Another effective way of obtaining and estimate the data was through subject matter expert. Since surface mounted technology was widely used in semiconductor industry, an electronic forum for expert sharing can be easily found on the internet [33].

Machine Manual

The last way of estimating the data was from the machine specification and machine manual provided by each machine. In this study, the cycle time for Screen

Printer, Glue Dispenser, Chip Shooter and Reflow Oven machine were obtained from the standard cycle time stated in machine manual respectively.

Process Parameter

Cycle time distribution

As mentioned previously, the cycle time data was only available for the Pick and Place machine while other machines cycle time was obtained from the machine manual. With 25 set of data available for pick and place's cycle time, a normal distribution graph with mean and standard deviation as parameters had been selected to represent the time taken for this machine due to several reasons:

(i) Cycle time is an application example for normal distribution which has a symmetrical bell-shaped curve and evenly distributed around mean. However, it must be careful that the relatively large standard deviation with mean may easily result in a negative value of cycle time [34].

(ii) Cycle time at each station is independent and normally distributed with a mean and coefficient of variation has been studied in previous research and the result obtained was quite accurate [35].

The cycle time for pick and place machine was shown in Figure 3.4.

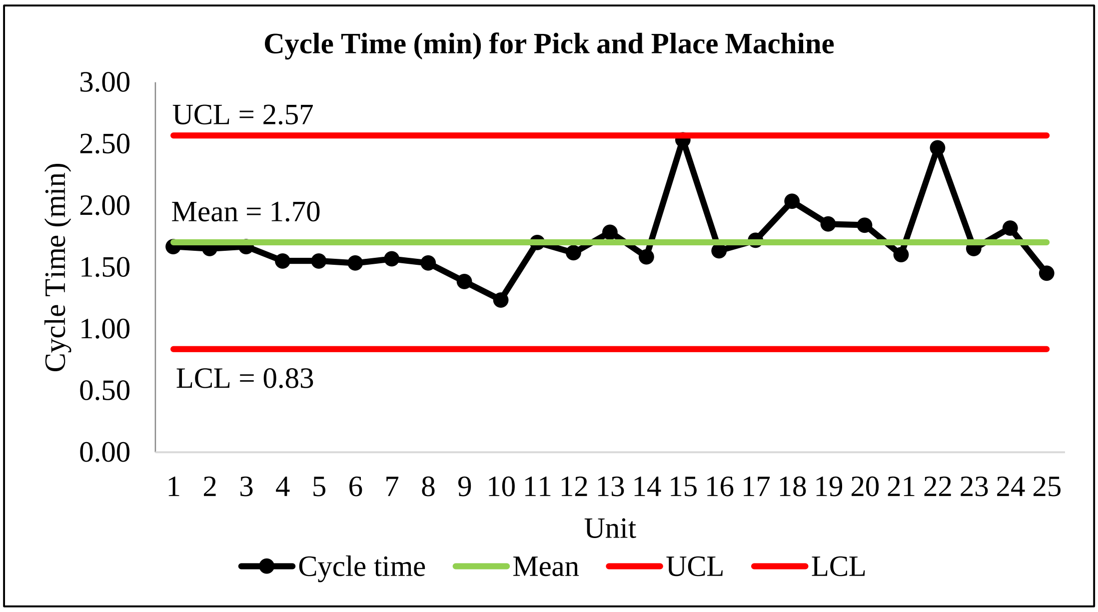


Figure 3.4. Cycle time (min) for Pick and Place Machine

Setup time distribution

Machine setup and the changeover was done when the SMT production line was changing from one batch of PCB to another batch of PCB. Even the setup time was sharing the same properties as cycle time, normal distribution was not used in this case as one of the criteria of using normal distribution was having at least 20 set of data on hand. On the other hand, the changeover time was also dependent on the batch model changed as it may be a minor or major changeover. Thus, by knowing the minimum amount of setup time for minor changeover and the maximum amount of setup time for major changeover, a triangular distribution was used except reflow oven which had a standard setup time of 7 minutes regardless minor or major changeover.

There were three parameters for triangular distribution which were min, mode and max. With the min and max number were known, the mode number can be estimated using the following formula.

$$\text{Mode} = 3\ \text{mean} - \text{min} - \text{max}\ [36]$$

The cycle time and setup time for each machine was summarised in Table 3.5.

Table 3.5. Process parameters for each machine

	Cycle time (min)	**Setup time (min)**
Screen Printer	0.21 [37]	Triangle (1.38,5.79,6.87)
Glue Dispenser	0.43 [38]	Triangle (0.42,2.10,3.82)
Chip Shooter	0.40 [39]	Triangle (0.75, 2.36, 3.55)
Pick and Place	Normal (1.7,0.29)	Triangle (0.8, 1.75, 2.93)
Reflow Oven	7	7
Warehouse	4320	-

The cycle time for warehouse represented the time taken from placing the order of spare part from supplier until the supplier delivered the spare part with the correct amount. The lead time taken was set to be three working days (4320 min). The spare part used for each CM was six while PM used up two spare parts each time. The reorder point for the spare part was set according to Economic Order Quantity (EOQ) with an optimum order quantity of 600 and the reorder point was set to be 30 units based on the calculation shown below.

$$Q^* = \sqrt{\frac{2DS}{H}} \text{ [40]}$$

Q^* = Optimal order quantity
D = Annual demand in units for inventory item
S = Setup or ordering cost for each order
H = Holding or carrying cost per unit per year

The monthly demand for the spare part was 300 units and thus the annual demand was about 3600 units (300 x 12) while the ordering cost and holding cost were set to be RM 100/ order and RM 2/unit/year based on the research done previously [22].

$$Q^* = \sqrt{\frac{2(300\ x\ 12)100}{2}}$$

= 600 units

Reorder point, ROP = Demand per day x Lead time for a new order in days
= 10 x 3
= 30 units

Therefore, when the spare part inventory level dropped to 30 units, an order was placed to the supplier with a quantity of 600 units. However, if only CM was applied in the simulation, the optimum order quantity was set to be 445 units while reorder point was 18 units based on the formulae above as the demand for spare part was lower.

Customer demand

Customer demand was generated randomly in simulation based on a uniform distribution between a batch of 20 to 55.

Shift time

In this simulation, there were two types of labour used which were operators and maintenance team which was basically formed from a group of maintenance engineers. The working hours was set with the reference of Malaysia Employment Act 1955 by which employee shall not work more than eight hours in one day or in excess of a spread over a period of ten hours in one day or more than five consecutive hours without leisure of not less than thirty minutes [41]. Operators were divided by three shifts as stated in Table 3.6.

Table 3.6. Shift time for operator

Operator Type A			Operator Type B		
Shift	**Time**	**Description**	**Shift**	**Time**	**Description**
1	6:30 am – 10:00 am	Working	1	6:30 am – 10:30 am	Working
	10:00 am – 10:30 am	Break		10:30 am – 11:00 am	Break
	10:30 am – 2:30 pm	Working		11:00 am – 2:30 pm	Working
2	2:30 pm – 6:00 pm	Working	2	2:30 pm – 6:30 pm	Working
	6:00 pm – 6:30 pm	Break		6:30 pm – 7:00 pm	Break
	6:30 pm – 10:30pm	Working		7:00 pm – 10:30pm	Working
3	10:30 pm – 2:00 am	Working	3	10:30 pm – 2:30 am	Working
	2:00 am – 2:30 am	Break		2:30 am – 3:00 am	Break
	2:30 am – 6:30 am	Working		2:30 am – 6:30 am	Working

Nevertheless, in order to increase the productivity of SMT production line, the resource scheduling was normally arranged so that the operators were always there to resolve any of the minor breakdown and changeover. Thus, in the simulation there had two operators type A were having shift time as stated on the left side of Table 3.6 while the another two operators type B were having shift time as stated on the right side of Table 3.6 by which they were having different break time.

Similarly, the maintenance team was divided into two shifts which were day shift and night shift sharing the same working hours as shown in Table 3.7.

Table 3.7. Shift time for maintenance engineer

Shift	Time	Description	Shift	Time	Description
1	8:00 am – 12:00 pm	Working	2	8:00 pm – 12:00 am	Working
	12:00 pm – 12:30 pm	Lunch time		12:00 am – 12:30 am	Break time
	12:30 pm – 3:00 pm	Working		12:30 am – 3:00 am	Working
	3:00 pm – 3:30 pm	Tea time		3:00 am – 3:30 am	Tea time
	3:30 pm – 6:00 pm	Working		3:30 am – 6:00 am	Working
	6:00 pm – 6:30 pm	Dinner		6:00 am – 6:30 am	Breakfast
	6:30 pm – 8:00 pm	Working		6:30 am – 8:00 am	Working

Basically, there were four maintenance engineers were allocated in each shift time as summarised in Table 3.7. In Witness Simulation, the starting time must be at 12 am every day, thus, the labour shift time was adjusted and started at 12 am to match with clock system in the simulation. The details of shift generated was attached in Appendix.

3.2.2 Step 5: Set the maintenance strategies for each machine

PM and CM were set as maintenance strategies (MS) for each machine. In this research, only these two strategies were focused and the maintenance was done according to time-based instead of a number of products produced. As there were many different definitions and opinion related to machine breakdown occurrences, there was no an actual fact or rules that can really track which statement was the truth. However, undeniably, machine breakdown was a stochastic phenomenon that can happen in anywhere and anytime.

In addition, the presence of the operator was also taken into consideration as minor breakdown which was able to be solved on the spot such as tape stuck, the components not in place, feeder error and others. In fact, there was a series of scenario and possibilities when running the simulation as the machine breakdown was a stochastic process and for each breakdown, the availability of spare part and maintenance team cannot be predicted. Thus, a process flow was shown in Figure 3.5 to show how the simulation was running and response for each scenario.

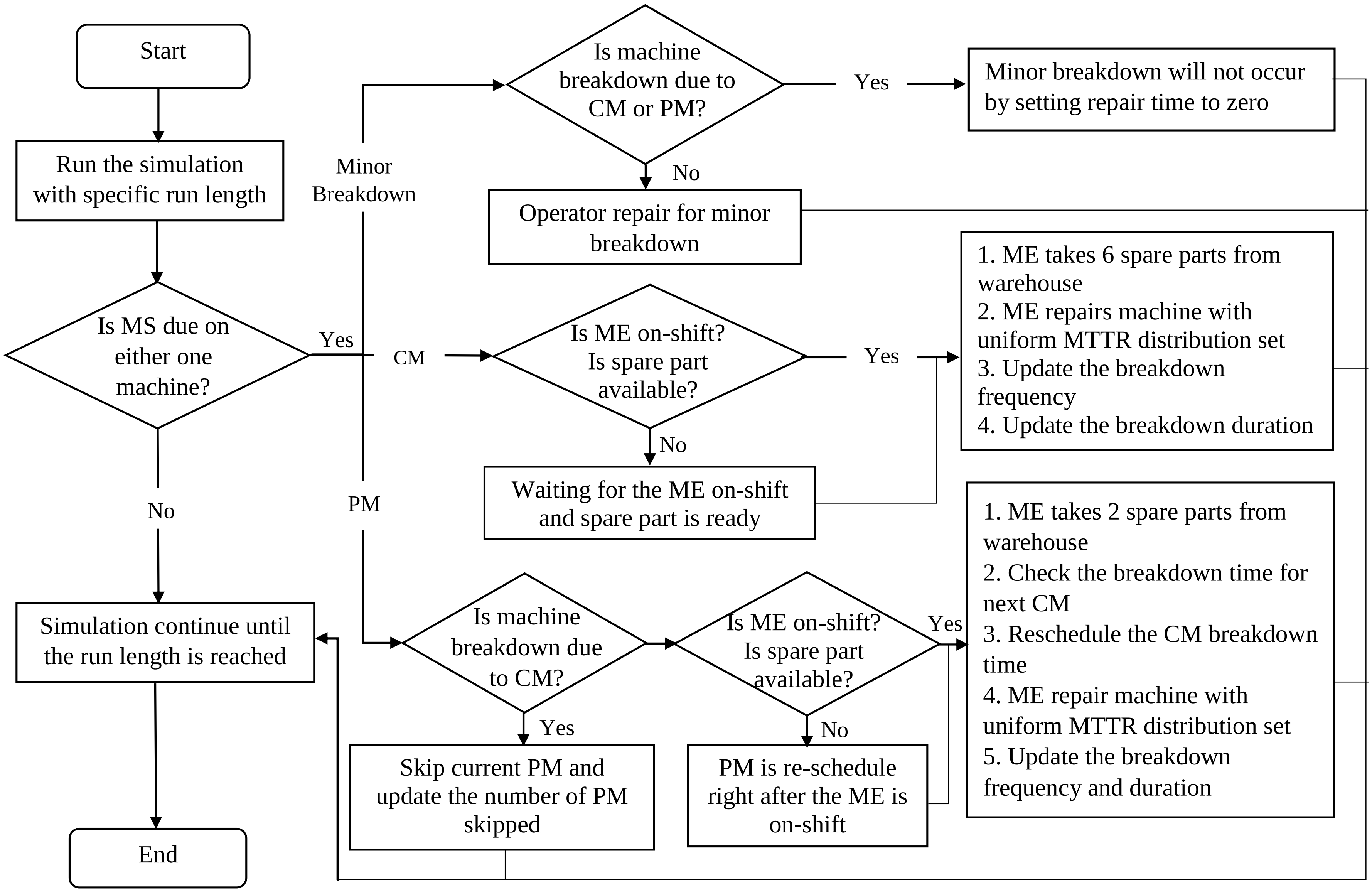


Figure 3.5. Simulation modelling of maintenance strategies

Breakdown interval

There are a lot of terms used when setting the machine breakdown such as Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), Mean Time to Fail (MTTF). Poor understanding and differentiate between these terms may cause a serious error in simulation. By understanding the term used in the simulation was the key to select which term should be used. Figure 3.6 showed the illustration of these three terms.

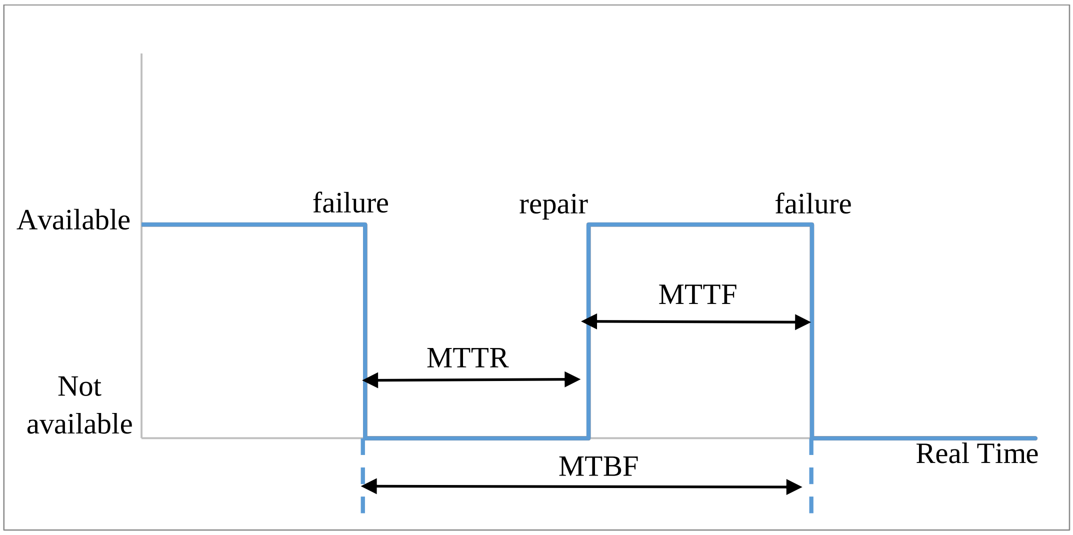


Figure 3.6. MTBF, MTTR, MTTF [42]

In Witness Simulation, MTBF and MTTR were used to set the maintenance strategies which represented the time between machine failure and repair time respectively. For example, if the breakdown interval was set to be 1440 minutes, the first failure will occur at 720th minutes while the second failure will occur at 2160th minutes.

Machine breakdown was reasonably always being estimated to follow a Weibull distribution curve as discussed in the literature review and it was interrelated with the reliability of the machine. Weibull distribution was used instead of negative exponential, another distribution which was also commonly used in time between failure as the machine failure rate was unexpected and changed according to machine life stage which make Weibull distribution with two parameters was more appropriate to reflect the behaviour of machine's reliability [43]. In fact, there was a special characteristic of machine reliability as it showed a bathtub curve as shown in Figure 3.7. Thus, the historical data may not really reflect and predict the future trend of machine breakdown at a different life.

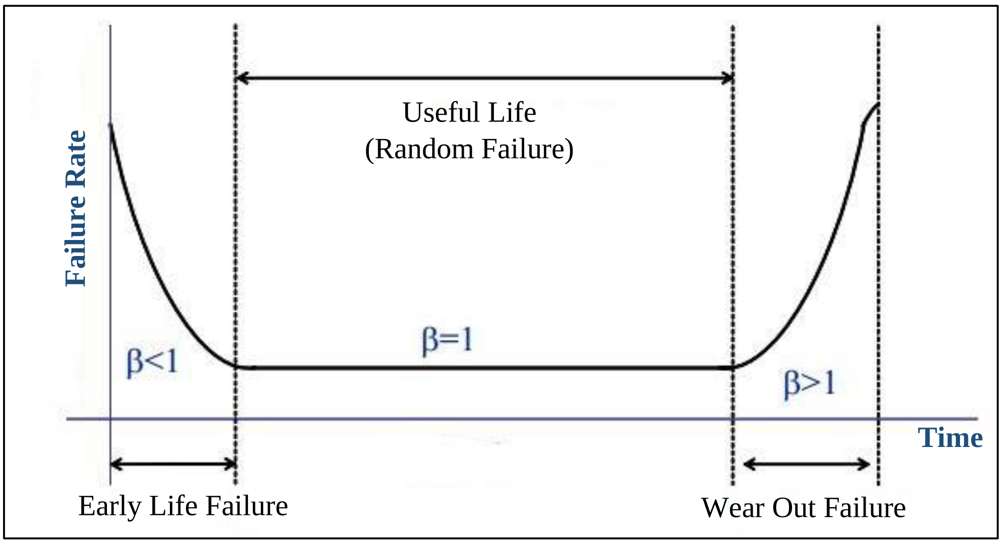


Figure 3.7. Bathtub curve [44]

The bathtub curve shows the failure rate of a machine or even a product throughout its lifespan. In the early life, the failure rate may decrease and reach a stable and steady failure rate during useful life but towards the end of the lifespan, the machine is in the stage of wear out when the failure rate of a machine is rather high and keep increasing.

All these stages of machine life can be estimated using Weibull distribution's parameters, Weibull (β, η). The scale parameter (η) of Weibull distribution was related to the MTBF and the lifetime while the shape parameter (β) contributed to the shape of distribution [45]. Figure 3.7 showed if $\beta < 1$, the probability distribution graph showed the early stage of machine life as the machine may face failure as it was a new setup and it may have some underlying uncertainty. After a period of time, the machine reached its normal operation by which $\beta = 1$, the graph was exactly the same as negative exponential distribution indicated the useful life of the machine. Lastly, when $\beta > 1$, the graph showed the wear out stage of the machine. Thus, CM or major breakdown was set using Weibull distribution same as the minor breakdown. On the other hand, daily PM (1440 minutes) was set in fixed time interval without following any distribution.