Total Productive Maintenance Assessment on Discrete Manufacturing System

by

Mohd Fairozlan Bin Ahmad Tarmizi

Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHD FAIROZLAN BIN AHMAD TARMIZI

ABSTRACT

This project focuses on improvement and improvisation of a manufacturing line by using Total Productive Maintenance concept as tools to help reduce the amount of losses due to machine breakdown and other blockage during production**.** The main objective of this project is to reduce the frequency of breakdown in order to avoid losses to scrap and also to increase internal supply chain performance in a given four month period. The methodology of this project consists of visual observation of the actual production line and at the same time doing the time study to help find out the waiting time for any bottleneck point and variability effect.. Manufacturing simulation software WITNESS also has been used in order to find the number of throughput in a controlled condition and shortest time possible. From that three models were developed to ensure every parameter is considered before taken into the real operation. Input data for the simulation is attained from real data from copper wire factory. Model 1 is generated based on reliability analysis, model 2 is focused on queuing theory and waiting time and model 3 is based on buffer flexibility. The model is generated to target time of four month time using WITNESS software.. The breakdown problem in model 1 has been reduced from **40** breakdowns per month to **25** breakdowns per month which is about **37.5%** reductions. The total throughput from model 2 yield **16800** kg of copper wire compared to normal model which yield **8400** kg in a basis of four month. Model 2 is preferable to be use in real production base on highest throughput yielding and considerable amount of breakdown per month.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The current project is focused on the optimization of the copper wire plant system. The plant works in discrete workstations whereby the production system is based on several levels. The factory is using first in first out operation so that the production can be registered neatly. Productive maintenance plan suggest the use of preventive measure during planning in production. The machine will actually work every time with the variable set up time and breakdown time. By reducing the amount of both times, the production will achieve more value added period which will help decrease the capital cost. In this matter, increasing the profit implying decrease of cost of production as the element of trading are not yet involved.

1.2 PROBLEM STATEMENT

Discrete manufacturing system are consists of several cluster of machine designed to be in specific area due to its production requirement and geographical attributes of the factory. Despite having a good localized production system, this system is vulnerable to loss of communication to each workstation working outside the designated area. This harvests some critical problems especially when the machines stop running due to near end life time. Those problems are;

1. The output of production deteriorates by 25% from factory standard.
2. Increase of frequent bottleneck problem in drawing area forcing labor to remove wire spools to other area increasing buffer area.
3. Very high of scrap rate due to frequent breakdown which increase by 30% in the past six month.

1.3 PROBLEM IDENTIFICATION

The current problems which always delay the project are mostly the legal document when doing data retrieval.

Some of the issues also include:

1. Buffer starvation due to increase in variability in production process.
2. High quantity in Finished Good Inventories (FGI) due to unpredicted customer demand.
3. Poor line balancing as the product does not have a justified production route.
4. Increase in inventory level which slows production speed and excessive use of materials.

1.4 SIGNIFICANT OF THE PROJECT

The project is focused on a method or plan to decrease the set up time and forecasting the unplanned breakdown time in order to decrease downtime and speed up manufacturing process. The Total Productive Maintenance has the entire tool to help improve the production performance and reduce loss problem due to high scrap rate.

1.5 OBJECTIVE

The objective of this project is to produce an effective production system based on productive maintenance system which is:-

1. To increase mean time between failure of drawing and enameling machine during busy hours.
2. Provide a suitable routing for supply chain in order to reduce the amount of bottleneck in each workstation.
3. To devise a working process plan in order to help to reduce breakdown problem and increase production quantity.

1.6 SCOPE OF STUDY

The scope of study is mainly on the total improvement of the plant where the total productive maintenance is used as a new concept of changing the system works. The queuing theory will be used to monitor supply chain performance.

1.7 THE RELEVANCY OF THE PROJECT

The project is important to explain the effect of machine breakdown related to increase in bottleneck situation in discrete manufacturing. The discreet manufacturing is more complicated as it doest not have stable buffer capacity and also waiting time. Thus the project in this area of production is critical to find the actual key factor of the problem and how to control it.

1.8 FEASIBILITY OF THE PROJECT

Right now the project is going to simulation and analysis phase as the data are yet to be collected. The project will be given about four month of period to actually collecting data in this period so that it is more accurate and reliable. The project mostly covers only the breakdown analysis, material planning and waiting line models which can be carried out with several tests and simulation.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 TPM CONCEPTS

Total Productive Maintenance (TPM) is defined as "concept that incorporates a plant methodology which enables continuous and rapid improvement of the manufacturing process through use of employee involvement, employee empowerment and closed-loop measurements of results". (Robinson, Ginder, 1993, p.3)

The concept came up with "several elements of strategies that have been defined by the Japan Institute of Plant Maintenance". (Suzuki, 1994, p.6). These strategies are to

(1) maximize overall equipment effectiveness,

(2) establish an understanding preventive maintenance (PM) system covering the life of the equipment**,**

(3) involve all departments that plan, and maintain equipment,

(4) involve all employees from top management to front-line workers and

(5) promoting preventive maintenance through motivation management.

2.2 TPM PRINCIPLES

TPM principles are based on five important elements known as "The Five Pillars of TPM". Each pillars represent different area that supports the TPM concept and applied to ensure increased productivity and free of equipment degradation. The principles as defined as;

2.2.1 Planned maintenance

Planned maintenance activities is described the activities which is planned by reducing the need to do reactive maintenance. This will ensure increase in equipment reliability and uptime, reduce quality defects and improve safety.

2.2.2 Maintenance free

This system is designed to practice the concept which equipment will need less maintenance in order to improve reliability. Also if the equipment requires maintenance the system will help to speed recovery process so the equipment can become operational faster.

2.2.3 Individual kaizen

Kaizen is one of the important concepts in Japan manufacturing industry that uses TPM as a method of improvement. Its philosophy is the search of continuous improvement. Kaizen impose activities to be directed towards improvement. Therefore, any team activity that focuses on the increasing equipment effectiveness, quality improvements or any area of business is considered fall under area of kaizen.

2.2.4 Education and training

Another important concept of TPM is education and training. By acquiring knowledge, the employees should be able to improve their effectiveness and quality of work. This depends on their involvement and understanding of equipment and knowledge.

2.2.5 Self maintenance

This maintenance is referring to a basic program of maintenance activities which are performed by the operators. Some of self maintenance involves with activities like cleaning, dusting and lubricating. The graphical interpretation of the whole TPM ideas is shown in the figure below:

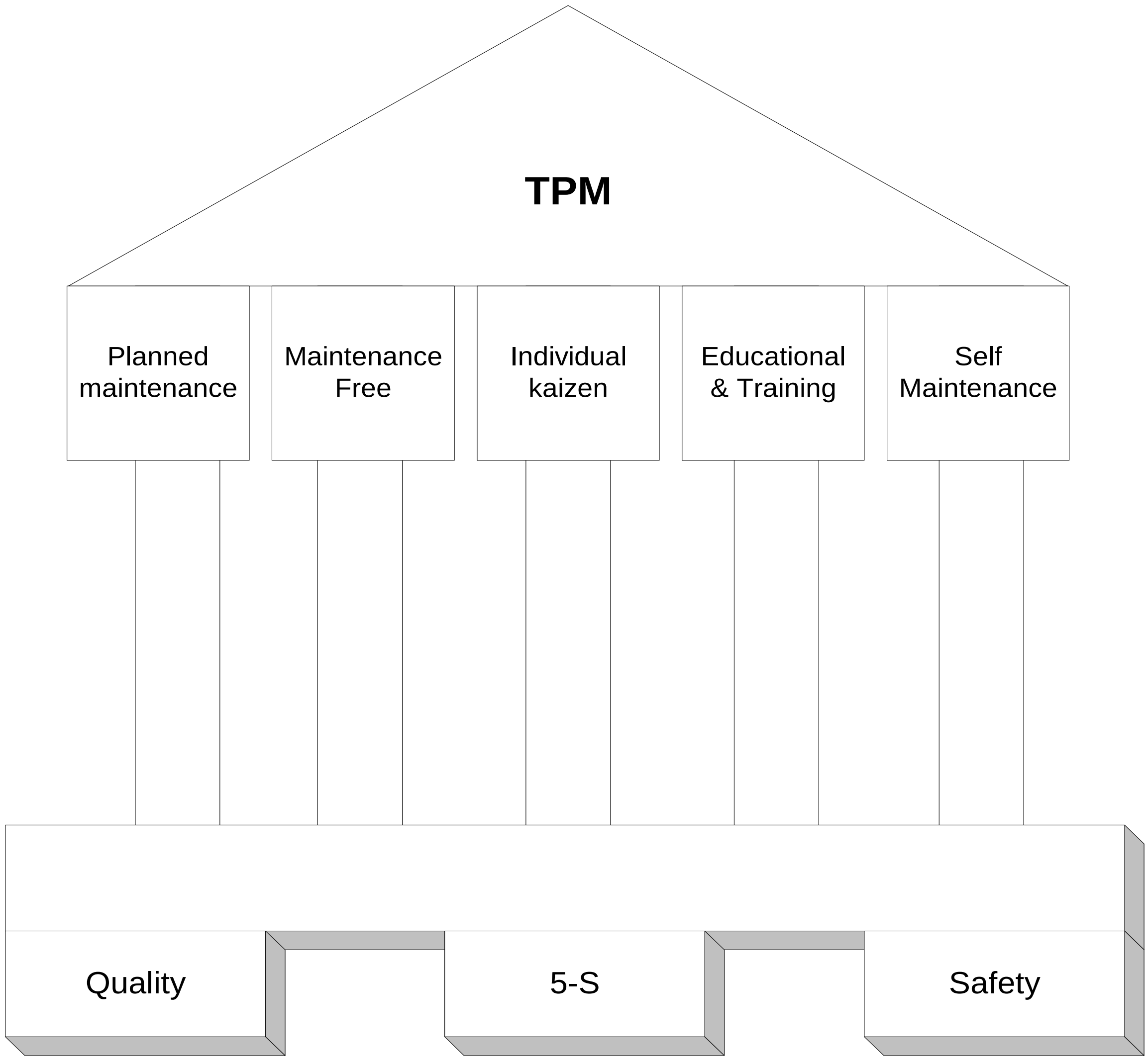

Figure 2.1: A conceptual depiction of TPM concepts and five pillars. (Stephens, 1992, p. 75)

By adding quality and safety into the picture, it is also rather interesting to find the term 5-s in the **figure 2.1**. It pointed that "The 5-s is a concept for a house keeping and it refers to five Japanese word that start with letter "s". It represents tidiness, organization, cleanliness and discipline". (Stephens,1992,p.75). The five Japanese words is seiri (sorting), seiton (organization), seiso (sweeping, workplace hygiene),seiketsu (neatness) and shitsuke (strictness or discipline).

2.3 TPM QUANTITATIVE ELEMENTS

2.3.1 Preventive Maintenance

Preventive maintenance is defined as equipment inspection and testing to avoid premature equipment failures, and lubrications, cleaning, adjusting, and minor component replacement to extend equipment life. (Tomlingson, 1993. p. 23, p.27.)

2.3.2 Purpose

Preventive maintenance generally helps the reduction of equipment failures by implementing (1) equipment inspection to uncover deficiencies before failure and in sufficient time, plan deliberate repairs(2)non-destructive testing techniques (predictive maintenance) to detect equipment degradation and monitor equipment condition to identify abnormal operation.(3) condition monitoring by preserving equipment life with;

i. Lubrication to reduce friction or any other tribological effect on the equipment moving parts.
ii. Routine cleaning and adjusting done in conjunction with inspection or lubrication, or performed by operators.
iii. Replacement of minor components to reduce chances of more important components failing.

2.3.3 Cost of preventive maintenance

The management system must always determine the return on investment (ROI) before allocate any additional investment for a preventive maintenance program. This is to ensure that the financial state is sufficient for the program to go on. The problems with the return it is literally impossible to segregate the intrinsic return of the investment of a few minutes of the operators' time per day from the tangible financial benefits.

By focusing on breakdown frequency we could justify just how much the preventive maintenance can help the situation in financial way. By starting with number of expected breakdowns we come to the equation by Stephens;

$$\textbf{Expected breakdowns} = \Sigma\left[\frac{(\textbf{Number of failures}) \times (\textbf{Frequency})}{\textbf{Total frequency}}\right]$$

This lead to the cost by multiplying the number of PM procedures by the failure risk for the cost per failure

Number of annual PM = Available hours per year / PM frequency

Annual PM cost = Number of annual PM × Cost per PM

∴ Cost of failure = Number of PM per year × (1- reliability) × Cost per failure

Thus,
Total cost of PM = Annual PM cost + Cost of failures (with PM)

2.4 RELIABILITY ANALYSIS

2.4.1 Definition

Reliability is pointed as measure of production system to identify how the machine can produce quality product before it fails and is a very useful toll to determine the maintenance level of each production. The reliability of equipments, products and facilities is a crucial consideration during design. It is significant to the planner and is a factor to consider in quality management and in maintenance and replacement.

Figure 2.2 shows the classic "bath tub" pattern. It determines the failure rate, i.e. the quantity of failures per unit time, expresses as a fraction of number of good products. There are three phases involved:
1-2 'burn-in' or 'infant mortality' or 'early life' failures;
2-3 'random' or 'normal operating, or, middle life, failures;
3-4 'wear-out' or 'old age' failures.

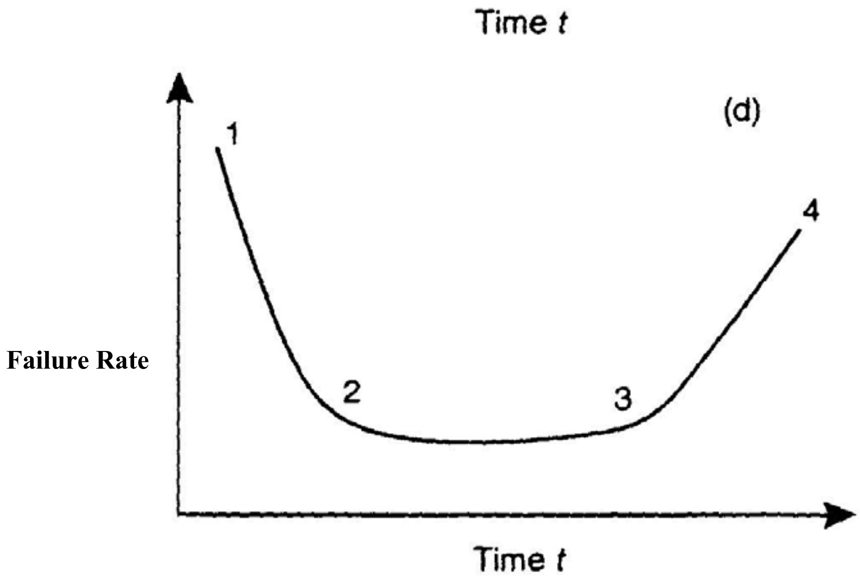

Figure 2.2: Reality Distributions

2.4.2 Relative Frequency Histogram

To determine the probability of failure occurring between times ti-1 and ti, we can multiply the ordinate y by the interval (t_{i-1}, t_i). Further observation in **Figure 2.3** will discover that "probability of a failure occurring between to and tn, where to and tn are the earliest and latest times, respectively, at which the equipment has broke down, is unity. This is valid only if the failure is occurring in the interval (t_o, t_n) and the area of the histogram". (Jardine, Tsang, 2006, p.222)

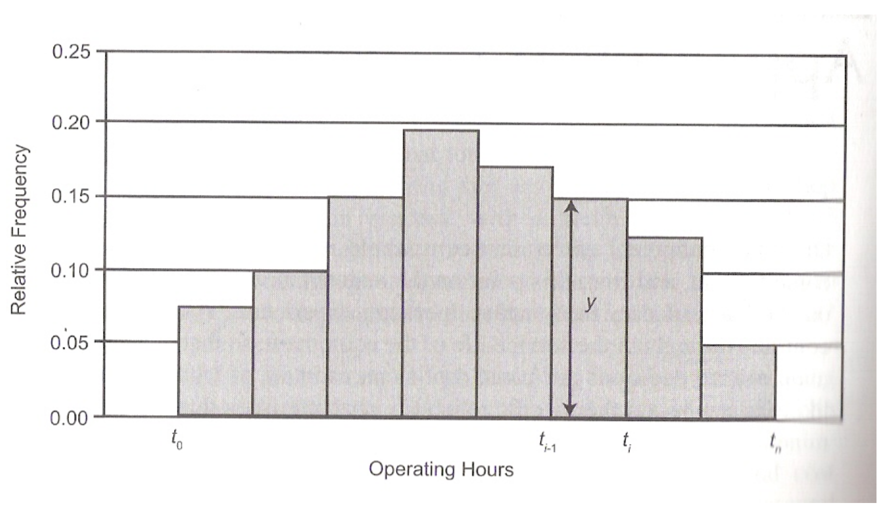

Figure 2.3: A histogram of time to failure (Jardine, Tsang, 2006, p.222)

2.4.3 Probability Density Function

In maintenance studies the probability density function is rather utilized rather than relative frequency histograms. This is because

1. Most of the time the modeling variable such as time to failure is a continuous variable.
2. It is the most easier to be exploited and utilize and,
3. It gives a clearer clarification of the true failure distribution.

Probability density distribution is similar to frequency histogram but it uses continuous curve instead of bar, giving an advantage in accuracy in plotting data and tabulation. **Figure 2.4** shows the graphical interface of probability density distribution. The equation of the curve of the probability density function is depicted by f (t).

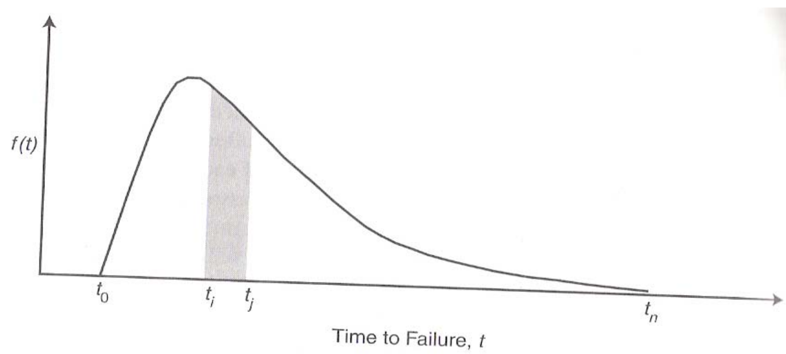

Figure 2.4: Probability density function. (Jardine, Tsang 2006, p.222)

As shown in **figure 2.4**, the curve has changes shape due to several modifications in the function of the probability density function. In this case, the function f(t) is denoted by f(t) = 0.5 exp (-0.5t). Similar to relative frequency diagram the area under the curve is equal to 1.

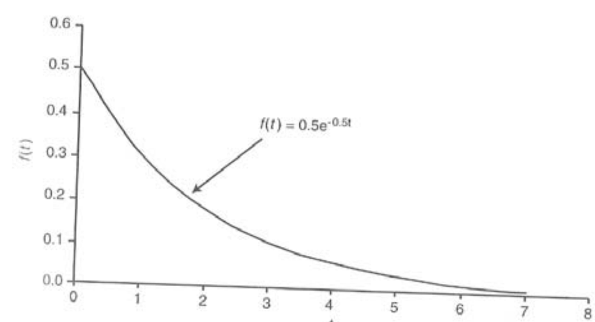

Figure 2.5: A probability density function of exponential distribution. (Jardine, Tsang, 2006, p.223)

In **figure 2.5**, the probability (hazard) of a failure occurring between times ti and tj can be noted by the shaded area under the curve. By using calculus method, this area can be the integral between ti and tj of f(t) represented by,

$$\int^{t_j} f(t)dt$$

t_i

Thus the probability of a failure to be occurred in between period t0 and t∞ is then

$$\int_{t\infty}^{t_0} f(t)dt = 1$$

2.5 VARIABILITY IN PRODUCTION

2.5.1 Process time variability

The random variable of primary interest in manufacturing is the effective process time of a job at a workstation. The label effective is quoted because we are referring to the total time observed by a job station. By implementing this from logistical view, we could assume that if machine B is idle because it is waiting for a job to finish on machine A, it does not important to identify whether the job is actually being processed or is being put on hold due to maintenance of machine A. It is still give the same impact to machine B. this condition and other effects will be put together into one aggregate measure of variability.

2.5.2 Measures and classes of variability

To analyze variability in an accurate manner some quantitative method should be done. This can be achieved by using standard measures from statistics to determine a set of factory physics variability classes.

Variance is a measure of absolute variability (denoted by σ^2) is the same condition as the standard deviation (Represented by σ) determined as the square root of variance. Normally obsolete variability is less critical than relative reliability. As example a standard deviation of 50 micrometers (μm) would show excessively low variability in the length of bar with a nominal length of two inches, but would represent higher variability for a diameter of a copper wire whose mean diameter is 25 micrometers.

The term coefficient of variation (CV) is an appropriate measure of the variability. The variable t is used as mean because we are considering time as primary random variables. Thus the coefficient can be written as

$$c = \frac{\sigma}{t}$$

In many cases, sometime it is easy to to use squared coefficient of variation (SCV)

$$c^2 = \frac{\sigma^2}{t^2}$$

2.5.3 Low and average variability

In process time view it is better to think that the actual time that a machine or an operator spends on the job by eliminating failure or setup condition. This period of time will actually generate a classic bell-shaped curve on the probability distribution. The curve in **figure 2.6** shows the process time with a mean of 20 minutes and a standard deviation of 6.3 minutes. It can be seen that the area under the curve is symmetrically distributed around the value of 20. Thus CV for this condition is around 0.32 and classified as low variability range.

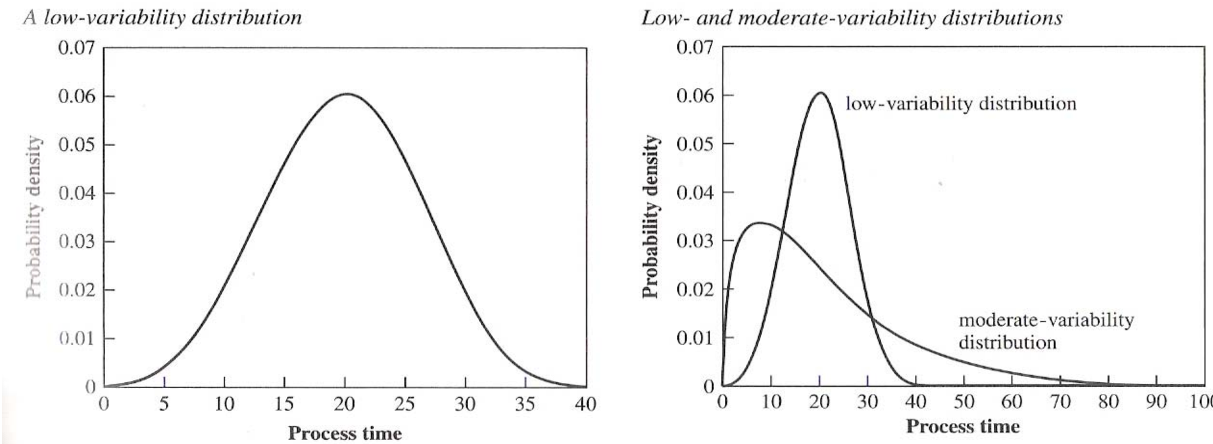

Figure 2.6: Graphical depiction of low and moderate variability

The classes of variability has been standardize to develop easy understanding of a situation and to help planner plan for better control in process time. **Table 2.1** below shows the classes of variability accordingly.

Variability Class	Coefficient of Variation	Typical Situation
Low (low Variability)	**C < 0.75**	**Process times without outages**
Moderate	**0.75<c<1.33**	**Process times with short adjustments (e.g setups)**
High (HV)	**C >1.33**	**Process times with long outages (e.g, failures)**

Table 2.1: Classes of variability (Hopp, Spearman, p. 252)

2.6 SUPPLY CHAIN MANAGEMENT

The objective of every production is to produce as many end items in a shortest amount of time. This can be achieved if there is a good inventory control which determine the relationship of each production level and provide clearer condition for monitoring. In modern terms, the overall system wide coordination of inventory is formerly konown as supply chain management. (Jardine, Tsang, 2006, p.582, p.583 p.587)

There are four categories of inventory which is crucial to ensure a good supply chin management:

1. Raw materials in which denoted as components, subassemblies or materials that are purchased outside the plant and then used for further production function and process.
2. Work in process (WIP) which includes all unfinished items that have been released to the production line.
3. Finished Good Inventory (FGI) is finished product that has yet to be sold or distributed.
4. Spare parts which are define as the components that are used during maintenance or repair of production machine.

2.6.1 Raw Materials

There is not possible to always receive new raw materials from supplier in a given time before production. Thus most manufacturers carry stocks of raw materials. There are three main factors that control the size of these stocks.

1. Batching. This refer to the inventory that addresses batching consideration as cycle stocks, since it represents stock held between ordering cycles.
2. Variability. When the production start early from the planned start date, the deliveries will be behind schedules or quality problems will cause excessive scrap loss. The line will shut down because of the lack of materials when there is not enough extra stock.
3. Obsolescence. Changes in demand or design will render some materials no longer required, thus some inventory in manufacturing systems does not address either of the above purposes.

2.6.2 Work in Process (WIP)

Most of the production line should have a clear and steady WIP in order to ensure low variability and efficient manufacturing. The WIP can be identified as on of these conditions:

1. Queuing if it is waiting for a resource (person, machine, or transport device)
2. Processing if it is worked on by a resource.
3. Waiting for batch if it has to wait for other jobs to arrive in order to form a batch. The batch may serve as a bulk for a manufacturing operation or a move operation.
4. Moving if it is actually being transported between resources.
5. Waiting to match if it consists of components waiting at an assembly operation for their counterparts to arrive so that assembly can be done. Once the entire set has arrived, any additional waiting time for the assembly will be considered as queuing time.

2.6.3 Finished Good inventory (FGI)

Some end products have to just wait in the warehouse to be distributed to customer instead of having delivered a soon after the production has ended. Thus many manufacturers have FGI after production to keep them on hold after production. There are five factors that issues FGI;

1. Customer responsiveness. To provide delivery lead times that are shorter than manufacturing cycle times, many firms make use of Make-to-stock **(MTS)** policy. This is influenced by the commodity properties of product whereby the price is set by the market. The only issue is how to deliver this to customer effectively. The amount of FGI needed to support a given make-to-stock system depends on the variability of customer demand and the desired level of customer service.
2. Batch production. If the production occurs in pre specified quantities (batches), then output will sometimes not match customer orders and any excess will go into finished good inventory.
3. Forecast errors. When jobs are released without firm customer orders, either to restore stock in a make-to-stock system or to meet anticipated orders in a make-to-order system, product will be built that does not sell as predicted. This leftover will end up in FGI.
4. Production variability. In a MTS system where orders can not be distributed early, some variability effects in production timing will cause product to be in FGI while waiting for shipment. In either a make-to-order of a make-to-stock system, variability in production quantity can result in overproduction relative to demand. This excess also will go to FGI.
5. Seasonality. Some products will have demand which varies greatly with changing of season. Thus some manufacturers tend to produce this as a built-ahead inventory which later becomes part of FGI.

2.6.4 Spare Parts.

Spare parts are defined as materials that are used in production but not directly to the product. They only support production by getting the machine running and avoid waste of time due to unplanned breakdown. The primary reasons for stocking up spare parts are;

1. **Service**. The main function of any spare parts is to support maintenance and repair process. F a repair personnel must wait for a part from outside the plant, it will greatly increase repair time which is nor preferable in any occasion. Thus to increase the service level a good amount of spare parts should be in the stock.
2. **Purchasing and production lead times**. If spare parts could be bought or produced instantly, there is no need to stock them ahead of production. However this is not possible thus to attain a certain service, spare parts should always be in the stock.
3. **Batch replenishment**. If there are economies of scale in replenishing spare parts than it is sensible to buy them in bulk.

2.7 QUEUING THEORY

The science of waiting is known as queuing theory. A queuing system is “a combination the components that have been considered so far which is an arrival process, a service process and a queue”. (Groover, 2001,p 800, p.801.). In other verification it is noted that “all the results in queuing theory suggest that both the arrival and the service processes are random”. (Nahmias, 2005,p. 457, p.458).

Arrivals can consist of individual jobs or batches. Jobs can be identical or have different characteristics. Inter arrival times can be set as constant or random. The workstation can have a single machine or cluster of machine in parallel, which can have constant or random process times. The queuing discipline can be first- in-first-out (FIFO), last-come-first-served (LCFS), earliest due date (EDD), shortest process time (SPT) or any schemes feasible. The queue space can be unlimited of finite.

2.7.1 Notation and measures

In order to use queuing theory to determine the performance of a single workstation, some of the parameters are standardize. **Table 2.2** shows the variables that denotes the parameter

Variables	Description
r_a	Rate of arrival in jobs per unit time to station.
ta	1/ra; average time between arrivals
ca	Arrival coefficient of variability(CV)
m	Number of parallel machine at station.
b	Buffer size
te	Mean effective process time. The rate of the workstation is given by re = m/te
ce	CV of effective process time

Table 2.2: Queuing notations and variables used

CHAPTER 3

METHODOLOGY

3.1 PROCEDURE IDENTIFICATION

Most of the data were acquired in a real working machine which is connected to a response feedback system of the factory indoor mechanism system. The systems tabulates every 30 minutes the exact status which is live information to retain reliability. The common method used for this analysis is to recall back the information from this live input and output data for the past four month from 12^{th} February. The procedure includes (by sequence):-

1. Identifying planning condition and parameters from drawing and enameling machine
2. Quantify waiting time, throughput time and unplanned time in between production of each workstation.
3. Analyzing buffer condition which includes quantity of spool and type available.
4. Produce report on WIP for production, reliability status and performance measure and plant productivity.
5. Develop several simulations and testing on the data obtained to prove the theory.
6. Devise several production plant models to pin point problematic area of production.

3.1.1 Identifying planning condition

The most critical part of this project is to know the ground data which is the data of copper wire process before, during and after the production. Mostly the data from the production is based on copper wire specification and machine capabilities. By manipulating this critical data a new and improved design could be design which can abolish small flaw in the production**.** Analysis focuses on five wire type or product as they represent more weight in average and has more value added properties due to continuous demand from customer. The data from the **table 3.1** shows the top 5 produced copper wire as a reference and sample data.

Top 5 produced copper wire	Density	Spool size (mm)	Production level
0.055 mm	8930 kg/m3	420	3
0.045 mm	8930 kg/m3	330	3
0.038 mm	8930 kg/m3	330	2
0.028 mm	8930 kg/m3	240	2
0. 018 mm	8930 kg/m3	160	1

Table 3.1: Top 5 produced copper wire specification for each diameter size.

The production of each diameter demand an accurate and careful material resource planning as the production are limited to each extend of production required range. In this case the copper wire production manufacturing lead time is proportional to :-

1.) The weight of copper wire
2.) The number of assigned spools
3.) Drawing and enameling machine type and specification
4.) Production level.

By using spools as the requirement to hold each copper wire production, the set up time will be increased as to compensate the reloading period and manual labor time. The human worker will actually standby for each spool installation. As shown in **Table 3.1**, each diameter is assigned each specific spool size due to capacity planning and minimizing stock value. **Table 3.2** below shows each spool maximum carrying capacity to hold the copper wire during and after production.

Spool size (mm)	Average spool capacity (kg)
160	45.23
240	120.69
330	256.48

420	389.57
550	450.48

Table 3.2.: Top 5 produced copper wire specification for each diameter size.

3.1.2 Quantify waiting time in between production of each workstation

Waiting time for each demand was obtained by spool size, which determines the maximum capacity it can hold for a certain value before having to be replaced for a new one. The quantity of copper wire will be plotted by weight in which the customer required and from **table 3.2**, each spool can hold up to certain weight depending on copper wire diameter size. **Figure 3.1** shows some numbers of spools are utilized for the each customer order

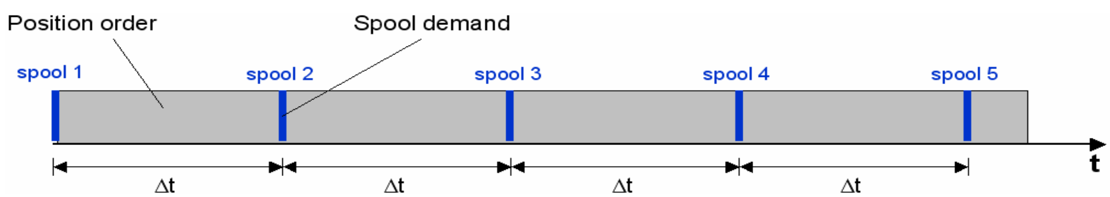

Figure 3.1: Example of copper wire spool demand through production in drawing area.

3.1.3 Spool cycle time

The cycle time in production is the period, which consists processing, waiting, and reposition time. The spool cycle time basically defines the time to produce copper wire with certain spool usage. The cycle time could provide data about the production rate, machine efficiency, order effectiveness and also copper wire material flow.

In general, the cycle time is the period trough the whole production process. There are three main cycle times, which are crucial for production time. They are:

- **Process time**

  Process time is consists of two process time: -

  –Processing Time on Drawing Machine (tp^M)

  –Processing Time in Bare Wire Inspection

  (Inspection time; tp^I).

- **Transport/Reposition time**

  Transport time is composed of two conditions: -

  – Transport time from drawing machine part to bare wire inspection area (tT^1)

  – Transport time from bare wire inspection to enameling area (tT^2).

- **Waiting time**

  Waiting time is divided by three situations: -

  – Waiting time after drawing process for pick up to bare wire inspection area

  – Waiting time immediately before bare wire inspection.

  - Waiting time after inspection and before pick up to enameling area

For production on machine cycle time, the most important element is average spool size. This is because the rate of installation is varied due to spool sizes maximum capacity. Thus from a planner point of view, larger sizes is always the best because it has lower set up time due to planned interruption. However in most cases this is not generally applicable.

The distance from each wire spool utilization can be forecasted and will help the planner to plan each copper wire beforehand and meet the dateline. Equation below is used as a software algorithm to estimate how many spool is neded from each order generation.

$$\Delta t = \frac{\overline{m}_{Spule}}{\alpha_{nom}^{E} * OSP^{E} * OPE^{E} * \beta_{Bare}} \quad and \quad \beta_{Bare} = \frac{A_{Bare} * \delta_{Bare}}{A_{Bare} * \delta_{Bare} + A_{Enamel} * \delta_{Enamel}}$$

with	Δt	=	Distance between two spool demands
	$\overline{m}_{Spool}$	=	Average spool weight
	α_{nom}^{E}	=	Nominal production rate of the enamel machine
	OSP^{E}	=	OSP value enamel/drawing machine
	OPE^{E}	=	OPE value enamel/drawing machine
	β_{Bare}	=	Rate of bare wire to total output of the enamel/drawing machine
	A_{Enamel}	=	Cross-section enamel layer [m^2]
	δ_{Enamel}	=	Density enamel [kg/m^3]

Customer based production actually exist and initiated by customer order. The factory operates on timeline given by client and this will produce a priority and a non priority production situation. The other production is made just to compensate the later production level. As each production level is inter-related, some production will be halt if there is problem in the earlier level. Thus the production was separated by two types, Make-to-order and Make-to-Stock.

Production Planner

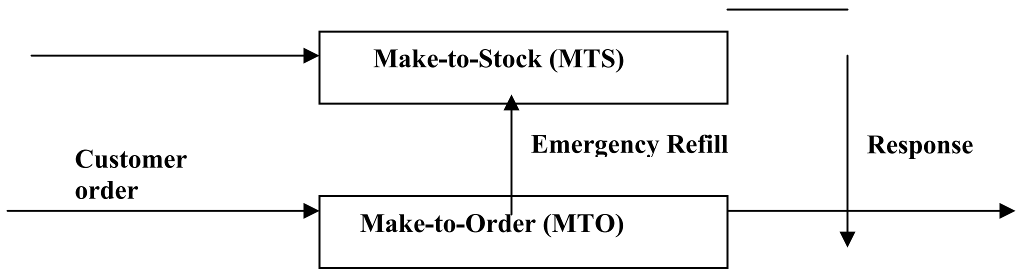

Figure 3.2: General depiction of MTS and MTO product relation

The Make- to- order product are “generated from client request, given the exact quantity of wire and timeline before shipping. Make-to-stock was developed to compensate the production of Make-to-order product. Most of the cases are to replace defected wire from poor production of Make-to-stock product and by doing this in parallel it save a lot of time. However there is certain limit where the quantity of Make-to-stock product can be produced too much as there is need to optimize between profit and safety”. (Bell, 2006, p.93, p.94, p.96)

3.1.4 Reliability

Reliability test is a measure of how a machine can do their task by referring to their rate of product failure. As mentioned earlier the plant operator is aware of how much the machine is defected as this will tell how much make- to- stock is leveled. The technician log book report will actually reveal the repair history of the entire machine in the factory. Data from the report will actually generate a level of machine reliability and most importantly in what area and time of production. The reliability of the machine will be weighted out by referring to the production level and machine type. The testing will be of two ways, which are;

1. Copper wire breakage during inspection period.
2. Copper wire breakage during production.

Obviously the copper wire in the level 4 productions will hardly to face copper wire breakage due to higher tension resistance from bigger diameter from drawing effect, however it may face frequent breakdown for higher maintenance because of bigger size.

As mentioned, the reliability is measure d of how much the product is defected. By testing in smaller scale as prove of concept, each production level is considered to have production reliability;

Production level 4 = 0.95

Production level 3 = 0.90

Production level 2 = 0.85

Production level 1 = 0.80

The production reliability is defined by multiplication of individual probability of having good products. Thus;

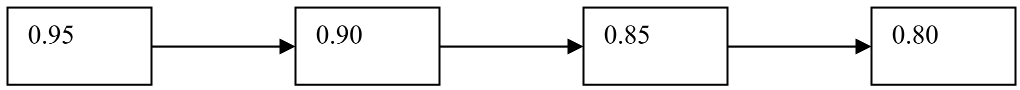

Figure 3.3: Reliability block diagram representing each level in a serial production

Then,

$$Rp = 0.95 \times 0.90 \times 0.85 \times 0.8$$
$$= 0.58$$

However by adding redundancy from Make-to-stock products; the reliability of production has been altered;

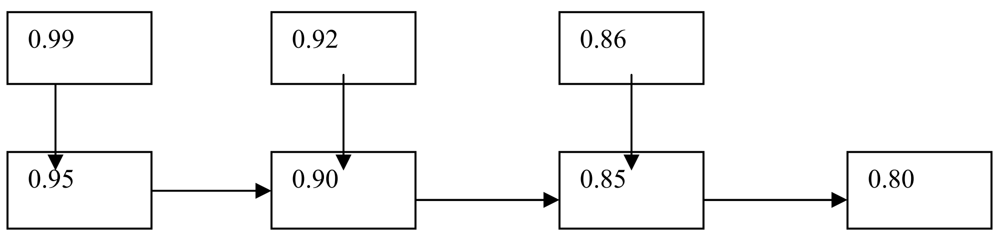

Figure 3.4: Reliability block diagram representing each with the existence of MTS product

$$\text{New } Rp = [0.95 + 0.99(1 - 0.95)] \times [0.90 + 0.92(1 - 0.90)] \times [0.85 + 0.86(1 - 0.85)] \times 0.8$$
$$= 0.77$$

It is shown that by adding Make-to-stock product into production will greatly increase the production reliability. Increased reliability will ensure the success rate of machine producing good product and lessen the human involvement due to process downtime.

3.2 DEVISED PLANT MODEL FOR THE WIRE COMPANY.

3.2.1 Old model

Figure 3.5 below shows the current model used by the wire factory to produce 28 micrometer diameter wire.

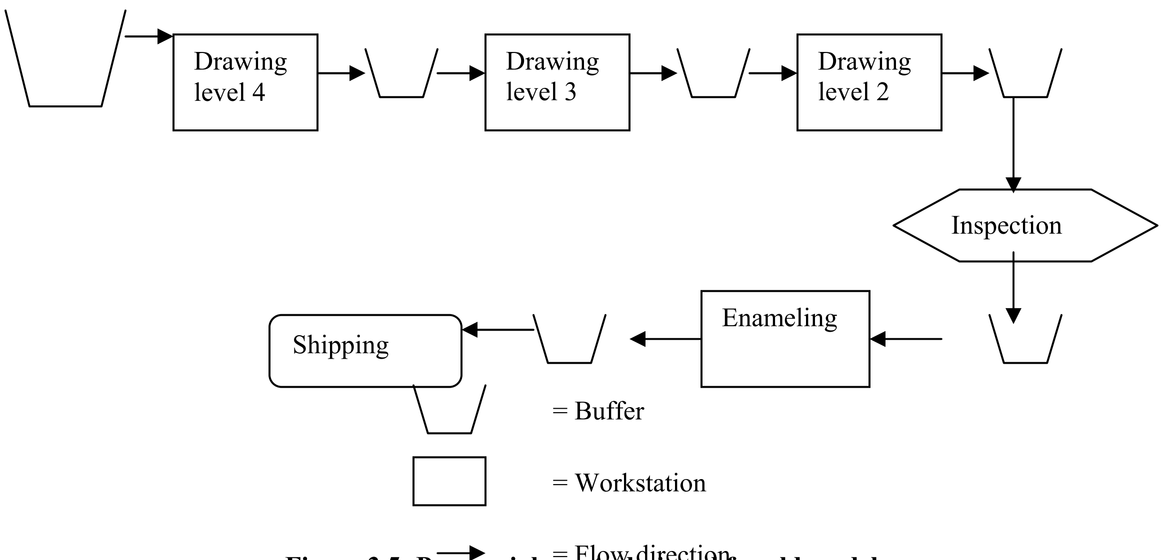

Figure 3.5: Process job route designed for old model

Production level	Wire diameter (μm)	Wire quantity (kg)	Machine Speed (m/s)	Maximum buffer size (per100 kg)	Mean time between failure (minutes)	Specified Repair time (minutes)
Level 4	125	100	42	12	5500	45
Level 3	45	100	42	30	7500	30
Level 2	28	100	25	100	9000	30
Enameling	28	100	25	100	1800	30
Inspection	Given mean time of 5 minutes per 100 kg					

Table 3.3: Production input parameter for old model

3.2.2 Model 1(Reliability based solution)

Figure 3.6 below shows model 2 as an option by the wire factory to produce 38 micrometer diameter wire.

Raw material

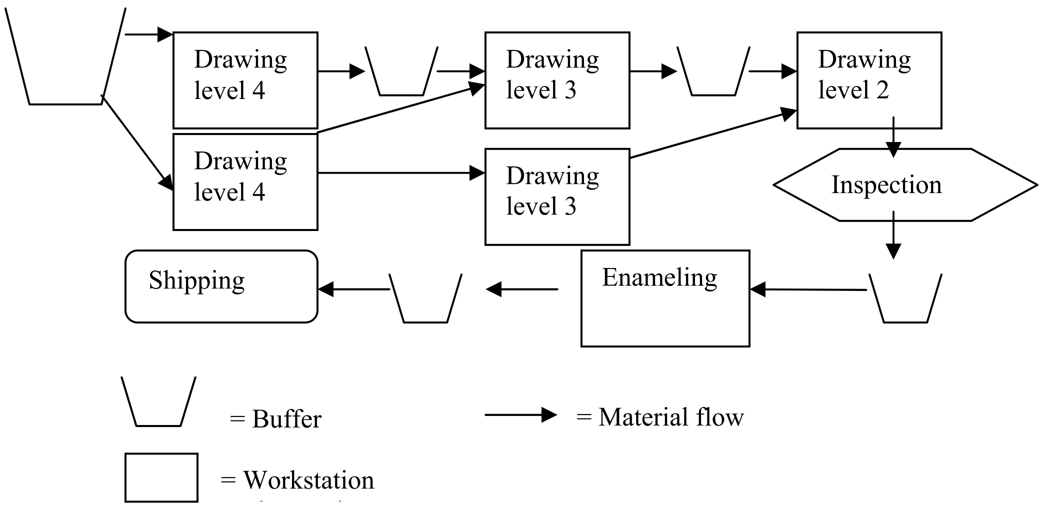

Figure 3.6: Process job route designed for model 1

In this model the drawing machine for level 3 and level 2 are associated with the successor of another drawing machine of the same specifications. In order to increase reliability, each primary drawing machine for process level 3 and 2 will be fed with part from their secondary machine whenever there is break down from predecessor machine.. The production with this model will be run for four moths to find the total throughput, variability level, mean distribution and machine utilization.

Production level	Wire diameter (µm)	Wire quantity (kg)	Machine Speed (m/s)	Maximum buffer size (per100 kg)	Mean time between failure (minutes)	Specified Repair time (minutes)
Level 4	125	100	42	12	5500	45
Level 3	45	100	42	50	7500	30
Level 2	38	100	25	100	9000	30
Enameling	38	100	25	1000	1800	30
Inspection	Given mean time of 5 minutes per 100 kg					

Table 3.4: Production input parameter for model 1

Model 2 (Queuing theory solution)

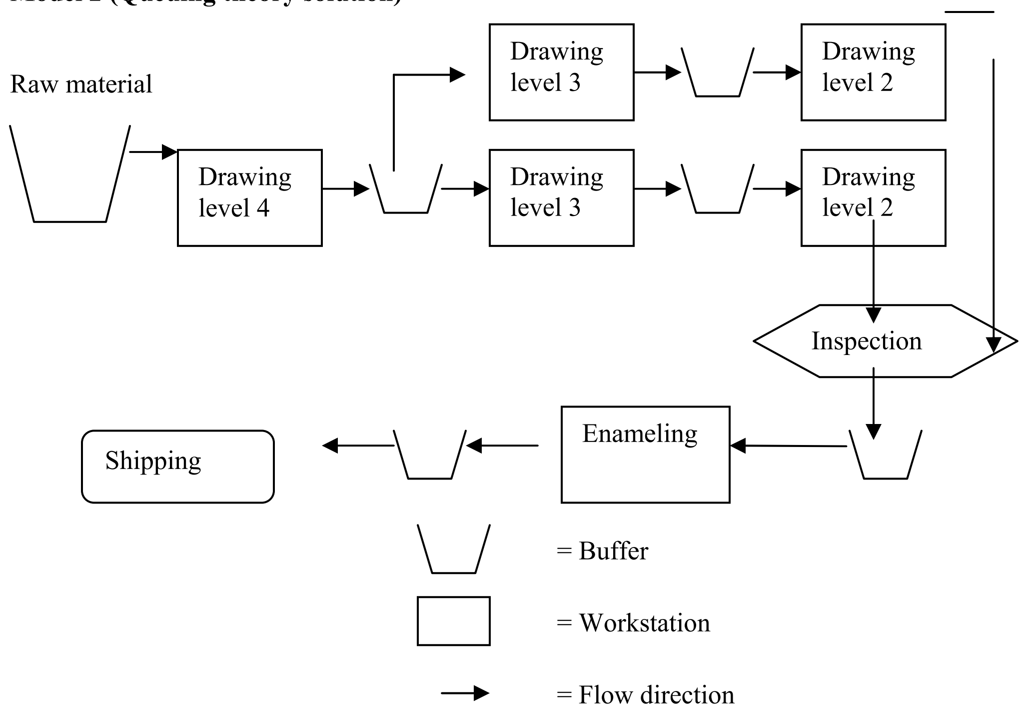

Figure 3.7: Process job route designed for model 2

In model 2 the production started with the spool being distributed to two production route. From buffer 1 the copper wire will be distributed to both identical drawing machines which are parallel to each other. This will reduce bottleneck problem in buffer 1 after drawing level 4.

Production level	Wire diameter	Wire quantity (kg)	Machine Speed (m/s)	Maximum buffer size (per100 kg)	Mean time between failure (minutes)	Repair time
Level 4	125	100	42	12	5500	45
Level 3	45	100	42	50	7500	30
Level 2	38	100	25	100	9000	30
Enameling	38	100	25	1000	1800	30
Inspection	Given mean time of 5 minutes per 100 kg					

Table 3.5: Production input parameter for model 2

Model 3 (Buffer flexibility solution)

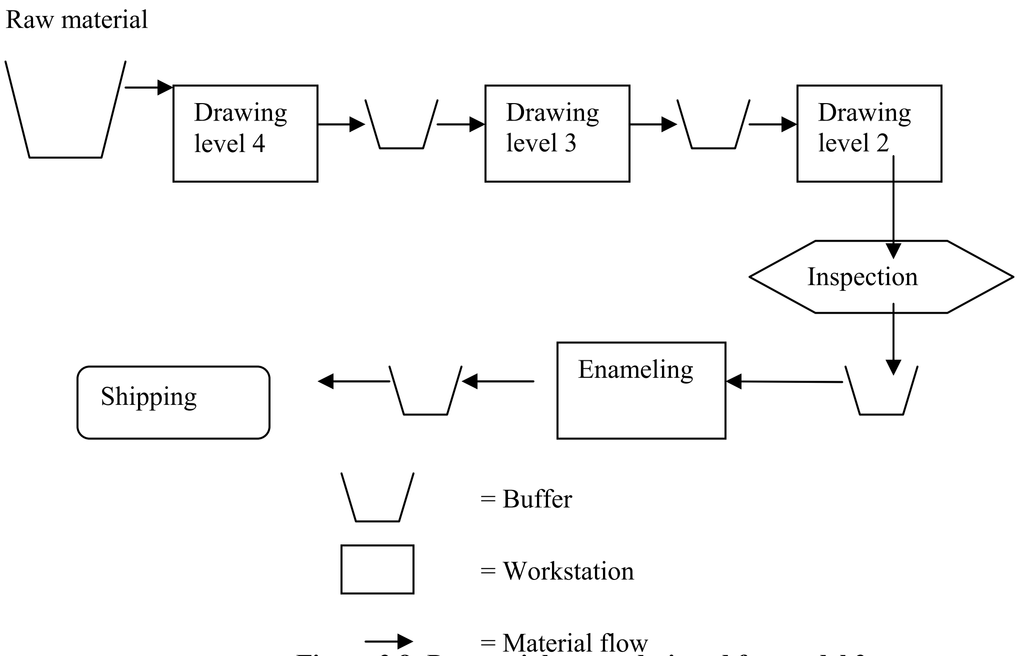

Figure 3.8: Process job route designed for model 3

In order to reduce queuing time, the buffer capacity for each production level is increased drastically. This will prevent buffer bottlenecks and ensure continuous production. For level 4 drawing machine, the buffer size is increased almost 1700% due to its shorter cycle time where the subassembly part will tend to pile up rapidly.

Production level	Wire diameter	Wire quantity (kg)	Machine Speed (m/s)	Maximum buffer size (per100 kg)	Mean time between failure (minutes)	Repair time
Level 4	125	100	42	200	5500	45
Level 3	45	100	42	200	7500	30
Level 2	28	100	25	200	9000	30
Enameling	28	100	25	1000	1800	30
Inspection	Given mean time of 5 minutes per 100 kg					

Table 3.6: Production input parameter for model 3

3.3 COMPUTER SIMULATION

3.3.1 Witness Manufacturing simulation Software

Witness simulation software is computer program that uses graphical depiction and manufacturing algorithm to create a live production situation. It is created by Lanner Corporation to help reducing time constraint of having to record data from real life manufacturing scenario. Simulation projects have several unique aspects that must be manage particularly carefully in order to ensure their success. A simulation project will involve a typical sequence of events:

1. Establish objectives.
2. Decide the scope and level of detail in the model.
3. Collect data.
4. Structure the model.
5. Build the model.
6. Run the model.
7. Generate reports.
8. Test the model.
9. Experiment.
10. Document the model.
11. Present the results and implement changes to the real-life system.

There are three elements available in Witness software that mostly used in creating simulation. They are;

1. Normal element
2. Designer element
3. System element

3.3.2 Normal simulation elements

A normal simulation element becomes a working part of the model as soon as it has been created and it will be displayed in the window.

3.3.3 Designer elements

A designer element is an element template that you create and store in a separate window (the designer elements window). You can copy the designer element into your model from the designer elements window. The copy becomes a normal simulation element, and you can rename it and amend its details. Designer elements can build models very quickly.

3.3.4 System elements

System elements are certain items (such as special locations and WITNESS variables that you can display in a similar way to simulation elements. The system element can not be modified and created in any way.

CHAPTER 4

DISSCUSSION AND RESULTS

4.1 PERFORMANCE MEASURE OF PRODUCTION LEVEL

4.1.1 First Modeling

Description

The first modeling was made by changing the old model from single manufacturing line
to variable routing . This is done in production level 3 and production level 2 where as the variability is mostly take effect on production line. The drawing machine M26 in level 3 production level is capable to produce 45 micrometer diameter wire is set to 2 parallel machine at the station. Drawing machine H52 is capable to produce 25 micrometer diameter wire. From reliability issue the each machine from process level 3 and 2

Results from Simulation

Mean throughput time = 91463.98 minutes/100kg @ 15.24 hours/kg

Standard deviation= 47464.63 minutes

Variability level= 0.52

Total throughput over time = 8400 kg per month

Mean breakdown reported from plant = 25 per month

4.1.2 Second Modeling

Description

This experiment is to prove the effectiveness of having parallel machines in production in term of shorten queuing time. The machines in process level 3 and process level 2 is picked to have identical machine during production due to existence of bottleneck working parts in the area.

Results

Mean throughput time = 91420.20minutes /100kg @ 15.2367 hours/kg

Standard deviation = 47448.39 minutes

Level of variability = 0.52

Total throughput over time = 16800 kg

4.1.3 Third Modeling

Description

The buffer in this pant model is increased drastically to reduce bottleneck in the buffer which can be critical if the machine is in full utilization. There are no changes however in any of the material routing.

Results

Mean throughput value =91463.98 minutes/100kg @ 15.24 hours/kg

Standard deviation =47468.63 minutes

Level of variability = 0.52

Total throughput over time =16800 kg

4.2 TIME STUDY

Most of non production time is plotted by manual inspection as it does not have any records and mostly performed by human workers. This will result a high level of variations and can not be recorded unless by inspection.

	Inspection time Ultra fine [min]	**I**
Average:	5.06	I
Average 95%:	4.00	
	Transport time 1 [min]	**T1**
Average:	2.00	
Average 95%:	2.00	
	Transport time 2 [min]	**T2**
Average:	2.50	
Average 95%:	2.00	
T1 + T2	4.50	

Table 4.1: Non production time during production

T1	Transport time from drawing machine part to bare wire inspection area (tT^1)
T2	Transport time from bare wire inspection to enameling area (tT^2).

From the **table 4.1,** both inspection and transportation time are not significant and almost negligible when compared to large scale of production time. This will happen when most of the machine from each process level is situated quite close to each other.

	Waiting time Ultra fine 1 [min]	**W1**
Average:	99.02	
Average 95%:	83.00	
	Waiting time 2 [min]	**W2**
Average:	137.25	
Average 95%:	150.50	
W1 + W2	236.27	
	Waiting time 3 (ultra fine [min])	**W3**
Average:	1,930.82	
Average 95%:	1,397.93	
W1 + W2 + W3	2,167.10	

Table 4.2: Non production time resulted from bottleneck operation

W1	Waiting time after drawing process for pick up to bare wire inspection area
W2	Waiting time immediately before bare wire inspection.
W3	Waiting time after inspection and before pick up to enameling area

Table 4.3: Waiting time representation

From **table 4.2**, waiting time 3 was found as the highest time consumed during non production period. From **table 4.3** waiting time 3 is the same as the production cycle time enameling process including set up time for the enameling machine. The table shows the difference of almost 8700%. Thus focusing on the enameling machine production time would be able to solve the serious bottleneck problems in the copper wire panning.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

From the results and discussion in this method, we can found out what the real problem is in the production line by implementing total productive maintenance. The breakdown problem in model 1 has been reduced from 40 breakdown/month to 25 breakdown/month much to be satisfied about. The total throughput from model 2 yield 16800 kg of copper wire compared to normal model which yield 8400 kg in a basis of four month. Model 3 however does not really show any significant changes with normal model as control model. There is still room for improvement for model 1 and model 2 whereby shortening cycle time will actually help the production to produce copper wire at faster rate. This can be done with machine modification instead of buying new machines that require more resource. Frequent inspection from labor enforcement will help to even reduce breakdown and decrease amount of scrap.

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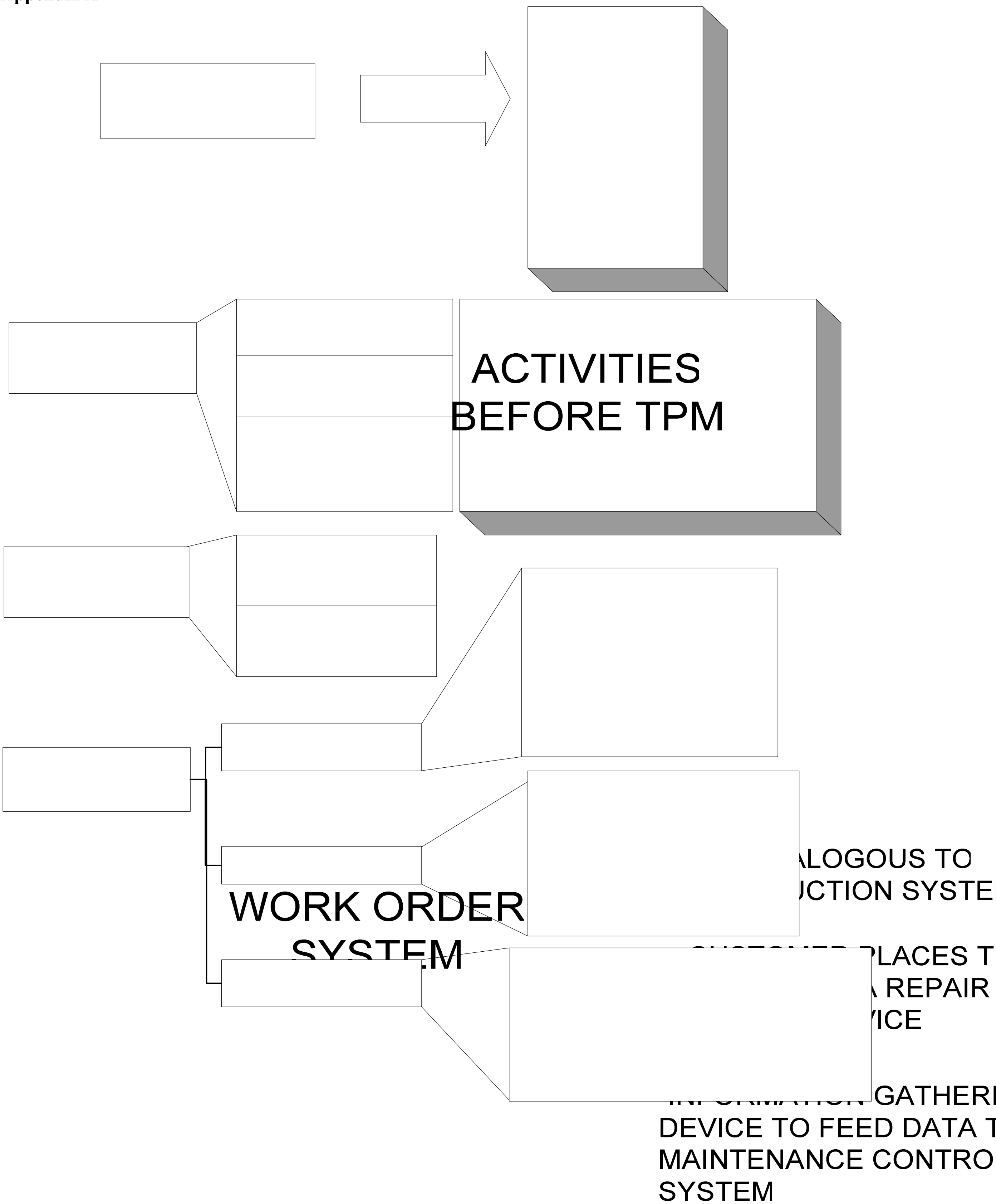
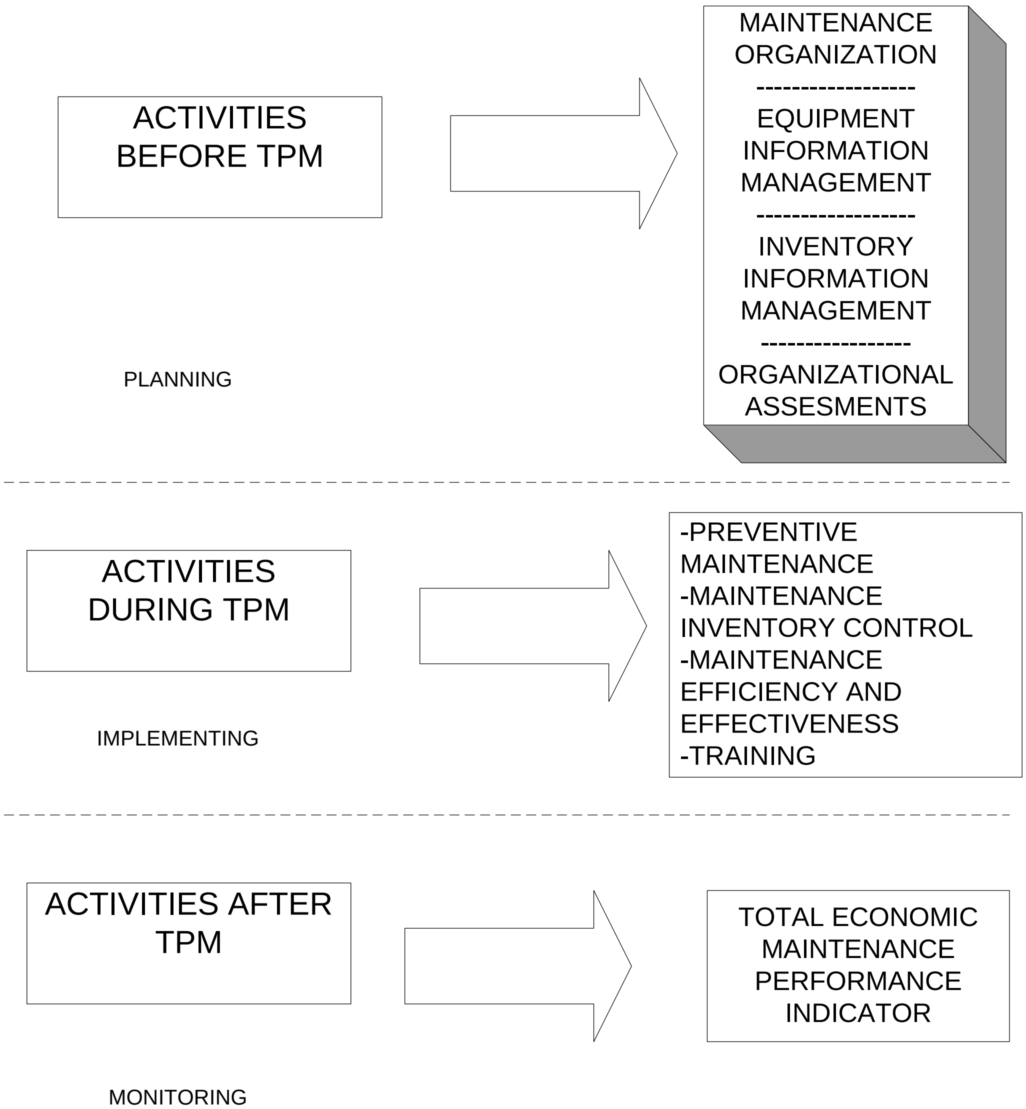
APPENDICES

Appendix A



Appendix B

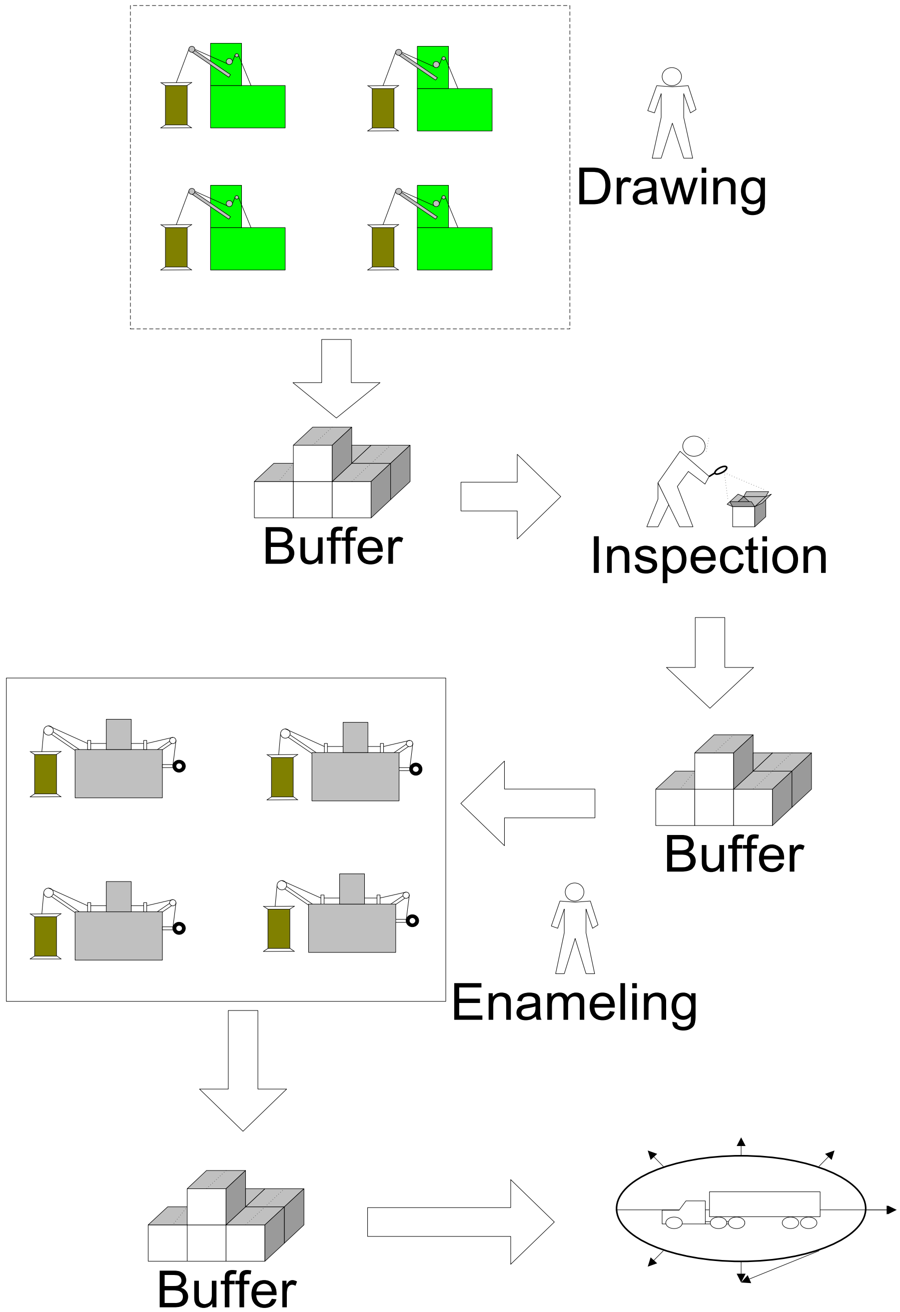

ACTIVITIES BEFORE TPM
MAINTENANCE ORGANIZATION

EQUIPMENT INFORMATION MANAGEMENT

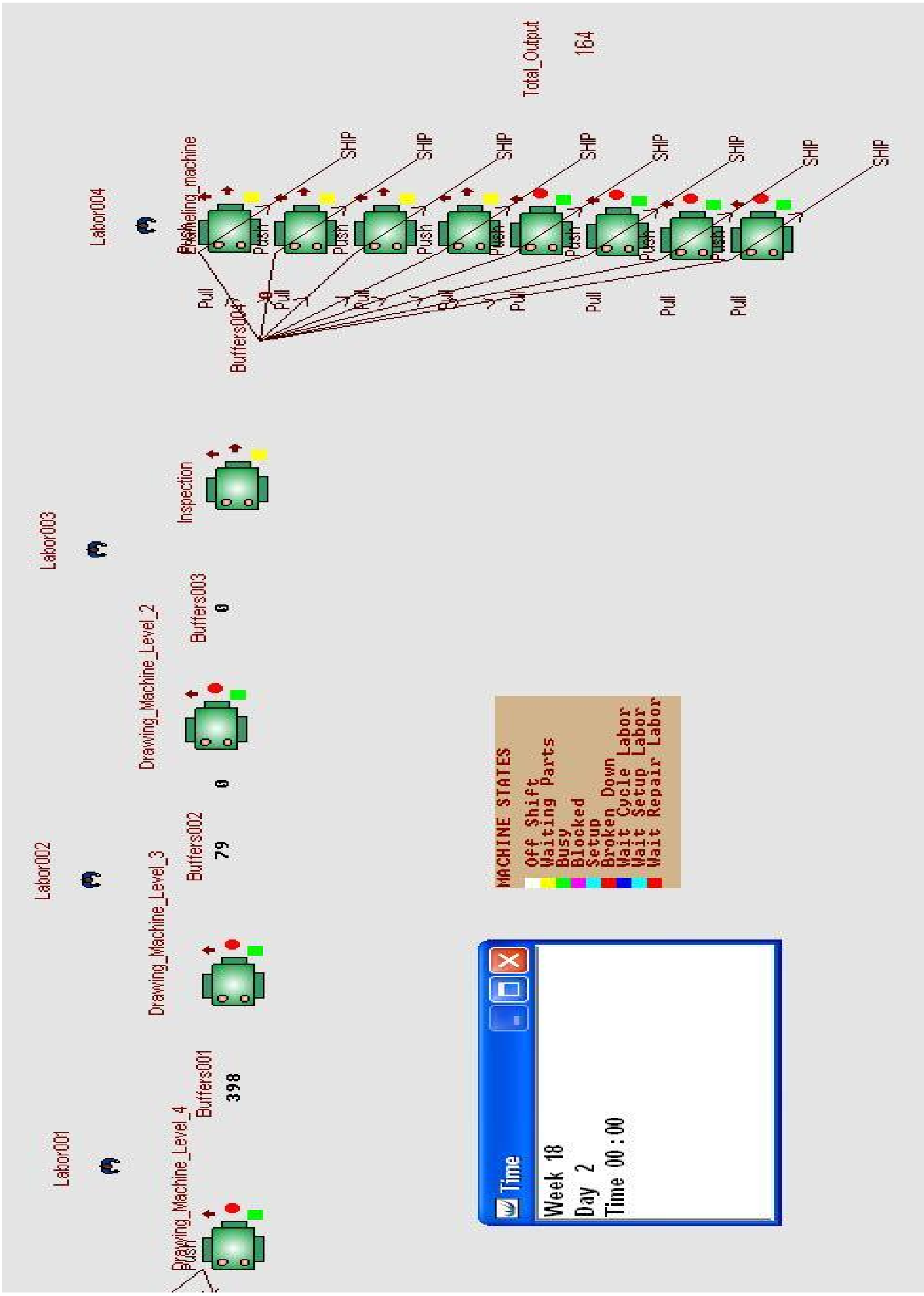
INVENTORY INFORMATION MANAGEMENT

ORGANIZATIONAL ASSESMENTS
PLANNING
ACTIVITIES DURING TPM
-PREVENTIVE MAINTENANCE
-MAINTENANCE INVENTORY CONTROL
-MAINTENANCE EFFICIENCY AND EFFECTIVENESS
-TRAINING
IMPLEMENTING
ACTIVITIES AFTER TPM
TOTAL ECONOMIC MAINTENANCE PERFORMANCE INDICATOR
MONITORING

Appendix C

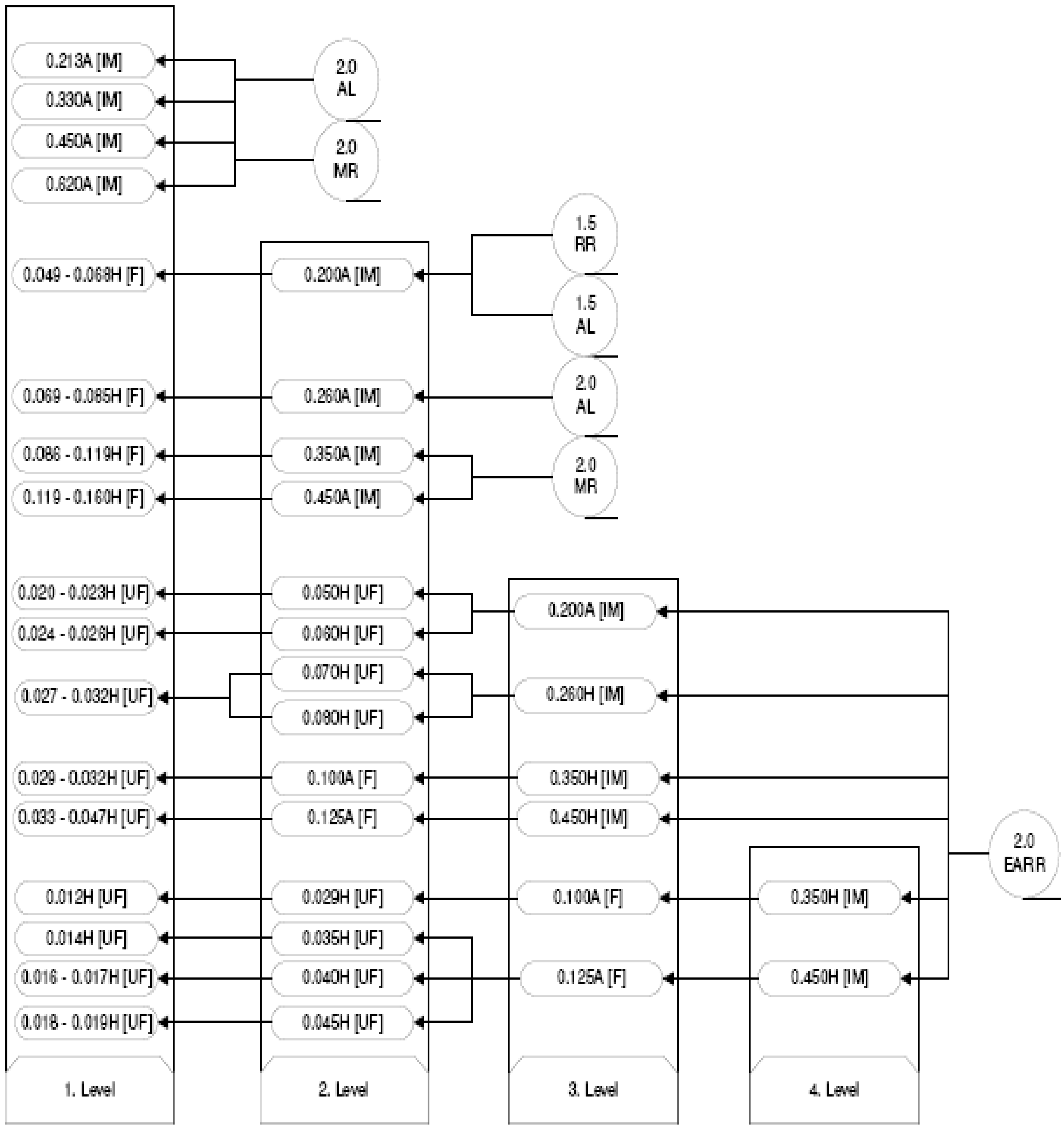


Appendix D



Witness Simulation 1

Appendix E



The copper wire size production level

Appendix F

Similarities and differences between TQM and TPM :

The TPM program closely resembles the popular Total Quality Management (TQM) program. Many of the tools such as employee empowerment, benchmarking, documentation, etc. used in TQM are used to implement and optimize TPM.Following are the similarities between the two.

1. Total commitment to the program by upper level management is required in both programmes
2. Employees must be empowered to initiate corrective action, and
3. A long range outlook must be accepted as TPM may take a year or more to implement and is an on-going process. Changes in employee mind-set toward their job responsibilities must take place as well.

The *differences* between TQM and TPM is summarized below.

Category	**TQM**	**TPM**
Object	Quality (Output and effects)	Equipment (Input and cause)
Mains of attaining goal	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality for PPM	Elimination of losses and wastes.

Types of maintenance :

1. Breakdown maintenance :

It means that people waits until equipment fails and repair it. Such a thing could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost.

2. Preventive maintenance (1951):

It is a daily maintenance (cleaning, inspection, oiling and re-tightening), design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. It is further divided into periodic maintenance and predictive maintenance. Just like human life is extended by preventive medicine, the equipment service life can be prolonged by doing preventive maintenance.

2a. Periodic maintenance (Time based maintenance - TBM) :

Time based maintenance consists of periodically inspecting, servicing and cleaning equipment and replacing parts to prevent sudden failure and process problems.

2b. Predictive maintenance :

This is a method in which the service life of important part is predicted based on inspection or diagnosis, in order to use the parts to the limit of their service life. Compared to periodic maintenance, predictive maintenance is condition based maintenance. It manages trend values, by measuring and analyzing data about deterioration and employs a surveillance system, designed to monitor conditions through an on-line system.

3. Corrective maintenance (1957) :

It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or improving maintainability

4. Maintenance prevention (1960):

It indicates the design of a new equipment. Weakness of current machines are sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing) and are incorporated before commissioning a new equipment.

TPM - History:

TPM is a innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However the concept of preventive maintenance was taken from USA. Nippondenso was the first company to introduce plant wide preventive maintenance in 1960. Preventive maintenance is the concept wherein, operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines, however with the automation of Nippondenso, maintenance became a problem as more maintenance personnel were required. So the management decided that the routine maintenance of equipment would be carried out by the operators. (This is Autonomous maintenance, one of the features of TPM). Maintenance group took up only essential maintenance works.

Thus Nippondenso which already followed preventive maintenance also added Autonomous maintenance done by production operators. The maintenance crew went in the equipment modification for improving reliability. The modifications were made or incorporated in new equipment. This lead to maintenance prevention. Thus *preventive maintenance* along with *Maintenance prevention* and *Maintainability Improvement* gave birth to ***Productive maintenance***. The aim of productive maintenance was to maximize plant and equipment effectiveness to achieve optimum life cycle cost of production equipment.

By then Nippon Denso had made quality circles, involving the employees participation. Thus all employees took part in implementing Productive maintenance. Based on these developments Nippondenso was awarded the distinguished plant prize for developing and implementing TPM, by the *Japanese Institute of Plant Engineers* (JIPE). Thus Nippondenso of the Toyota group became the first company to obtain the TPM certification.

TPM Targets:

P
Obtain Minimum 80% OPE.
Obtain Minimum 90% OEE (Overall Equipment Effectiveness)
Run the machines even during lunch. (Lunch is for operators and not for machines !)

Q- Operate in a manner, so that there are no customer complaints.

C-Reduce the manufacturing cost by 30%.

D-Achieve 100% success in delivering the goods as required by the customer.

S -Maintain a accident free environment

M - Increase the suggestions by 3 times. Develop Multi-skilled and flexible workers.

Motives of TPM	1. Adoption of life cycle approach for improving the overall performance of production equipment. 2. Improving productivity by highly motivated workers which is achieved by job enlargement. 3. The use of voluntary small group activities for identifying the cause of failure, possible plant and equipment modifications.
Uniqueness of TPM	The major difference between TPM and other concepts is that the operators are also made to involve in the maintenance process. The concept of *"I (Production operators) Operate, You (Maintenance department) fix"* is not followed.
TPM Objectives	1. Achieve Zero Defects, Zero Breakdown and Zero accidents in all functional areas of the organization. 2. Involve people in all levels of organization. 3. Form different teams to reduce defects and Self Maintenance.
Direct benefits of TPM	1. Increase productivity and OPE (Overall Plant Efficiency) by 1.5 or 2 times. 2. Rectify customer complaints. 3. Reduce the manufacturing cost by 30%. 4. Satisfy the customers needs by 100 % (Delivering the right quantity at the right time, in the required quality.) 5. Reduce accidents. 6. Follow pollution control measures.
Indirect benefits of TPM	1. Higher confidence level among the employees. 2. Keep the work place clean, neat and attractive. 3. Favorable change in the attitude of the operators. 4. Achieve goals by working as team. 5. Horizontal deployment of a new concept in all areas of the organization. 6. Share knowledge and experience. 7. The workers get a feeling of owning the machine.

OEE (Overall Equipment Efficiency) :

OEE = A x PE x Q

A - Availability of the machine. Availability is proportion of time machine is actually available out of time it should be available.

A = (MTBF - MTTR) / MTBF.

MTBF - Mean Time Between Failures = (Total Running Time) / Number of Failures.
MTTR - Mean Time To Repair.

PE - Performance Efficiency. It is given by RE X SE.

Rate efficiency (RE) : Actual average cycle time is slower than design cycle time because of jams, etc. Output is reduced because of jams
Speed efficiency (SE) : Actual cycle time is slower than design cycle time machine output is reduced because it is running at reduced speed.

Q - Refers to quality rate. Which is percentage of good parts out of total produced sometimes called "yield".