TOTAL PRODUCTIVE MAINTENANCE (TPM) APPROACH TO IMPROVE OVERALL EQUIIPMENT EFFICIENCY (OEE) IN ROBERT BOSCH AUTOMOTIVE STEERING SDN. BHD

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ABSTRACT

The manufacturing industries especially in an automotive manufacturing industry has gone through significant changes in last decade where the competition has increased dramatically. So, good maintenance is fundamental for productive manufacturing system by implementing Total Productive Maintenance (TPM) as an alternative approach for the equipment maintenance in order to achieve zero breakdowns and zero defect. By TPM approach, it able to keep the current plant and equipment at its higher productive level through cooperation of all areas of organization. In order to ensure the effectiveness of the TPM implementation, the overall equipment effectiveness is a core element as a tool to measure as well as to improve the productivity of manufacturing organization. The aim of this report is to study an approach of Total Production Maintenance by implementing TPM 4 Pillar Model to improve Overall Equipment Efficiency (OEE) in Robert Bosch Automotive Steering Sdn. Bhd. In this study one machine has been selected as a case study to identify and analyse the implementation of TPM using TPM 4 Pillars Model to ensure that machine always in optimum condition and ready for operation. This study will involve in identification of main problem that need to be eliminated, effectiveness of implementation of autonomous maintenance and planned maintenance to reduce unplanned breakdown as well as seek any opportunities of improvement of that machine and targeting to exceed the target set of OEE which is 97.5%. 3 months breakdown and OEE data have been collected for further analysis and come up with the summary of finding to ensure that implementation of TPM 4 Pillars Model is success for this plant.

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ABSTRAK

Dalam beberapa dekad lepas, industri pembuatan terutamanya di dalam bidang automotif telah mengalami perubahan yang drastik dimana persaingan telah berlaku dengan begitu dramatik. Oleh itu, penyelenggaraan yang baik adalah asas kepada sistem pengeluaran yang produktif dengan pelaksanaan TPM sebagai pendekatan alternatif untuk penyelenggaraan peralatan bagi mencapai matlamat kerosakan dan kecacatan sifar. Melalui pendekatan TPM, ianya mampu mengekalkan mesin dan juga peralatan dalam tahap produktif yang lebih tinggi melalui kerjasama semua pihak di dalam organisasi. Selain itu, di dalam memastikan perlaksanaan TPM yang efektif, OEE adalah teras utama sebagai alat untuk mengukur, dan pada masa yang sama memperbaiki produktiviti di dalam organisasi pembuatan. Laporan ini dihasilkan bertujuan untuk mengkaji pendekatan TPM dengan melaksanakan model ‘TPM 4 Pillars’ untuk memperbaiki OEE di Robert Bosch Automotive Steering Sdn. Bhd. Di dalam laporan ini, sebuah mesin telah dipilih sebagai bahan kajian kes untuk mengenalpasti dan menganalisis perlaksanaan TPM menggunakan ‘TPM 4 Pillars’ model untuk memastikan mesin tersebut sentiasa didalam keadaan yang optimum dan bersedia untuk beroperasi. Kajian in akan melibatkan pengenalpastian masalah utama yang perlu dihapuskan, keberkesanan perlaksanaan penyelenggaraan autonomi dan peyelenggaraa terancang untuk mengurangkan kerosakan tidak terancang dan pada masa yang sama melihat sebarang peluang untuk penambahbaikan terhadap mesin tersebut dan juga mencapai target OEE melebihi 97.5%. Data kerosakan dan OEE untuk tiga bulan berturutan bermula dari Jun, Julai dan Ogos telah diambil untuk kajian lebih mendalam bagi mendapatkan dapatan ringkasan penemuan dalam kajian untuk memastikan perlaksanaan ‘TPM 4 Pillars Model” di kilang ini berjaya.

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21 April 2020

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION OF THE STUDY

In this past few decades, the manufacturing and service have experienced an exceptional degree of change which made it become more challenging and complicated. Moreover, in the recent years, they are tremendous developments have taken place in the maintenance management of the production system to ensure the reduction of wastage in term of energy and resources can be achieved. Through the study, we can find the main reasons of this enhancement of this maintenance management in the production side which is to reduce any wastage in this area. Besides, neither big production nor small scale production of company, they are realized that good maintenance management will helps them to optimize their productivity as well as increase their production efficiency and effectiveness. Maintenance as the mainly process of maintaining a company's assets and resources which the ultimate purpose here is to ensure that production proceeds efficiently and that resources are used effectively (Chan, 2019). In general, most cases of business process, maintenance can be considered as one of integral part as it provides an additional value to the machines and equipment. So, it quite vital for any organization to introduce a maintenance management system to improve its quality and productivity.

Based on the above consideration, I have chosen this project to study more further about maintenance management. Scope of the project is more on Total Productive Maintenance (TPM) where 1 will study about how this TPM approach applicable to improve Overall Equipment Efficiency (OEE). Main business of Robert Bosch Automotive Steering Sdn. Bhd is producing steering gear unit with the annual volume of the production is around 2.2 million. This plant has two departments of production which are manufacturing and assembly department. Manufacturing department function is to produce completed gearing and hardening rack and pinion whereas assembly department function to produce completed steering gear unit. So, to ensure that the production operation efficiently and effectively, they need to ensure that there is no disruption due to equipment breakdown, stoppage and failure. Moreover, the manufacturing sector has been experiencing tremendous challenges in ensuring all products are delivered to customers on time as well as the current business environment and pressures from various parties for instances customers, suppliers, government and so forth have put manufacturing sectors under severe pressure (Amit Kumar Gupta, Dr.R. K. Garg, 2012). Here, TPM approach playing a big role to counter all of the overcome issues in the manufacturing sectors especially in Robert Bosch Automotive Steering.

According to Vorne (2019), Total Productive Maintenance (TPM) is a holistic approach to equipment maintenance that strives to achieve perfect production where there is no breakdowns, no small stops or slow running,no defects as well as other addition values in term of safe working environment which is no accidents. Besides, according to Robert Bosch Group approach, TPM is define as increases overall equipment effectiveness by eliminating sources of loss and by actively involving all employees, as well as machinery or equipment breakdowns and defects are indetified systematically, remedied and sustainably eleminated. This approach is emphasizing proactive and preventative maintenance to maximize the operational efficiency of equipment as well as creating a shared responsibility for equipment that encourages greater involvement by plant floor workers which is operators. TPM was introduced to achieve that following abjectives in Table 1 with two point of view which are from theprevious research and Robert Bosch Group itself.

Table 1 TPM Objectives

TPM Objectives (Venkatesh, 2015)	TPM Objectives (Robert Bosch Group)
• To avoid wastage in a quickly changing economic environment. • To produce goods without reducing producing quality. • To reduce cost. • To produce a low batch quantity at the earliest possible time.	To eliminate of loss sources of • Constuction defect on machines and equipment. • Unplanned machine breakdown. • Technical faults as well as small defects. • Quality defect caused by equipment (rejects, repairs)

• To ensure goods send to the customers must be non-defectives.	• Unplanned repairs.

TPM is actually originally came from innovative Japanese concept where it canbe traced back to 1941 when the maintenance was introduced in Japan. This traditional approach of TPM consist of 5S as a foundation as refer to figure 1 below.

Figure 1 TPM 5S Foundation (Vorne, 2019)

Based on the Figure 1 above, the goal of 5S is to create a work environment that is cleanand well-organized which consists of five elements as shown in Figure 2

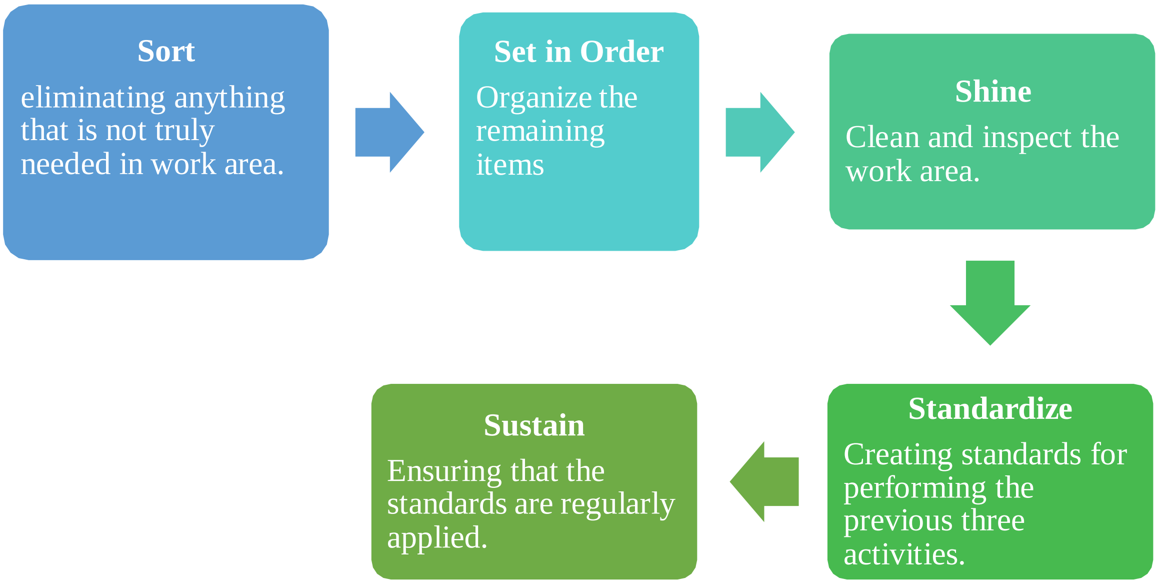


Figure 2 Five Elements in TPM 5S

1.2 RESEARCH BACKGROUND

This research will discuss about the approach of TPM Four Pillars that has beenimplemented in Robert Bosch Automotive Steering. This approach has been implemented and standardized to all plants under Robert Bosch Group. This company are maintaining high business standard by implementing Q Basic Value Stream and TPM Four Pillars is one of that Q Basic.

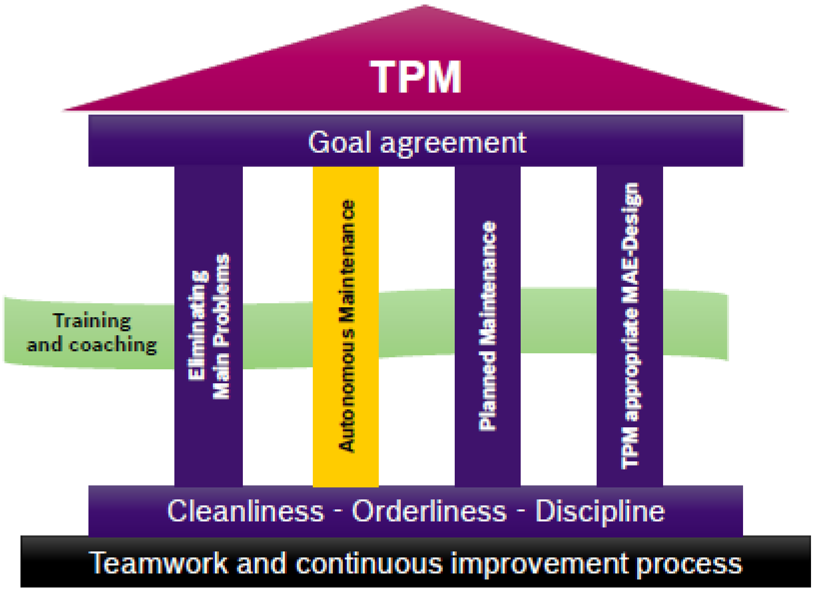


Figure 3 TPM 4 Pillars (Robert Bosch Intranet)

Figure 3 above show TPM 4 Pillar foundation that being as TPM approach that used in RBAS plant. This TPM approach 4 Pillars focusing on

I. Eliminating Main Problems
   - Here all downtimes of machinery and equipment are recorded and evaluated, causes are analysed and measures are defined. The implemented measures are used to derive and establish standards. The effectiveness of these measures must be checked and if necessary, further optimizations must be carried out.

II. Autonomous Maintenance (Process owner or operator)
   - After qualified training, operators take on responsibility for performing routine actions according to the maintenance schedule. Unplanned breakdowns necessitating minor repairs can be handled autonomously or a first qualified assessment can be made toward maintenance.

III. Planned Maintenance (Support Process or Maintenance Personnel)
   - Further maintenance measures requiring special expertise or appropriate tooling are carried out by maintenance according to the maintenance schedule.

IV. TPM Approach MAE-Design
   - Application of the experiences made in pillars 1-3 when re-planning machines and equipment in order to ensure higher availability of the equipment even during the run-up phase.

Scope of the study will be based on the these TPM 4 Pillars and one machine will be choosing as subject for this case study which is Maegerle Gear Grinding machine to find out the effectiveness of TPM 4 Pillars approach in improving OEE of the production. Regarding to TPM 4 Pillars approach, there are several causes of unplanned machine breakdowns as shown in Figure 4. So, this study will identify how to eliminate the causes of unplanned machine breakdown by focusing in TPM approach using the TPM 4 Pillars fundamental.

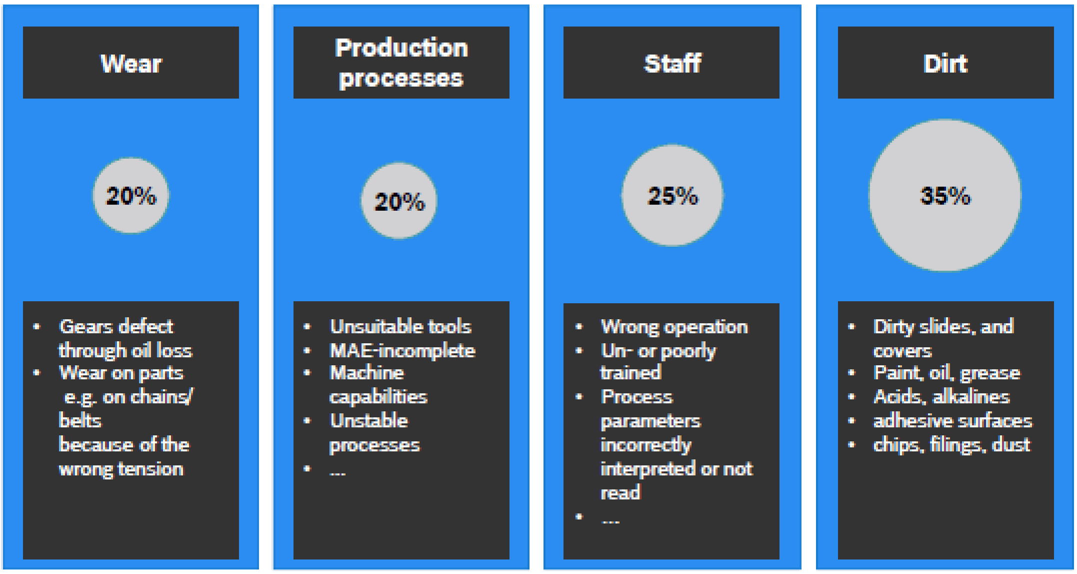
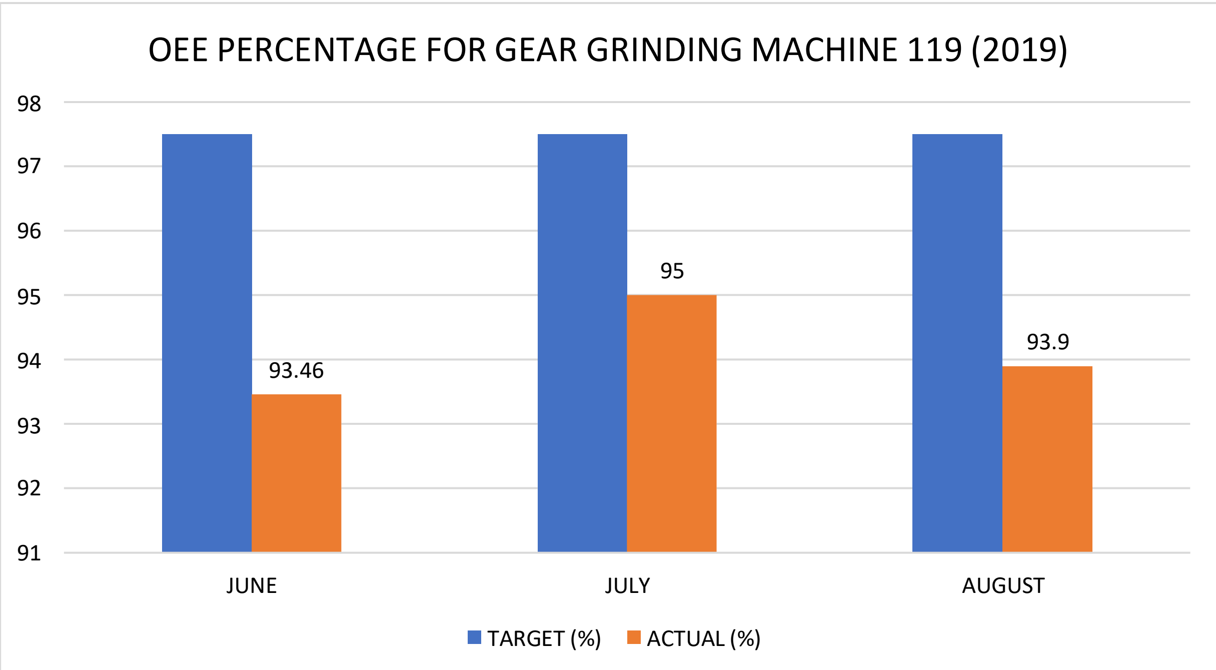


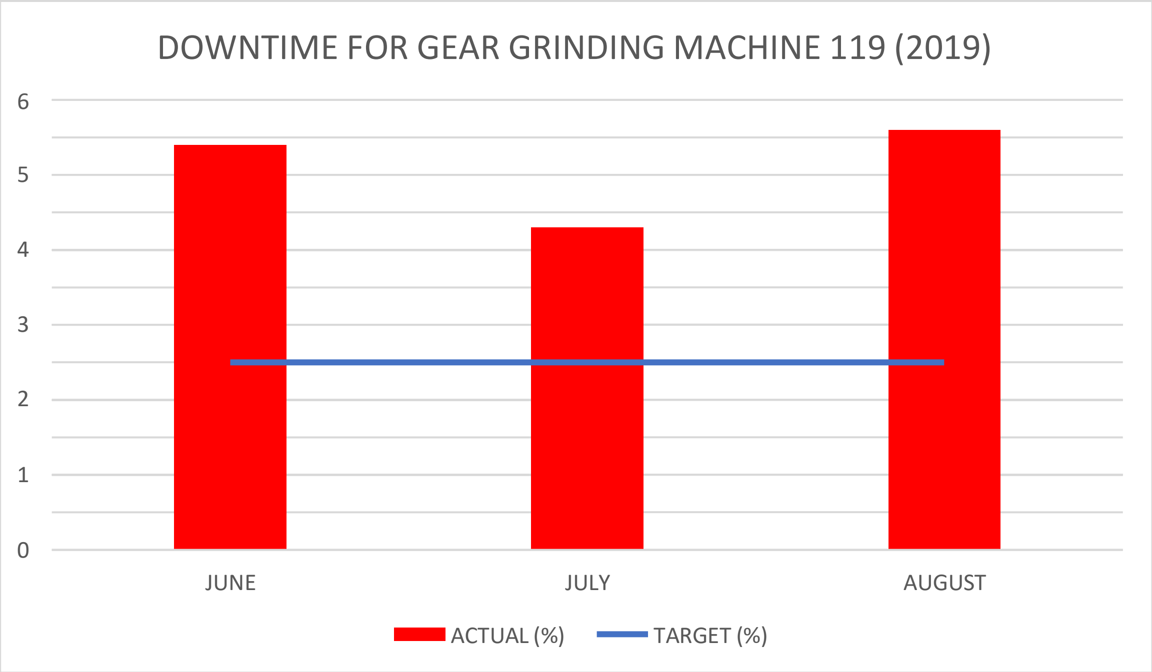
Figure 4 Causes of Unplanned Machine Breakdown (Robert Bosch Intranet)

1.3 PROBLEM STATEMENT



Graph 1 OEE Data June Until August For Gear Grinding Machine 119

Graph 1 above shows the data of OEE for Maegerle Gear Grinding machinewhich just achieving in average 94 % which below than company organizational manufacturing target set which are 97.5%. So, the data showed the Overall Equipment Effectiveness (OEE) value lower compared to the organizational manufacturing target. This data show that the machines were not utilized effectively and hence production rate and volume was affected. More over this machine is a crucial machine which is produce completed rack gear for production line. So, it will be hindering the line to operate efficiently.



Graph 2 Downtime Data for Gear Grinding Machine 119

Target downtime for Maegerle Gear Grinding Machine 119 is 2.5% from Production Operation Time (POT). But graph 2 above shows that actual downtime is higher than the target which will affect to the machine availability as well as reduce the Overall Efficiency Equipment (OEE) percentage in term of machine availability.

1.4 RESEARCH OBJECTIVES

This study focused on achieving the following objectives using 4 Pillar TPMmethodology:

- To analyse and eliminate loss sources due to unplanned machine breakdown.
- To analyse planned maintenance implementation and performance.
- To identify and analyse improvement opportunities through TPM 4 Pillar approach.
- To execute machine performance and achieving machine OEE target.
- To verify the equipment-related knowledge and experience among operators (autonomous maintenance)

1.5 SIGNIFICANCE OF THE RESEARCH

Study and research are something that crucial for organization specifically and country in general in order to help on giving the right and relevant solution for the specific problem outcome through the brainstorming and analysis. Furthermore, we ableto take corrective action to overcome the problem happened as well as might be happened in the future through the study and research. For instance, implementation ofTPM in the manufacturing side, there are many companies either small or large-scale companies that ignore about TPM implementation due to no awareness about itsbenefits. They just only focusing on the output volume and profit and think that TPM implementation just only wasting their money and time in term of investing for buyingspare part inventory, stopping the production operation for planned TPM activities which for them are better just focusing on the output to meet the customer demand. Hopefully this study will give at least little of awareness to the organization for them toimplement the TPM approach which proven able to give more in term of monetary or non-monetary value for their companies. TPM implementation is not only enhance their production efficiency and effectiveness, it also will help in cost saving in term of repaircost and spare part as well as enhance the employee satisfaction and safety.

1.6 DEFINITION OF TERMS

1.6.1 OEE

Overall Efficiency Equipment (OEE) is the ratio of Fully Productive Time and Planned Production Time

1.6.2 TPM

Total Productive Maintenance (TPM) is a maintenance philosophy aimed at eliminating production losses due to equipment status or in other words, keeping equipment in a position to produce at maximum capacity, the expected quality products, with no unscheduled stops.

1.6.2 MACHINE AVAILABILITY

The actual time that the machine or system is capable of production as a percent of total planned production time.

1.6.3 POT

POT stand for Production Operation Time which refer to the planned time of production operation after deduction of break time and change over time.

1.6.4 CYCLE TIME

Refer to the time required or spent to covert raw materials into finished goods.

CHAPTER 2

LITERATURE REVIEW

Prove had reveal by the literature that there are many challenges that facing by the manufacturing organizations worldwide to achieve successful operation in today's competitive environment where both effective and efficient maintenance practices and procedures must be as a support to ensure the organization is success in modern manufacturing. This modern equipment management has begun with preventive maintenance and evolved into productive maintenance. These two approaches originated form US and abbreviated as PM (Preventive Maintenance which all the activities are focusing in the maintenance department. However, when we talk about TPM (Total Productive Maintenance), all the activities are involving all participants. Manu Dogra, V M Subramanya Sharma, Anish Sachdeva, J. S. Dureja (2011), has emphasized on the fact that, TPM is promoted through astructure of overlapping small groups where in this system leaders of small group at each organizational level are members of small group at the next high level. Besides, there are only two success factors in a manufacturing organization and considered which are human-oriented and process oriented (One Yoon Seng,Muhamad Jantan,T. Ramayah, N/A). compare to previous approach where the organization were carrying out breakdown maintenance as and when the machinery went out of order, the maintenance crew was called to attend and put back it to normal for the production.

Over the past two decades, manufacturing organization have used different approaches to improve maintenance effectiveness which one of that approach is to implement and develop a TPM strategy to improve the performance of maintenance activities. According to Moore, R. (1997), TPM implementation methodology provides organizations with a guide to fundamentally transform their shop floor by integrating culture, process and technology. However, top management leadership and involvement, traditional maintenance practices and holistic TPM implementation innitiatives are significant contributions of TPM implementation success factors (I.P.S. Ahuja, J.S. Khamba, 2008). TPM seeks to integrate the organization to recognize, liberate and utilize its own potential and skills. Moreover, according to I.P.S. Ahuja, J.S. Khamba (2008), TPM is the proven manufaturing strategy that has been successfully employed globally for the last three decades for achieving the organizational objectives of achieving core competence in the competitive environment. As per discussed before, the concept of TPM originated in Japan's manufacturing industires by aiming to eliminate production loses due to limitations in the JIT process for production operations.

Nakajima who vice chairman of the Japan Institue of Plant Engineer (JUPE) is the major contributor of TPM has defined TPM as an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day to day activities involving workforce. First developed in Japan, TPM is team based productive maintenance and involves every level and fucntion in the organization from top executives to the production floor operators (Amit Kumar Gupta, Dr. R. K. Garg, 2012). According to Abhishek Jain, Rajbir Bhatti, Harwinder Singh Deep, Shiv kumar Sharma (2012), there are several types of maintenance which are:

- Breakdown maintenance which refer to the maintenance strategy where repair is done after the equipment or machine failure or stoppage or upon occurrence of severe performance decline. Disadvantages of this uplanned stoppage are excessive damage, spareparts problems, high repair costs, excessive waiting and maintenance time and high trouble shooting problems.
- Predictive maintenance which refer to as condition based maintenance by initiating in response to specific equipment condition or performance deterioration. Deployment of diagnostic technique to measure the physical condition of the equipment such as noise, vibration, temperature, lubrication and corrosion.
- Preventive maintenance which is a kind of physical check up of the equipment breakdown and prolong equipment life span. It comprise of maintenance activities that are undertaken after specified period of time or amount of machine use.
- Corrective maintenance which this concecpt of this system is to prevent equipment failure is further expanded to be applied to the improvement of equipment so that the equipment failure can be eliminated and enhance the maintainability.
- Maintenance prevention which start in the design satge of the new machine or equipment development to ensure the reliable equipment, easy to maintain, user friendly which able for the end user (operator) to run or adjust.
- Productive Maintenance which the aim is to increase the productivity of an enterprice by reducing the total cost of the equipment over the entire life cycle of the machine or equipment. It involving all the maintenance activities for the instance preventive maintenance, corrective maintenance and others.

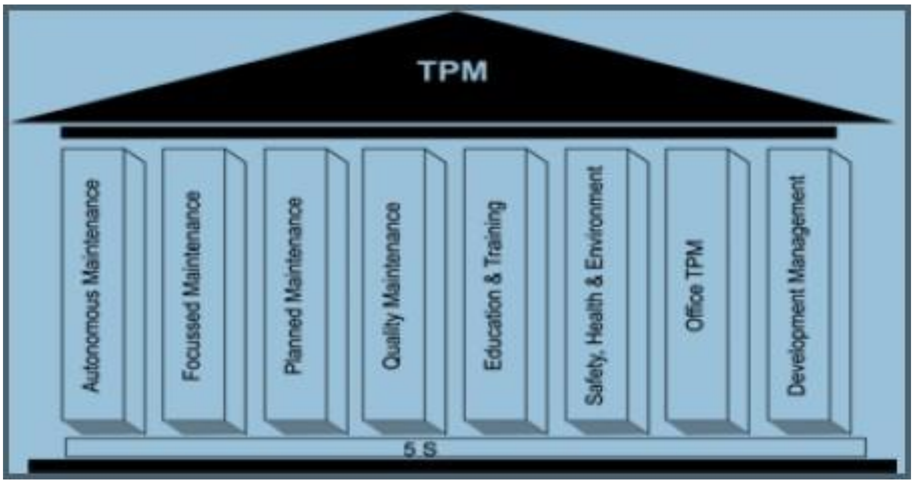


Figure 5 TPM Pillars (Harsha G. Hegde, N. S. Mahesh, Kishan Doss, 2009)

Previously in Chapter 1, we had discussed in general about the traditional TPM which have eight pillars of it instead of the TPM 4 Pillars. In detailed, this eight pillars of traditional TPM are mostly focused on proactive and preventive technique for improving equipment reliability which are (Vorne Industries Inc, 2011)

2. Autonomous maintenance
    - Places responsibility for routine maintenance for instance cleaning, lubricating and inspection, in the hands of operators by
        - Gives operators greater “ownership” of their equipment.
        - Increases operators’ knowledge of their equipment.
        - Ensures equipment is well-cleaned and lubricated.
        - Identifies emergent issues before they become failures.
        - Free maintenance personnel for higher-level tasks.

3. Planned maintenance
    - Schedules maintenance tasks based on predicted and measured failure rates.
        - Significantly reduces instances of unplanned stop time.
        - Enables most maintenance to be planned for times when equipment is not scheduled for production.
        - Reduce inventory through better control of wear-prone and failure-prone parts.

4. Quality maintenance
    - Design error detection and prevention into production processes. Apply Root Cause Analysis to eliminate recurring sources of quality defects.
        - ➢ Specifically targets quality issues with improvement projects focused on removing root sources of defect.
        - ➢ Reduces number of defects.
        - ➢ Reduce cost by catching defect early.
5. Focused improvement
    - Have small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation.
        - ➢ Recurring problems are identified and resolved by cross-functional teams.
        - ➢ Combines the collective talents of a company to create an engine for continuous improvement.
6. Early equipment management
    - Direct practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment.
        - ➢ New equipment reaches planned performance levels much faster due to fewer start-up issues.
        - ➢ Maintenance is simpler and more robust due to practical review and employee involvement prior to installation.
7. Training and education
    - Fill in knowledge gaps necessary to achieve TPM goals. Applies to operators, maintenance personnel and managers.
        - ➢ Operators develop skills to routinely maintain equipment and identify emerging problems.
        - ➢ Maintenance personnel learn techniques for proactive and preventive maintenance.
        - ➢ Managers are trained on TPM principles as well as on employee coaching and development.

8. Safety, health, environment
    - Maintain a safe and healthy working environment.
        - Eliminates potential health and safety risks, resulting in a safer workplace.
        - Specifically targets the goal of an accident-free workplace.
9. TPM in Administration
    - Apply TPM techniques to administrative functions.
        - Extends TPM benefits beyond the plant floor by addressing waste in administrative functions.
        - Supports production through improved administrative operations.

Pillar no.4 state about focused improvement or kaizen which is all activities that maximize the overall effectiveness of equipment, processes and plants through elimination of losses. This process is including identification, quantification and elimination of losses that affect productivity, quality, performance and other. Overall Equipment Efficiency (OEE) is a key metric of focused improvement where the focused improvement is characterized by a drive for zero losses. It means that, effort of continuous improvement is to eliminate any effectiveness losses. Measurement is an important requirement of continuous improvement processes (Amit Kumar Gupta, Dr. R. K. Garg, 2012). So, TPM can be defined in terms of overall equipment effectiveness (OEE), which in turn can be considered a combination of the operation maintenance, equipment management, and available resources. Besides, OEE measurement is an effective way of analysing the efficiency of a single machine or an integrated manufacturing system (Nakajima, 1988).

Overall Equipment Efficiency (OEE is comprised of six metrics that often referred as the hierarchy of metric which are (Raguram, 2014):

- Overall Equipment Efficiency (OEE) itself as a method of measuring the operational performance of a unit, in comparison to the desired performance.
- Total Effective Equipment Performance (TEEP) which measures the OEE set against time, in other words, 24 hours a day, over 365 days.
- Loading is part of the TEEP representing the amount of time that units are actually operational.

- Availability or uptime which is the time during which the equipment is available to operate.
- Performance which the speed at which a manufacturing unit operates as a percentage of the capacity of unit.
- Quality which the number of good or perfect items that are produced without any defect.

According to Nakajima (1988), the have six big equipment losses in general equipmentand plant as follows:

- Equipment failure or breakdown losses are categorized as time losses when productivity is reduced, and quality losses caused by defective products.
- Set up or adjustment time losses result from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirement of another item.
- Idling and minor stop losses occur when the production is interrupted by a temporary malfunction or when a machine is idling.
- Reduced speed losses refer to the difference between equipment design speed and actual operating speed.
- Reduced yield occurs during the early stage of production from machine start up stabilization.
- Quality defects and rework are losses in quality caused by malfunction production equipment.

The first two losses are known as downtime loss and are used to calculate availability of a machine. The third and fourth are speed losses that determine the performance efficiency and the final two losses are considered to be losses due to defects in the products. According to Venkatesh J (2005), OEE is measured in terms of these sic losses as per disccussed before, which are function of availability, performance rate and quality rate of the machine, production line or factory. Futhermore, it also able to increase the productivity, reduce the costs, shrinks the inventory, decrease the industrial accidents in production line as well as promote employee involvement (Suzuki, 1994). Use of the OEE indicator can be considered almost an evergreen within industries' practices (Ilaria Barletta, Jon Andersson, Bjorn Johansson, Gokam May, Marco Taisch, 2014). Based on the six losses which are as functions of availability rate, performance rate and quality rate of the machine or production line or factory that constitute

the three sub indicators which are equipment, effectiveness loss and oee factors as refere Figure 3 below (Ilaria Barletta, Jon Andersson, Bjorn Johansson, Gokam May, Marco Taisch, 2014).

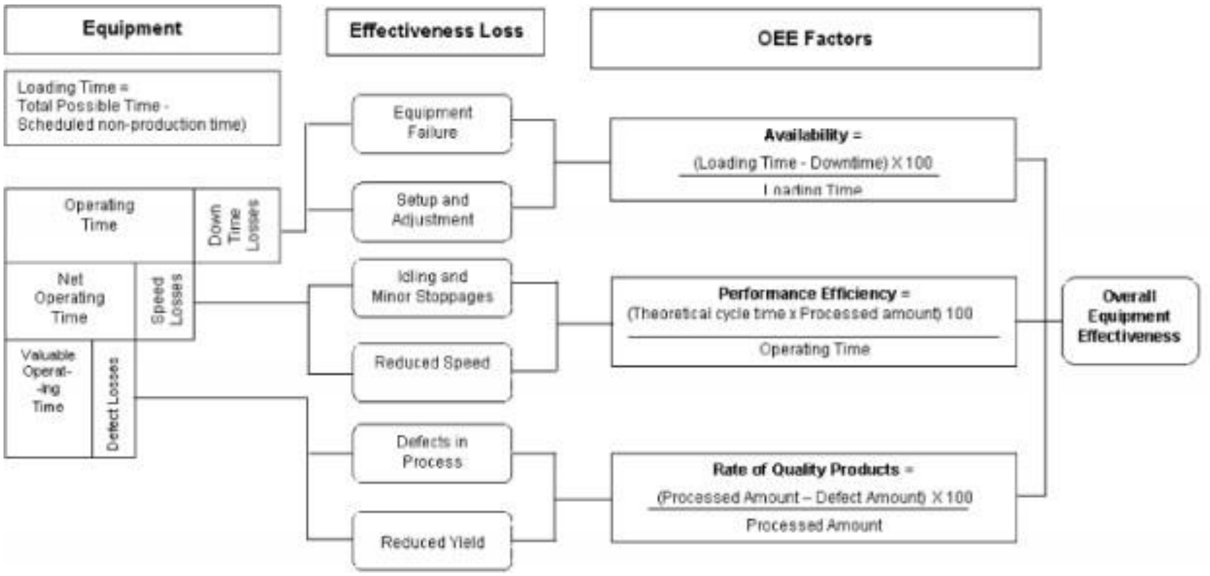


Figure 6 Overall Equipment Effectiveness Calculation and Losses

As refer to Figure 6, six major losses able to overcome by the Focused Equipment Improvement (FEI) and Autonomous Maintenance (AM) activities of TPM. These activities will be more effective if carried in small groups or teams which are more active, dynamic, self-motivated and also increasing one's self confidence of participants (Hemant Singh Rajput, Pratesh Jayaswal, 2012). But there are several cautions for using OEE indicator based on the wide spread and diverse understanding and use of OEE (Kalpande, 2014):

- The calculation OEE percentage is not intended for use as a corporate or plant level measure because it is a rough measure of selected equipment effectivenessonly.
- OEE calculation not valid for comparing or benchmarking different assets, equipment or processes because it is relative indicator of a specific single asset effectiveness compared to itself over a period of time. But it can be used to compare the same equipment, situation and process.
- OEE does not measure maintenance effectiveness because there are some of lossfactors are outside the direct control of maintenance team.
- Optimum level of OEE mostly depend on the capability or capacity of the asset, the business demands, and whether it is a constraint in the process flow.

In practice, OEE is calculated as the product of its three contributing factors which are:

$$OEE = Availability\ (A) \times Performance\ (P) \times Quality\ (Q) \times 100 \quad (1)$$

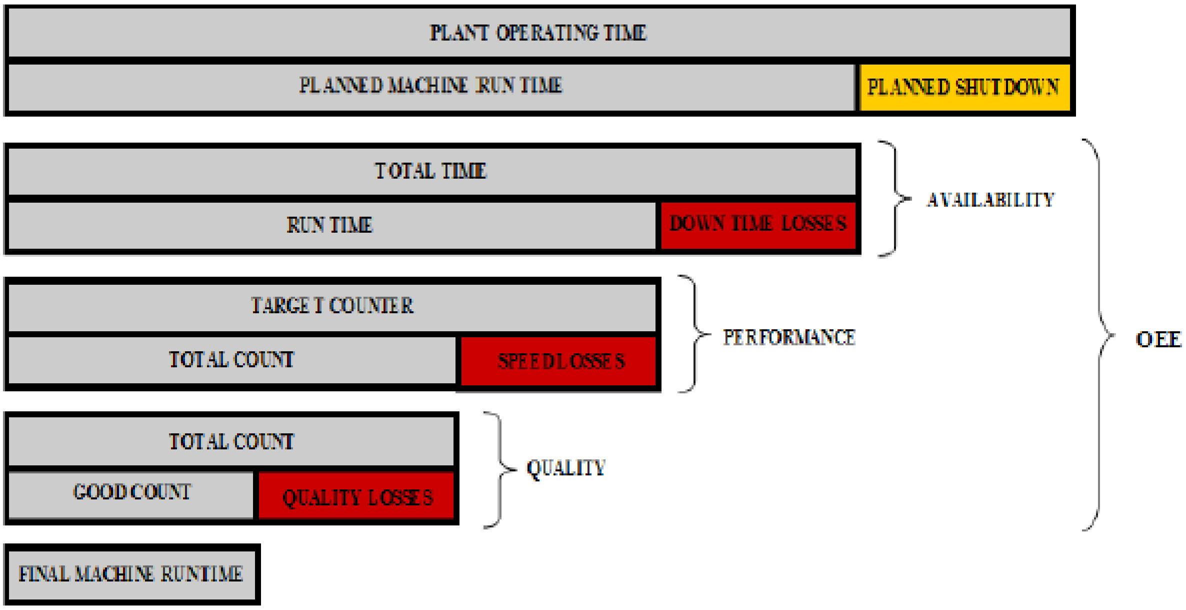
$$Availability\ (A) = \frac{Actual\ Run\ Time}{Planned\ Production\ Time} x100 \quad (2)$$

$$= \frac{Planned\ Production\ Time - Downtime}{Planned\ Production\ Time} x100 \quad (3)$$

$$Where\ Planned\ Production\ Time = Shift\ Time - Break\ Time \quad (4)$$

$$Performance\ (P) = \frac{Design\ Cycle\ Time \times Total\ Count}{Actual\ Run\ Time} x100 \quad (5)$$

$$Quality\ (Q) = \frac{Total\ Count - Reject\ Count}{Total\ Count} x100 \quad (6)$$



Refer to Figure 7, as per discussed, there the Overall Equipment Effectiveness is a major KPI (Key Performance Indicator) that accounts for three constituent elements which are (Kalpande, 2014)

- Availability which is the percentage of time that machines are available for scheduled production compared with the amount of time they were actually producing. Scheduled maintenance, planned downtime events, or equipment trials are not considered to be part of the time that machines are available for production. This allows a plant manager to readily identify whether machine downtime issues are part of a known calendar, or ifthere is a more serious problem.
- Performance which is the percentage of total parts produced on the machine to the production rate of machine. Performance compares the theorical machine rate with the number of items actually produced on a machine during its operating time. Performance allows a facility to compare availability downtime with efficiency. This can show

whether a specific line is having problems due to low output, or if the problem is excess downtime. In additional, if a machine has recurring efficiency issues, performance measurements can indicate problems with the machine itself, rather than an operator issue.

- Quality which is the percentage of items that pass the first quality inspection. This allows a plant manager to compare consistency between individual machines and in turn, allows for comparisons between different manufacturers, as well as machine, specifications, and even individual operators.

In TPM approach, key performance indicator (KPI) is very important in any organization as a performance measurement to identify the gap between current performance and desired performance which it provides an indication of progress leading to the closure of this gap. Key performance indicator actually provides general basic information that can be used in decision making for the management as well as for the employees where one of the important tools for the continuous improvement programs. Typical key performance indicator (KPI) for manufacturing and maintenance include of operational availability (OA), return on investment (ROI), operating cost, asset availability, Overall Equipment Effectiveness (OEE) and asset utilization (Dr Ramachandra, Prashanth, Dr. T. R. Srivinas, Raghavendra, 2016). To ensure the effectiveness of TPM approach, there are many critical successes to ensure it able to be successful. There are many literature discussions about the critical success factors of TPM among the scholars and experts and most of them emphasizing on the factors of the commitment and involvement of management, the promotional organization and overall involvement. The most suit of critical success factors of TPM for this research are (Katila, 2000):

- Education and training on TPM.
- Establishment of maintenance system.
- Real supervision of senior directors.
- Lead-in education on TPM.
- Plan the promotional organizational of TPM properly.
- Establish thoughtful preventive maintenance policies.
- Good maintenance data record or maintenance status.
- Upgrade in maintenance management technologies.

CHAPTER 3

METHODOLOGY

3.1 DESIGN OF THE EXPERIMENT

Total Productive Maintenance (TPM) stands for autonomous, planned and preventive maintenance of machinery and equipment. Its objective is to ensure productquality and delivery capability as well as the availability of machinery and systems. A comprehensive system for service or cleaning, inspection, and maintenance guaranteestrouble-free, high quality, and safe operation. These are preventive measures, which are carried out by trained personnel in accordance with specified standards for instance location, interval and activities. Special attention must be taken to avoid contamination through cleaning schedule. Unusual contamination or repeated damage in machinery and setup elements must be consistently analysed, understood and resolved.

This research design will be focusing on the TPM 4 Pillars approach that been implemented in all plants under Robert Bosch Group over the world. This approach hasbeen simplified from the traditional TPM 8 Pillars to TPM 4 Pillars. There are 3 principles of this TPM which are cleanliness, orderliness and discipline and focusing toward the teamwork and continuous improvement process.

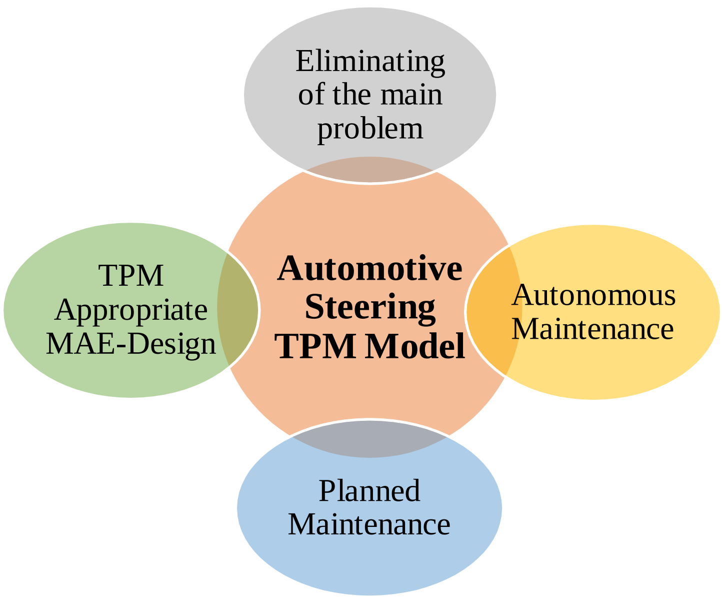


Figure 8 Automotive Steering TPM Model

Figure 8 show the Automotive Steering TPM Model which focusing in 4 Pillars of the TPM which are

I. Elimination of the main problem is the first pillar in TPM 4 Pillars which is the crucial process in the TPM. During this activity, main problem related to the equipment failures are identified and improvement goals are set in. This activity is called as focused kaizen where the cross-functional teams (production and maintenance) work together to come up with the root cause of the problems and apply solutions targeting continuous improvement. Identification of the main problem can be defined in the downtime summary by find out the repeated breakdown issues or highest downtime recorded and find out the root cause of that issues and the way how to tackle that issue from happened in the future. By eliminating the main problem, it will increase the machine availability and performance which affect to the production efficiency and effectiveness. Table 2 shows the following goal agreement in the first pillar.

Table 2 Goal Agreement of First Pillar

Eliminating of The Main Problem Goal Agreement
• Recording sources of losses and identifying core problems, • Derive and define fixed standards, • Define and implement TPM measures, • Root cause analysis, • Record loss sources and determine main problems.

II. Autonomous maintenance is one of the pillars to support TPM. It functions to detect early warning before machine breakdown. Here, operators carry out responsibility for performing routine actions according to the maintenance schedule and record abnormalities that they found in "Fuguai Tag" and highlight to maintenance personnel. This requires appropriate qualification with consideration of the requirements in terms of health, safety, and the environment that apply to these workplaces or systems. To ensure the effectiveness, the production personnel are responsible that the operators are doing the autonomous maintenance. This pillar includes the following activities in Figure 9 below

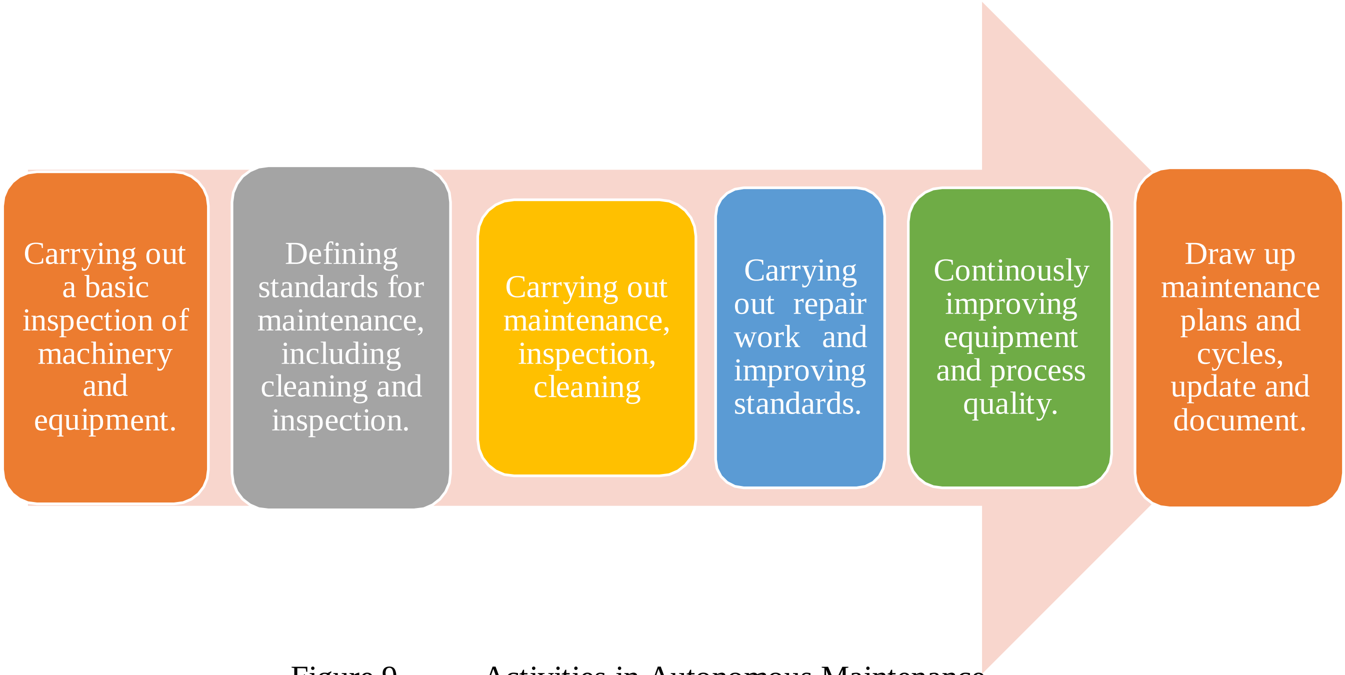


Figure 9 Activities in Autonomous Maintenance

III. Planned maintenance is a proactive approach to maintenance in which maintenance work is scheduled to take place on a regular basis. Here, type of work to be done and the frequency of the planned maintenance activities are based on the equipment being maintained and the environment in which it is operating. Maximizing the equipment or machine performance by keeping equipment running safely for as long as possible without that equipment deteriorating or having unplanned breakdown is the primary objective of planned maintenance. Preventive and predictive maintenance routine will be conducted based on the monitoring of machine's behaviour, the maintenance history, equipment or machine maker recommendation as well as the sensor data (depend on the equipment or machine type and technology). According to Robert Bosch TPM approach, planned activities for system maintenance are carried out by qualified specialist during teamwork. This pillar includes the following activities as shown in Figure 10.

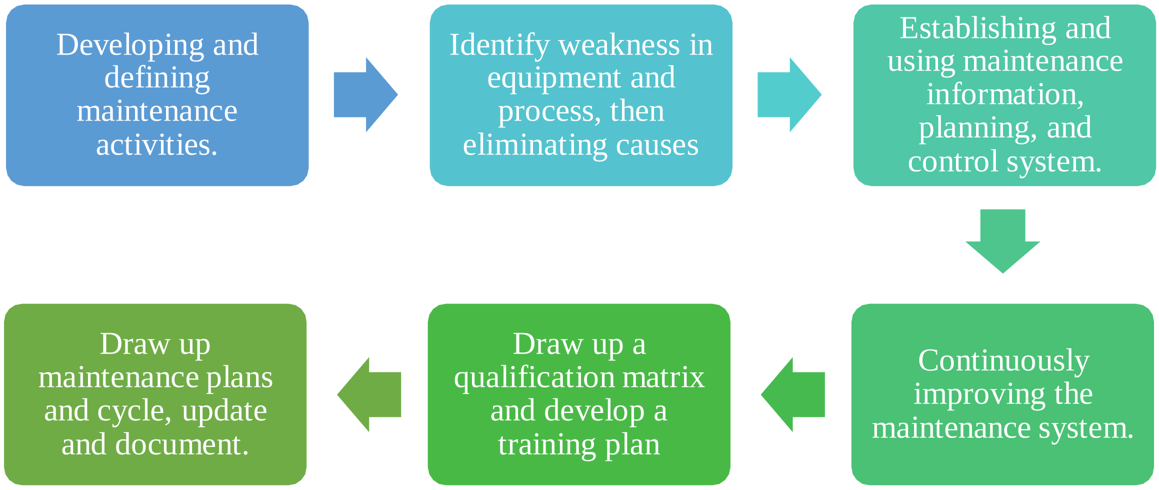


Figure 10 Activities in Planned Maintenance

IV. TPM appropriate MAE-Design. The following activities in this pillar shown in Figure 11 below.

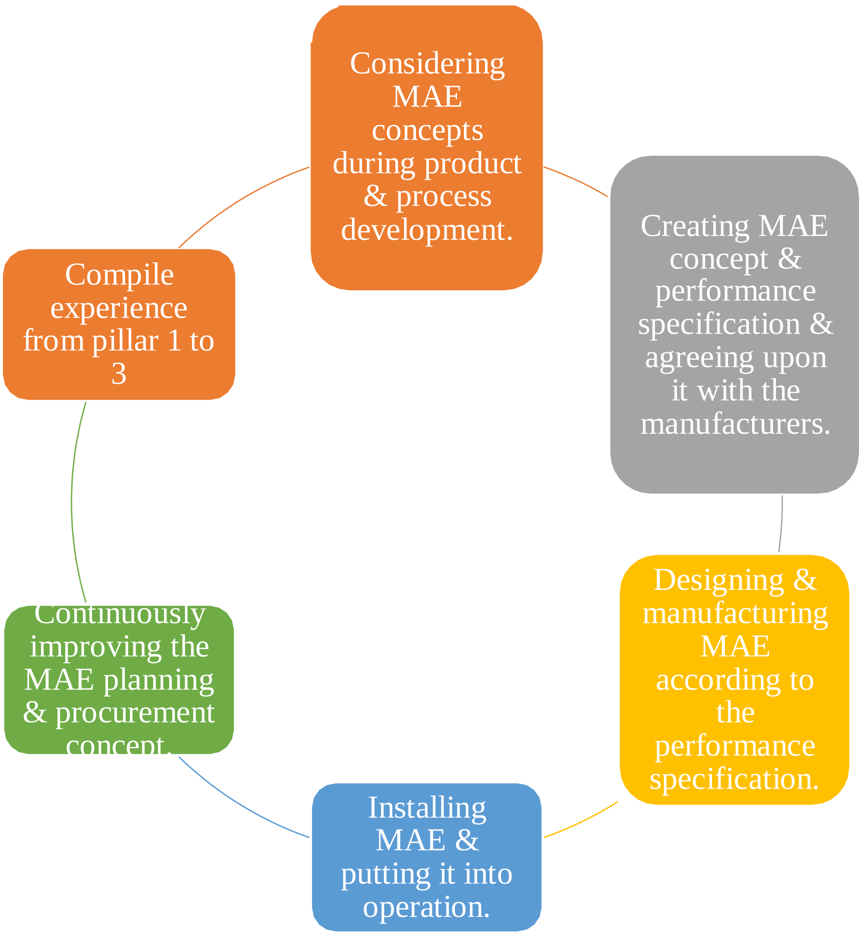


Figure 11 Activities in Pillar 4

3.2 CASE STUDY METHOD

For this research, qualitative research is used by using case study method as a data collection method. A case study is a research strategy and empirical inquiry that investigates a phenomenon within its real-life context (PressAcademia, 2018). Here Maegerle Gear Grinding Machine has been selected to be a subject for this case study. This machine is function to grind the raw material (rack) to make a gear as shown in Figure 12 below

Figure 12 Maegerle Gear Grinding Machine

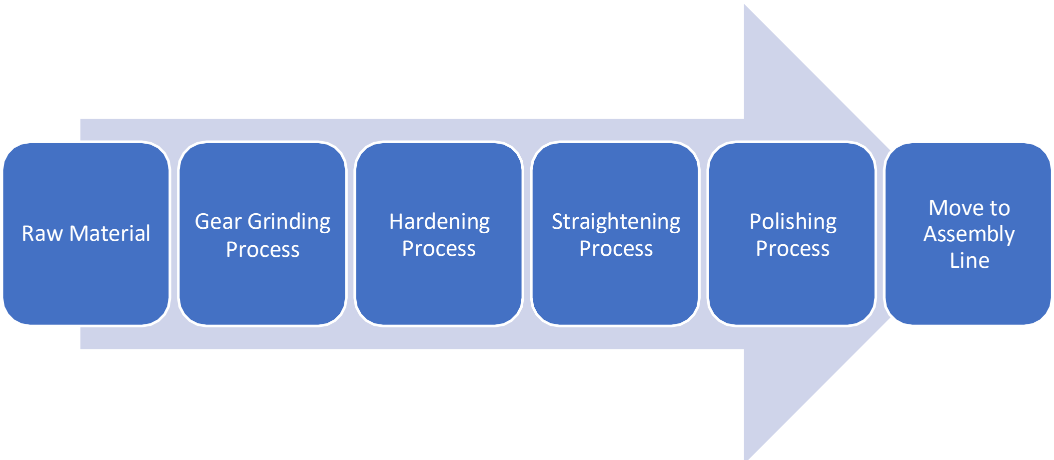


Figure 13 Rack Manufacturing Process Flow

Figure 13 show the rack manufacturing process flow which shows that gear grinding process is the first process in the process flow. So, this process is very crucial to ensure first piece flow process not interrupted which affected to other next of the process flow. To ensure these problems are not happened, all machines for gear grinding process in optimum availability condition and always able to support for the production demand. As per discussed before, the factor on which OEE depends are availability, performance and quality. So, to determine these factors, downtime, operation cycle time and total number of productions including rejected parts are needed to be known. For the data collection method, all data of the breakdowns are collected for the three consecutive months starting from June until August 2019. Data collection will be taking from the machine history record, monthly downtime summary and log book which recorded by the responsible shift maintenance personnel three shift every day in three consecutive months.

3.3 DMAIC ANALYSIS METHOD

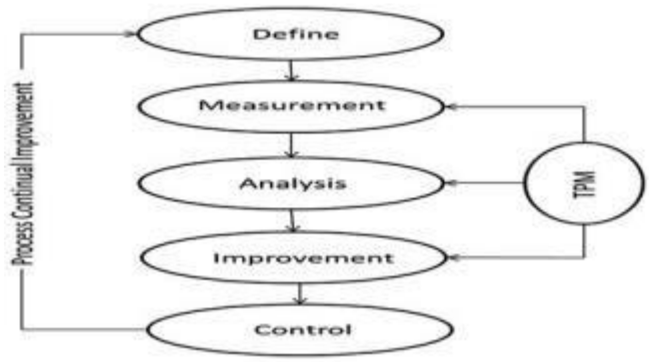


Figure 14 Methodology to Develop Integrated Model

To ensure that the effectiveness success of the TPM 4 Pillar, methodology to develop integrated model for process continual improvement is used as shown in Figure 14. There are 5 stages of with the detailed of key activities and tools of implementing the TPM oriented Lean Six Sigma (LSS) maintenance model in Table 3 (Barrak Alsubaie, Qingping Yang, 2016). Lean Six Sigma method model is a combination of lean methods and Six Sigma that using specific DMAIC processes to provide companies with better speed and lower variability to increase customer satisfaction. This approach has gained incresing recognition in process improvement practices.

Table 3 Key Activities and Tools of Implementing the TPM orientedLean Six Sigma (LSS) Maintenance Model

Stage	Activities	Tools
1. Define	• Build process improvement team. • Identify problem and weakness of the process • Select CTQ characteristics	• SIOPC (Supplier-input-process-output-customer) • Brainstorming • VOC (Voice of customer) • Pareto analysis
2. Measure	• Select measuring system • Gather information about key maintenance processes • Calculate the current OEE	• Process map • TPM (Total Productive Maintenance) • OEE (Overall Equipment Effectiveness)
3. Analyse	• Identify root causes of problems • Identify improvement opportunities	• Cause and effect diagram • 5W + 2H Analysis
4. Improvement	• Implementation of TPM • Propose solution and implement changes for maintenance improvement • Evaluate the process performance	• TPM (Total Productive Maintenance) • Poka-yoke • 5S

	• Calculate the new OEE	• TPM (Total Productive Maintenance)
5. Control	• Standardize the best practices • Integrate the changes to the organisation knowledge base • Continual improvement	• SPC (Statistical Process Control) • Performance management • Education and training

Besides, there are three main stages to the TPM Improvement Plan which are (EuroMotor Virtual College, N/A)

1. Stage 1: Condition where the present condition of the equipment is determined. Identification and planning of area for improvement produced for the future of the equipment.
2. Stage 2: Measurement where assessment and used the current effectiveness of the equipment as a baseline for measuring future improvement.
3. Stage 3: Improvement where improving the equipment effectiveness.
4.

3.3.1 DEFINE PHASE

This stage more focus on first pillar in TPM 4 Pillars which is to identifymain problem at the problem which need to be eliminated. Detailed process flowin define phase is shown in Figure 15 as well as machine process flow in Figure16 below. Expected outcome of this stage are to

- Understand process flow of the machine.
- Identify main problem by collecting three consecutive months of downtime summary.
- Calculation of MTTBF, MTTR & Availability data for analysis stage.

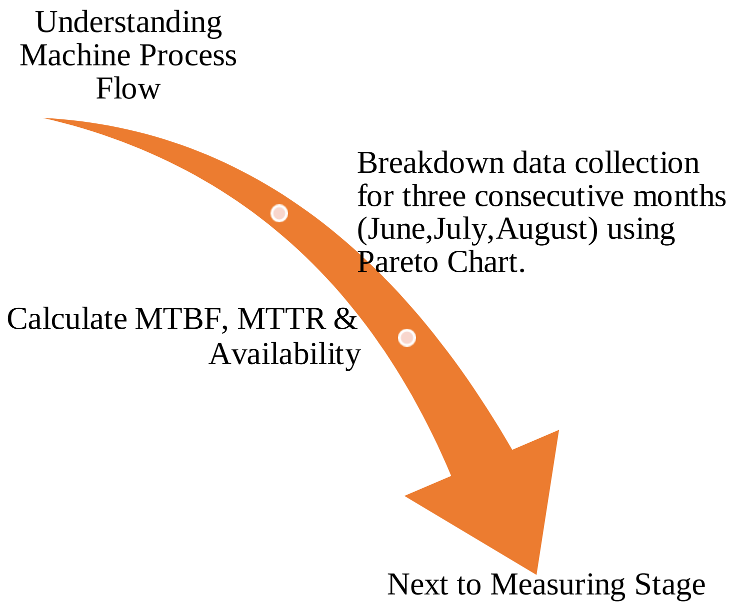


Figure 15 Define Stage Process Flow

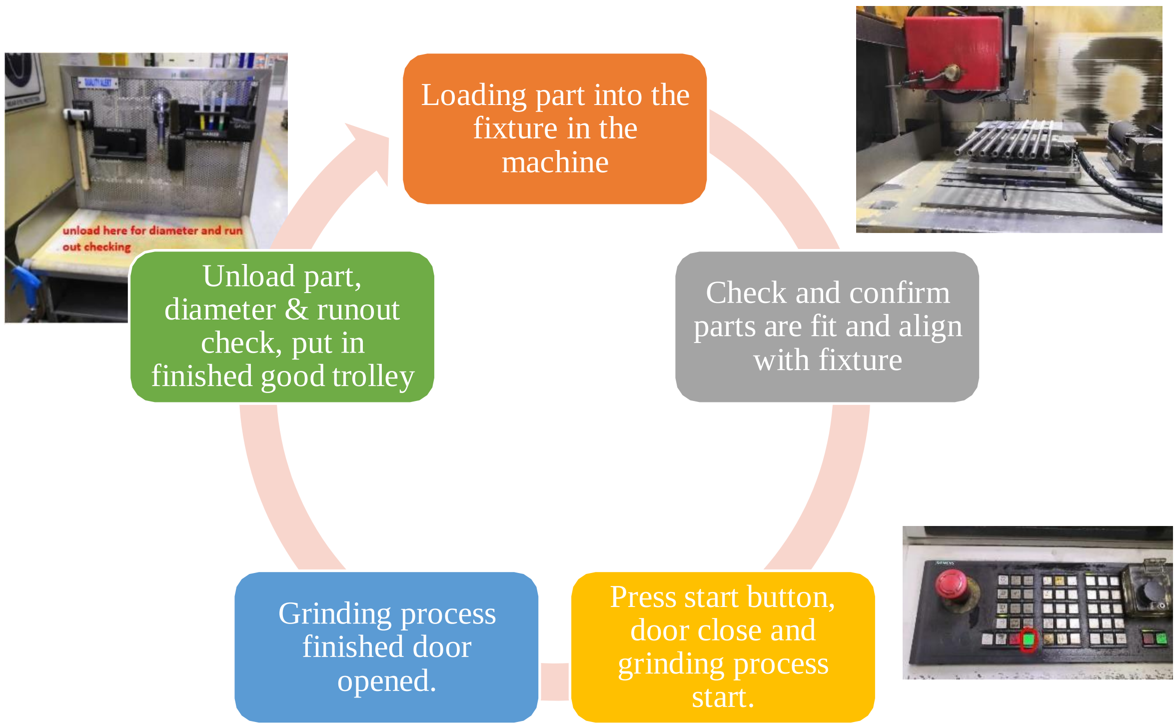
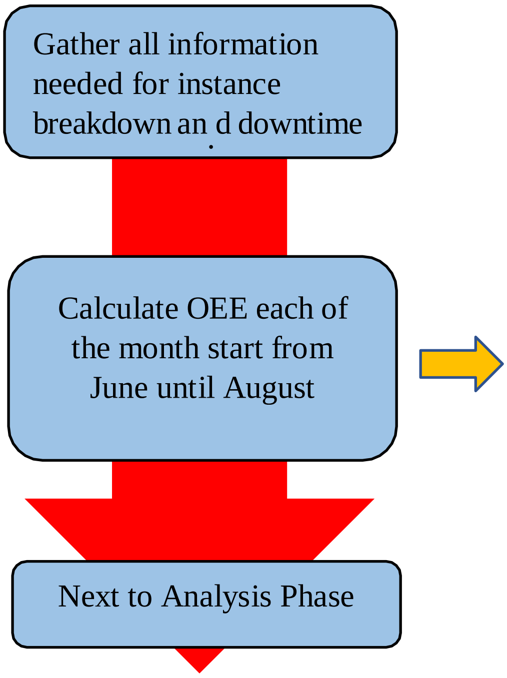


Figure 16 Machine Process Flow

3.3.2 MEASUREMENT PHASE

Figure 17 below shows the process flow in measurement stage to prioritize which factor in OEE that contribute to the low OEE achievement.



OEE Calculation Format		
A	Shift Time	0
B	Planned Downtime	0
C	Running Time (A-B)	0
D	Running Time Losses (C-D)	0
E	Operating Time (C -D)	0
F	Availability (E/C) x100	0.00
G	Output	0
H	Machine Speed (Number of Part/Hour))	0
I	Expected Output (H x E)	0
J	Efficiency (G x 100)/I	0.00
K	Rejection	0
L	Quality (G - K x 100)/G)	0.00
OEE = Availability x Efficiency x Quality		

Figure 17 Measurement Phase Process Flow

3.3.3 ANALYSIS PHASE

I. Step 1

- Identify the root cause of the problem through maintenance team discuss, observation and feedback from the production site (shift operators and supervisors.

II. Step 2

- Identify the improvement opportunities by maintenance team discussion and making cause and effect diagram (fishbone diagram to examination why something happened or might happen by organizing potential causes into smaller categories as shown in Figure 18. Related causes highlighted for further analysis. Analysing step also will be using 5W + 2H analysis method to find any opportunities for the continual improvement

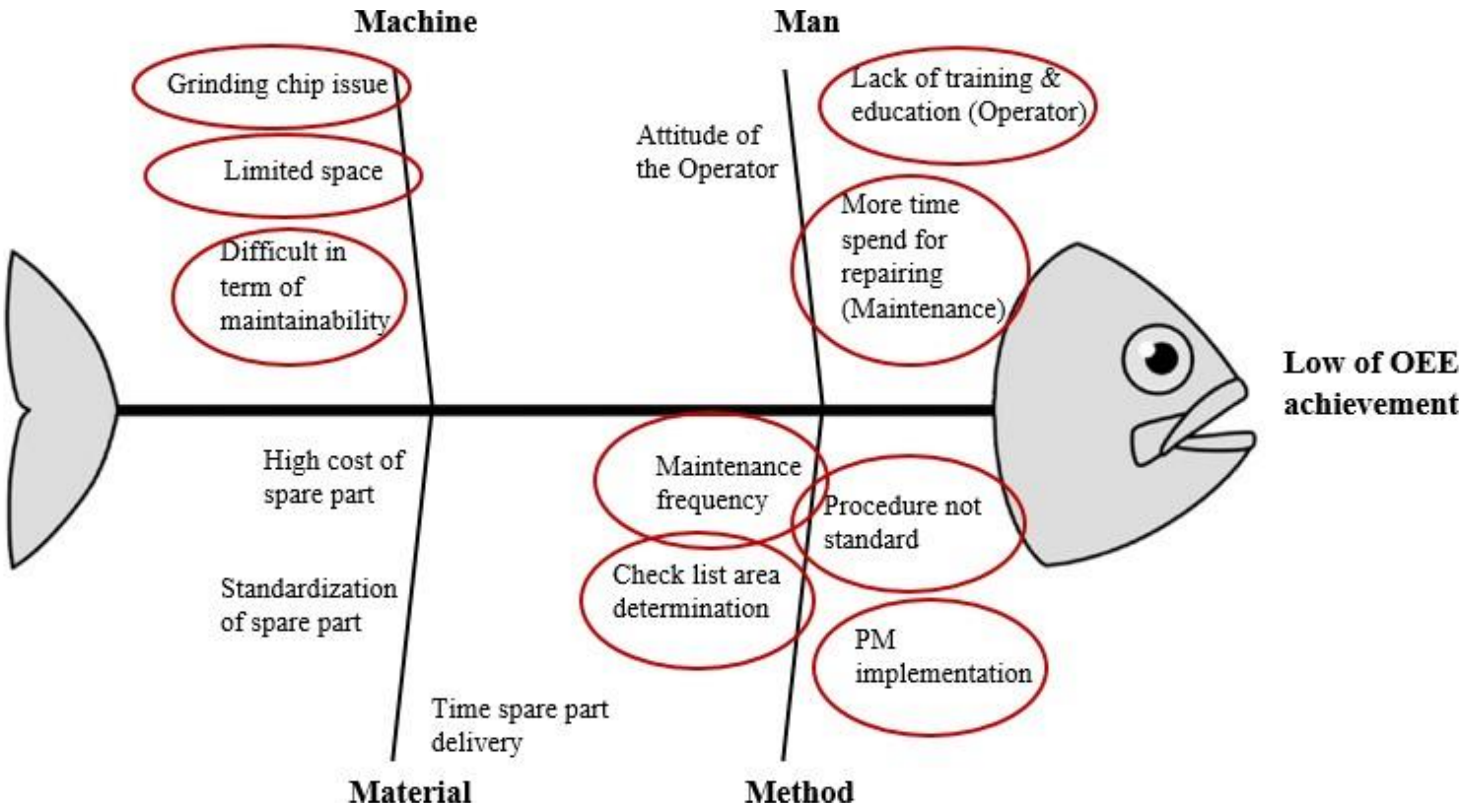


Figure 18 Fishbone Diagram Analysis

3.3.4 IMPROVEMENT PHASE

As refer in Figure 19 is the process that conducted in improvement stage by implementing all pillars in TPM 4 Pillars Approach.

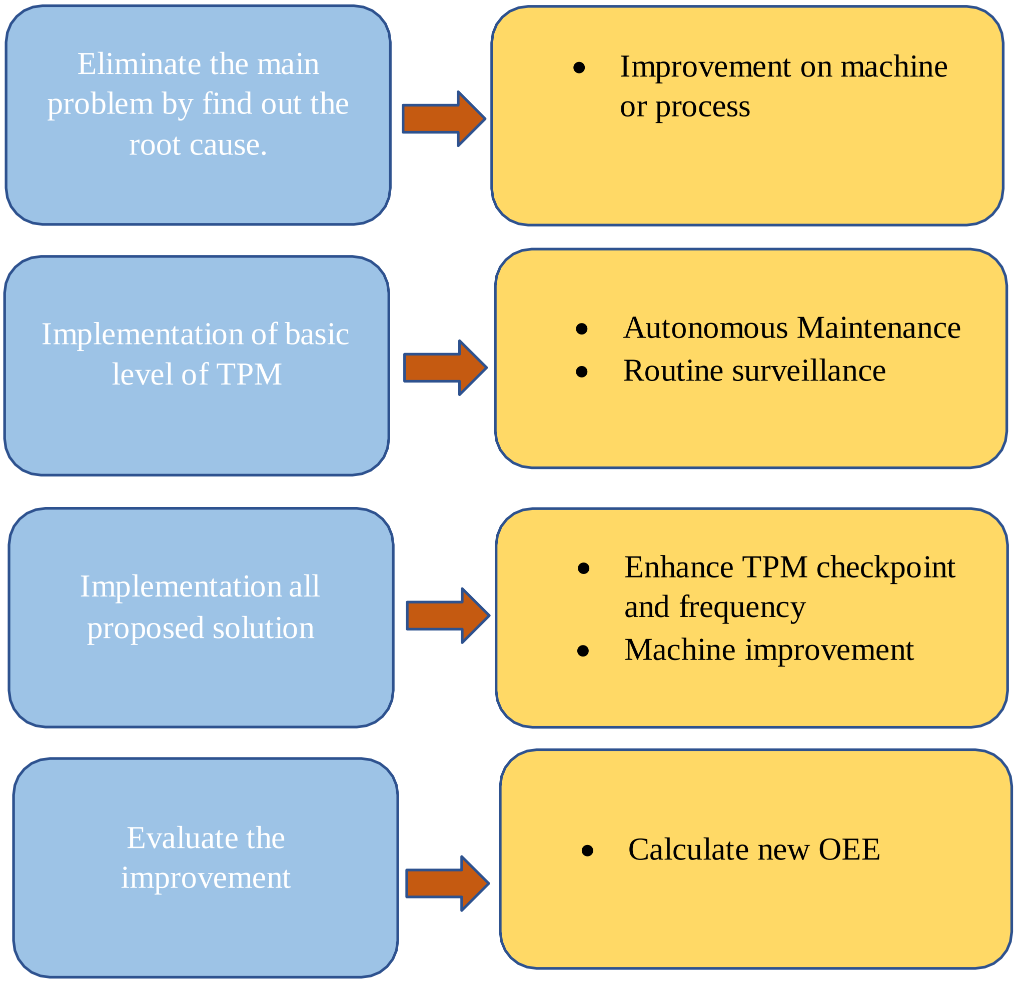


Figure 19 Improvement Phase Process

3.3.5 CONTROL PHASE

The following activities is conducted to ensure that the sustainable of all the correction and improvement action that been carried out as well as ensuring continual practices of TPM 4 Pillar Approach.

- Documented all the improvement.
- Weekly meeting for maintenance team internally
- Maintenance KPI monthly review by management
- Layer Process audit internally by another department.
- Regular training for the operators and maintenance personnel (yearly) and attendance are recorded.

CHAPTER 4

DATA ANALYSIS AND RESULTS

4.1 IDENTIFICATION OF THE MAIN PROBLEM

This research starts which the define stage to give the clear definition of problem by using SIPOC tool (supplier – input – process – output – customer). This tool is use to describe clearly the about maintenance process in the production area asshown in Figure 20.

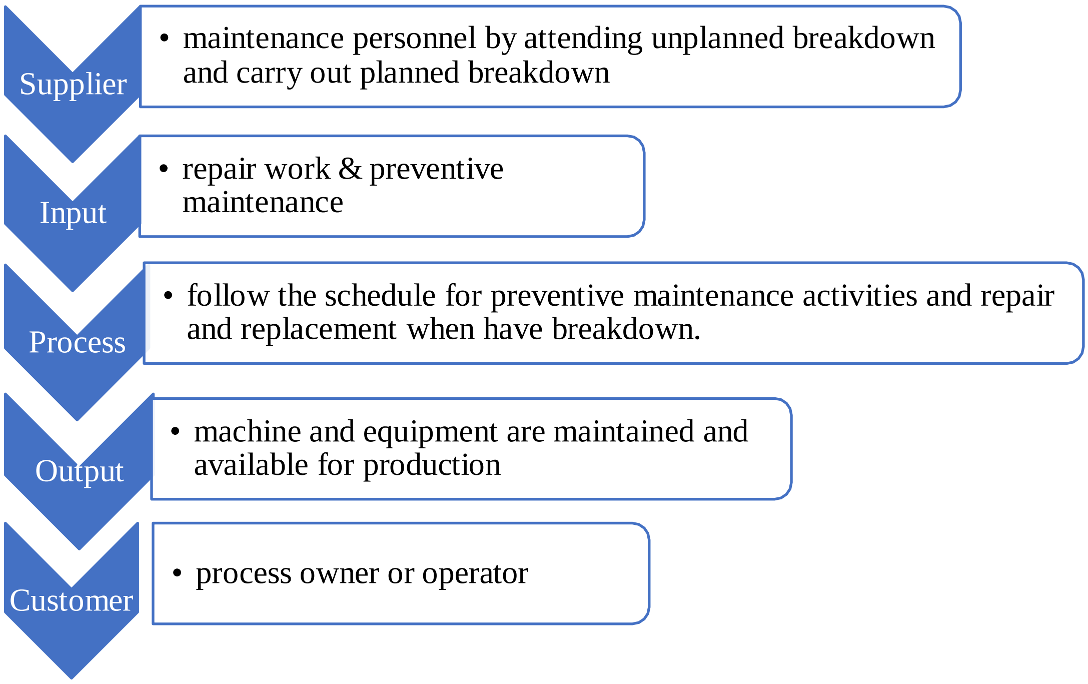
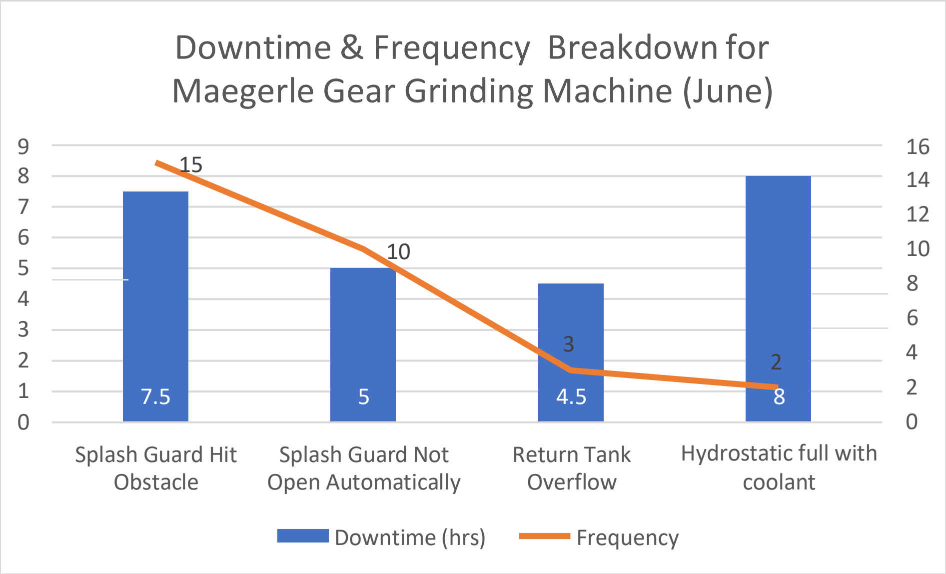


Figure 20 SIPOC Process Flow

Output form the maintenance through the unplanned maintenance and planned maintenance as well as complaint from the operators will be take into account as a brainstorming to find out the main problem of the machine to ensure machine always inthe optimum condition. Besides, all data of the downtime will be recorded to analyze and is classified as critical component.



Graph 3 Downtime & Frequency Breakdown for Maegerle Gear Grinding Machine (June)

Graph 3 shows downtime and frequency of breakdown in month June for Maegerle gear grinding machine. Based on the graph, it shown that total downtime for that machine in June with 462 hours of the operation time is 25 hours with 30 frequency of breakdowns. The calculation of the machine availability in equation (9) , MTBF (Mean Time Between Failure) in equation (7) and MTTR (Mean Time To Repair) in equation (8) are shown below.

$$MTBF = \frac{Operating\ time - Downtime}{Frequency} \tag{7}$$

$$= \frac{462-25}{30}$$

$$= 14.56\ hours$$

$$MTTR = \frac{Downtime}{Frequency} \tag{8}$$

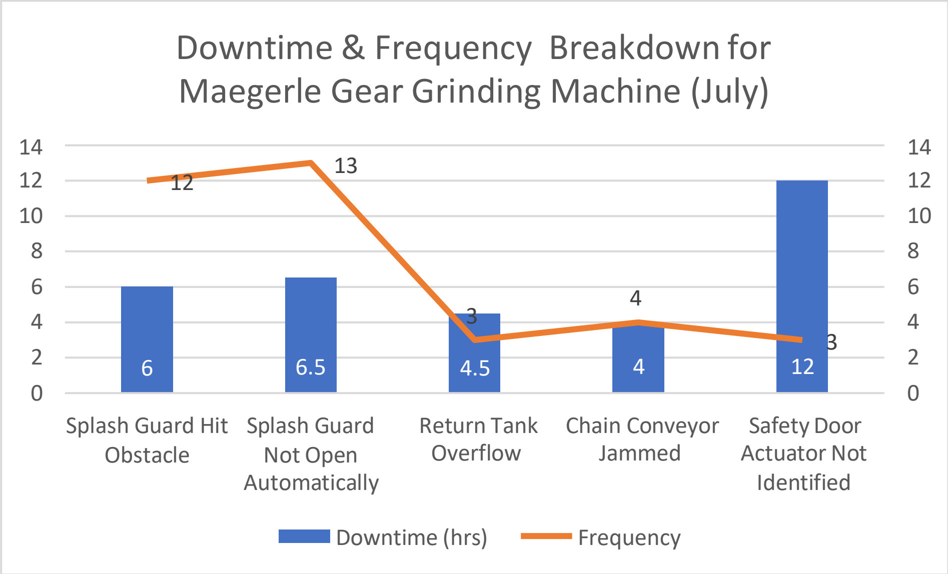
$$= \frac{28}{30}$$

$$= 0.93\ hour$$

$$Availability = \frac{MTBF}{MTBF+MTTR} \times 100 \quad (9)$$

$$= \frac{14.56}{14.56 + 0.93} \times 100$$

$$= 94\%$$



Graph 4 Downtime & Frequency Breakdown for Maegerle Gear Grinding Machine (July)

Graph 4 shows downtime and frequency of breakdown in month July for Maegerle gear grinding machine. Based on the graph, it shown that total downtime for that machine in July with 283 hours of the operation time is 21 hours with 32 frequency of breakdowns. The calculation of the machine availability in equation (12), MTBF (Mean Time Between Failure) in equation (10) and MTTR (Mean Time To Repair) in equation (11) are shown below.

$$MTBF = \frac{Operating\ time - Downtime}{Frequency} \quad (10)$$

$$= \frac{483 - 33}{35}$$

$$= 12.86\ hours$$

$$MTTR = \frac{Downtime}{Frequency} \quad (11)$$

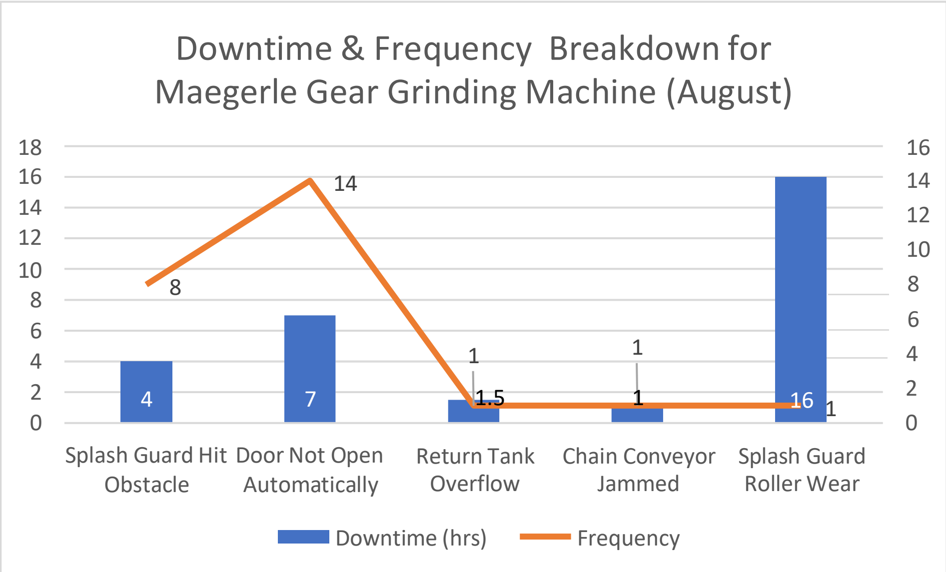
$$= \frac{33}{35}$$

$$= 0.94\ hour$$

$$Availability = \frac{MTBF}{MTBF+MTTR} \times 100 \quad (12)$$

$$= \frac{12.86}{12.86 + 0.94} \times 100$$

$$= 93.2\%$$



Graph 5 Downtime & Frequency Breakdown for Maegerle Gear Grinding Machine (August)

Graph 5 shows downtime and frequency of breakdown in month August for Maegerle gear grinding machine. Based on the graph, it shown that total downtime for that machine in August with 504 hours of the operation time is 29.5 hours with 25 frequency of breakdowns. The calculation of the machine availability in equation (15), MTBF (Mean Time Between Failure) in equation (13) and MTTR (Mean Time To Repair) in equation (14) are shown below.

$$MTBF = \frac{Operating\ time - Downtime}{Frequency} \quad (13)$$

$$= \frac{504 - 29.5}{25}$$

$$= 19\ hours$$

$$MTTR = \frac{Downtime}{Frequency} \quad (14)$$

$$= \frac{29.5}{25}$$

$$= 1.18\ hour$$

$$Availability = \frac{MTBF}{MTBF + MTTR} \times 100 \quad (15)$$

$$= \frac{19}{19 + 1.18} \times 100$$

$$= 94.15\%$$

Maintenance Department has their own which targetting 97.5 % for the uptime or machine availability, 2.2 hours below for MTTR and more than 100 hours for the MTBF. Based on the downtime record for this three consecutive months which is in June, July and August 2019, it shows that this machine just achieve in average 94 % which is below 3.5% of the target uptime or machine availability and 15.47 hours in average of MTBF which is far from the target of more than 100 hours. It is shows big losses from this machine which reduce the machine performance that will affecting the production efficiency and effectiveness. Based on the data, most of the breakdown come from the splash guard door problem which unable the machine to operate in optimum condition.

4.2 MEASUREMENT

In measure stage, all the information that getting from the data in the first stage will be gather before do analyzing process in analyze stage. Before that, we will calculate each of OEE for the three consecutive months which are June, July and August based on the data from the define stage before.

Table 4 OEE Calculation for June

OEE Calculation for June		
A	Shift Time	462
B	Planned Downtime	0
C	Running Time (A-B)	462
D	Running Time Losses (C-D)	25
E	Operating Time (C -D)	437
F	Availability (E/C) x100	94.59
G	Output	43200
H	Machine Speed (Number of Part/Hour))	100
I	Expected Output (H x E)	43700
J	Efficiency (G x 100)/I	98.86
K	Rejection	20
L	Quality (G - K x 100)/G)	99.95
OEE = Availability x Efficiency x Quality = 94.59% x 98.86% 99.95% **= 93.46%**		

Table 4 show the OEE calculation for June just recorded 93.46% which lower the OEE target. It cause by 25 hours losses in running time due to the breakdowns as well as cause 500 pieces loss in output due to the late operations by operator after machine repair done. 20 pieces part reject also recorded due to centerline out caused bythe operator mistake during loading the part into the fixture.

Table 5 OEE Calculation for July

OEE Calculation for July		
A	Shift Time	483
B	Planned Downtime	0
C	Running Time (A-B)	483
D	Running Time Losses (C-D)	21
E	Operating Time (C -D)	462
F	Availability (E/C) x100	95.65
G	Output	45950
H	Machine Speed (Number of Part/Hour))	100
I	Expected Output (H x E)	46200
J	Efficiency (G x 100)/I	99.46
K	Rejection	42
L	Quality (G - K x 100)/G)	99.91
OEE = Availability x Efficiency x Quality =95.65% x 99.46% x99.91% **= 95%**		

Table 5 shows the OEE data for July that just recorded 95% which still lower than the OEE target. 25 hours downtime recorded and losses of 250 pieces part compare to expected output. This month record quite higher of part reject which is 42 pieces due to the unstable machine condition caused by some of the downtimes happened made the machine automatically stop affected to the part rejection.

Table 6 OEE Calculation for August

OEE Calculation for August		
A	Shift Time	524
B	Planned Downtime	6
C	Running Time (A-B)	518
D	Running Time Losses (C-D)	29.5
E	Operating Time (C -D)	488.5
F	Availability (E/C) x100	94.31
G	Output	48700
H	Machine Speed (Number of Part/Hour))	100
I	Expected Output (H x E)	48850
J	Efficiency (G x 100)/I	99.69
K	Rejection	60
L	Quality (G - K x 100)/G)	99.88
OEE = Availability x Efficiency x Quality =94.31% x 99.69% x 99.98 % **= 93.9 %**		

In August, based on Table 6 OEE just recorded 93.9 % with the losses of 150 pieces in output and 60 pieces part rejected. As July, high part reject in this month also happened due to unstable machine condition caused by the breakdown which made machine automatically stop immediately.

In overall based on this data, cause of the low OEE percentage due to the low of machine availability machine compare to other factors of OEE which achieving in average 99%. Due to that, it also affect the efficiency which suspecting due to the late of machine operation after machine hand over to the production due to the breakdown. So, if we look at there, breakdown of the machine actually not just affect to the availability factor, it also will giving effectof the efficiency and quality factor as well. So, further study will be done to find out the root cause rsof the breakdown to ensure that the main problems of the machine able to be eliminated.

4.3 ANALYSIS FOR LOW OEE ACHIEVEMENT

Before analysis is done, understanding of the problem matter need to be cleared and identified. So, 5W2H analysis tool is used to understand a problem or opportunity for improvement from different perspectives. Throught it, the problem can be visualized in a clear and objective way as well as enhance the chances of making the most effective decision. Table 7 show the 5W2H analysis for this study.

Table 7 5W2H Analysis

What ? Countermeasures	Low OEE of Maegerle Gear Grinding Machine
Where ? Location	Manufacturing Production Line
Why ? Root cause	High downtime recorderd
When ? Process involved	As long as production exist
Who? Worker involved	Maintenance team Operator
How to? Solution developed	Eliminate all the main problem of that machine
How Long? Period	4 month- identify, analyse, improve and monitor

In methodology before, I have discussed about the fishbone diagram analysis. Through that, I highlighted all the relevant factors that contribute of the problem for the further study and find out the opportunities of the improvement to ensure that the root cause of the problem can be eliminated. Detailed discuss of the factors as below in Table 8 that found out during the observation, discussion, feedback received and the analysis done

Table 8 Root Cause Analysis

Factor	Root Cause	Observation
Man	Lack of training and education for the operator	• Previous direction from the management want operator just focus on the output without any concern about basic autonomous maintenance. • No training conducted for the operator about basic maintenance. • Training matrix for the operator not updated and reviewed by the production supervisor and engineer.
	Maintenance personnel spend more time for repairing	• Lack of knowledge and experience about that machine maintenance due to new design and system used. • Not detailed of SOP or Work Instruction for that machine. • Need to wait for support from the machine maker due to time different (Switzerland made) • Time taken for the maintenance to understand first about the machine before able to do repairing job.
Machine	Grinding chip issue	• During the observation, most of the breakdown happened due to the chip from the grinding process accumulated at the chip catcher and drop as a big wool. It causes the return pump was blocked and no suction which made the return tank overflow. besides, it also accumulates at chain and sprocket which made the chip conveyor was jammed.

		• Grinding chip sticking in between of the splash guard door and machine body that affecting accumulated when the door moved forward and backward (open and close). This cause will lead to the issue of splash guard not closed, safety door actuator not detected and roller of the splash guard door become wear.
	Limited space	• Limited space in between of the splash guard door and machine body. It made the cleaning process to take out the grinding chip from there is really hard and lead to higher downtime.
	Difficulty in term of maintainability	• No space for the maintenance to take out the grinding chip in between the splash guard door and machine body. • No structure for the chain block which made the work to take out pump for servicing become harder. Need to borrow forklift from the warehouse. • Capacity of the chip conveyor not suite compare to the volume of the coolant and chip from the grinding process.
	Maintenance frequency	• Older PM, not really specify the maintenance frequency which made the PM implementation not really effective and efficient.
	Checklist area determination	• Older PM just brief in general about the PM that need to carry out. Not mention detail about the checkpoint area that need to be inspect and service which made the objective of PM not achieved.

Method	Procedure not standard	• Procedure in the older PM check sheet not clear. Some of the check point not available in the machine. • Check sheet not documented and registered for the audit purpose.
	PM implementation	• Maintenance team not clearly understand about the PM. • No checklist to carry out PM and not updated after the PM is carried out. • No verification from the superior after PM activity is done by the maintenance personnel. • No systematic system of PM implementation which is no schedule (PM calendar). No assigned maintenance personnel for machine under their responsibility. • PM implementation not efficient and effective.

4.4 IMPROVEMENT

4.4.1 ELIMINATING THE MAIN PROBLEM

In the improvement step, the TPM 4 Pillar model will be as an approachto do the improvement process to ensure that OEE is able to be increased. The first stage in this improvement process is to eliminate the main problem of this machine. As per discussed in the analysis stage, found that the root cause of thismain problem is the grinding chip that accumulated and become the big wool. Here, based on the observation found that, it happened due to the chip catcher not really suitable for this machine operation. So, maintenance team turn flat side in front and the catcher side at the back as shown in Figure 21. It made thechip from the grinding process not sticking at the chip catcher, but just flow withthe coolant to the return tank. So, it helps to eliminate the cause of the return pump blocked and chip conveyor jammed as well.

Figure 21 Flat Side of Chip Catcher

For the second improvement to eliminate the root cause of the main problem of this machine is by making a small door at the machine body to easethe maintenance personnel to take out chip in between of the machine body andsplash guard door that comply with the pillar no. 4 in TPM 4 Pillar which is TPM appropriate MAE-design. It not only make the job on the maintenance personnel become more easier in term of maintainability, it also will reduce therepair time from 30 minutes before to just only around 5 to 10 minutes. The small door is shown in the Figure 22 and Figure 23 below.

Figure 22 Small door at Splash Guard Door Area

Figure 23 Area in between Splash Guard Door and Machine Body

4.4.2 IMPLEMENTATION OF AUTONOMOUS MAINTENANCE

As per discussed before, autonomous maintenance is the basic pillar in TPM 4 Pillars which some basic maintenance activities are conducted by the operators and share the responsibility to ensure machine always in the optimum condition. Main objective of this autonomous maintenance is to change the attitude of the operators from the "just operate the it, if problem call maintenance" to multitasking attitude. Before autonomous maintenance is conducted, operators are emphasize to implement 5S practice to ensure that the problem is visible in the first step of improvement. There some applications of this tool in maintenance process for the operator:

I. Sort

- Before
  - ➢ Issue of the reject parts were combines with the good parts which made customer complaint issue due to that rejected part was assembled in completed steering gear unit.
- After
  - ➢ NG part (not good) is put seperately in particular trolley with tagging. Operator need to fill up the Reject Form for NG part after end of the shift.

II. Set in order

- Before
  - ➢ Tools used by operator not managed properly
- After
  - ➢ Tools are put in their respective place with labelling to ease for identified. Refer to Figure 24

Figure 24 Tool Arrangement

III. Shine

- Before
  - ➢ Workplace not tidy and clean. Sometime, some tool left inside the machine which made accident when machine is operated by operator in next shift.
- After
  - ➢ 10 minutes for clean and tidy up workplace after operations finished and visual checking if there any abnormalities at the machine to ensure safe working environment and clean internal machine area.

IV. Standardize

- Before
  - ➢ Report from operator not recorded.
  - ➢ Training matrix not updated
- After
  - ➢ Shift report is compulsory need to be written at the end of the shift and check by the supervisor.
  - ➢ Training matrix is updated and reviewed with tagging (apprentis, skilled worker, skilled master)

V. Sustain

- After
  - Company mission and vision is displayed in production area.
  - Updated about production is displayed in the TV screen at production area.
  - Quality award conducted every 3 months to recognise the operator who find out any abnormalities.

Besides, for the autonomous maintenance, the operator will brief in detailed about the autonomous maintenance purpose and their responsibility on it. The operator need to update in TPM calendar after the job is carried out. There some of their jobs for the autonomous maintenance practice at the machine as shows in Figure 25:

I. 5S (every shift daily)

- Cleaning according to cleaning schedule
- Initial cleaning of machine

II. Inspection (every shift daily)

- Listen abnormal noise from machine
- Visual leakage

III. Inspection (weekly Friday morning shift)

- Check loose parts
- Visual oil level checking
- Visual air pressure level checking

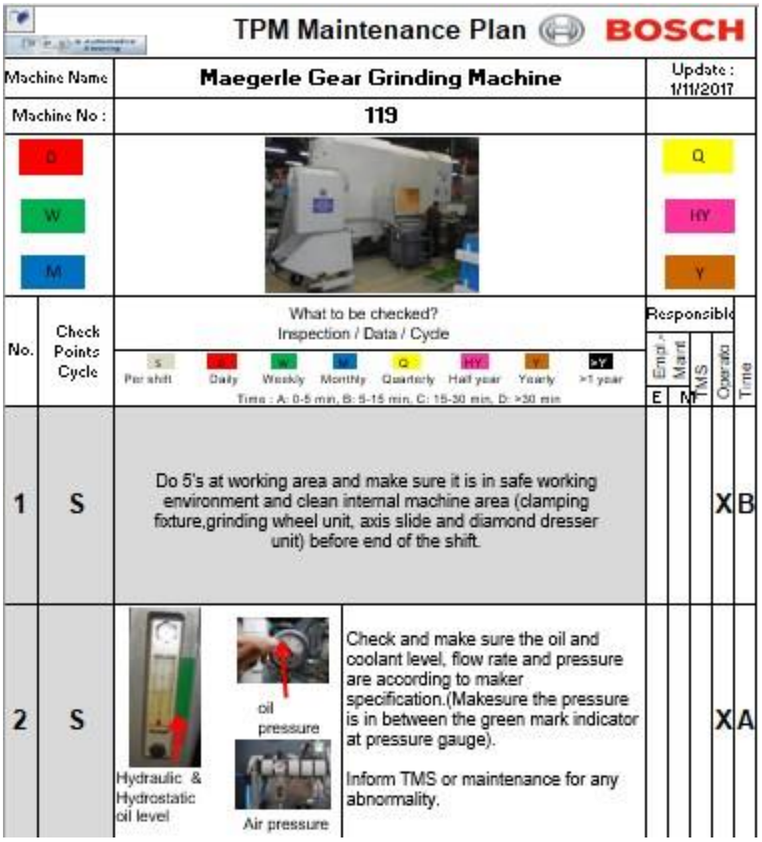


Figure 25 Autonomous Maintenance in TPM Checklist

Futhermores, implementation of Fuguai Tag is done in the production line for the early detection of any abnormalities by the operators during machine operation. For the Fuguai Tag, there have a target which is 4 Fuguai Tag every month for each of production departments (Rack, Pinion & Assembly). Figure 26 shows the process flow of Fuguai Tag and Fuguai Tag respectively.

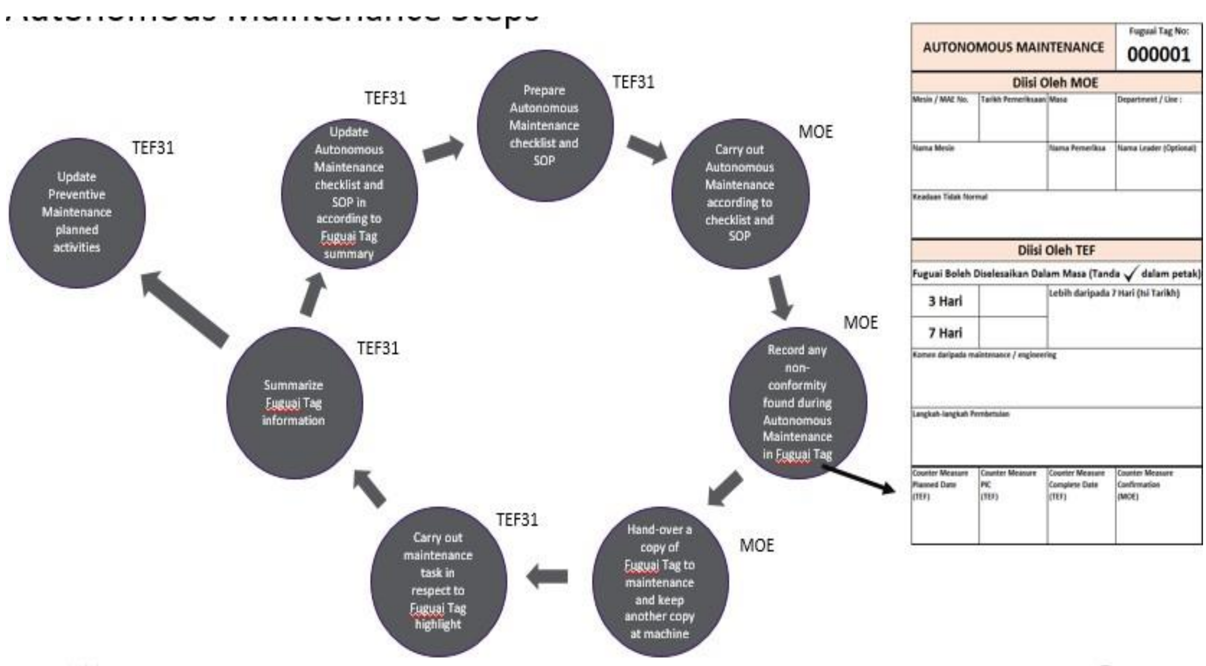


Figure 26 Fuguai Tag Process Flow and Form

4.4.3 Implementation of Planned Maintenance

This is 3rd pillar in the TPM 4 Pillars which aiming to ensure machine always in optimum condition without any breakdown. This planned maintenance will be carried out by the maintenance personnel based on the TPMschedule and checklist. All the activities that carried out need to be updated in the log book and sign by the PIC (person in charge) in the TPM calendar. This TPM format is change from the older one which not really relevent for the current manufacuring standard and identification of the check point is more detailed to ensure there is no checking point is missing as refer to the Figure 27. There have several frequency of planned maintenance which are:

I. Every shift
   - Routine surveillance by maintenance to all machine at early start of the shift.

II. Weekly

- Visual check of the any component of the machine. Any abnormalities is recorded in the TPM finding to be carried out during planned maintenance.

III. Monthly

- Temperature and vibration check of machine equipments.

IV. Half yearly

- Part replacement for any defect or machine maker recommendation.

V. Yearly

- Major servicing of the machine.

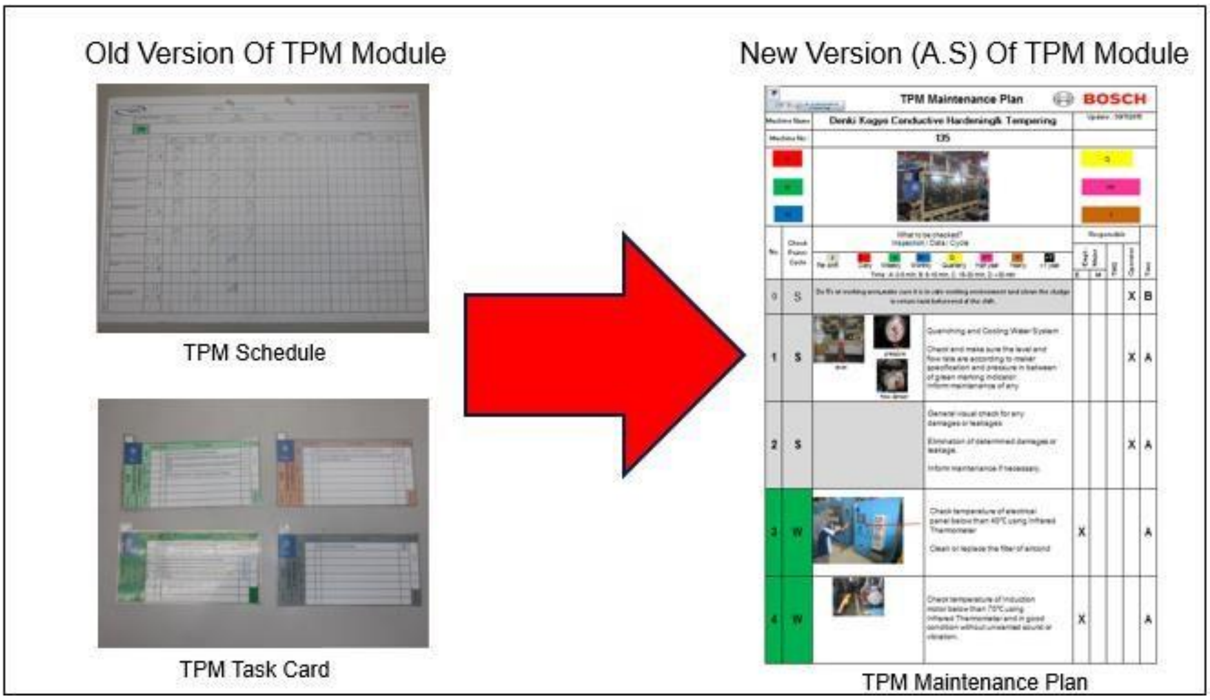


Figure 27 Old Version of TPM Module Vs New Version (A.S) of TPM Module

4.5 RESULT

After the all of the implementations is done, monitoring and improvement is updated and recorded. To identify objective of the TPM implementation is either success or not, OEE data after of next 4 month which is December is taken as a reference. Table 9 shows the OEE data for December

Table 9 OEE Calculation for December

OEE Calculation for December		
A	Shift Time	525
B	Planned Downtime	3
C	Running Time (A-B)	522
D	Running Time Losses (C-D)	2
E	Operating Time (C -D)	520
F	Availability (E/C) x100	99.62
G	Output	51984
H	Machine Speed (Number of Part/Hour))	100
I	Expected Output (H x E)	52000
J	Efficiency (G x 100)/I	99.97
K	Rejection	8
L	Quality (G - K x 100)/G)	99.98
OEE = Availability x Efficiency x Quality = 99.62% x 99.97% 99.98% **= 99.57%**		

Based on the OEE table above it shows that, there are improvement in in machine availability and performance as well as the quality. It prove that, the implementation of TPM 4 Pillar approach at this machine is success. Here, we can see that the target set is achieved and unplanned breakdown is able to reduce. It is because the root cause of main problem for this machine is successfully tackle and overcomed. Besides, support from the operators through the autonomous maintenance implementation helps the maintenance team to identify the problem early and counter measure to eliminate that problem can be done before the problem become bigger. Planned maintenance which schedule efficiently with detailed check point at the machine help the maintenance team to maintain the machine well and ensuring the optimum availability to run for production.

4.6 CONTROL

Control stage is the last stage in this research process flow to ensure that implementation of TPM 4 Pillar approach move continously and not stop only in the half way. In this control stage, there are several activities will be conducted to ensure that the system is implemented systematically and continuous improvement can be done efficient and effectively for other upcoming problem. So, the control stage includes all of this following activities:

i. Documented and standardized all the improvement.
   - All documents related to the TPM for instance TPM check sheet, calendar, TPM form and other are registered under Total Quality Management (TQM) for audit process.
   - Standardize operation 5S cleaning checklist previously controlled by production themselves to just only TPM check sheet combine with maintenance team to ensure that the implementation can be monitor more effective and efficient.
   - All documents related to the TPM are documented in only one folder which control by the maintenance as project owner.

ii. Weekly meeting for maintenance team internally
   - Weekly meeting at every Wednesday for maintenance team internally to discuss any finding during routine inspection or carry out TPM activities by maintenance personnel for brainstorming session to find out the solution or any improvement that can be done.
   - Here all teammates will voice out all the problem related to the maintenance issues.

Figure 28 Internal Maintenance Weekly Meeting

iii. Maintenance KPI monthly review by management

- In every month, all the breakdowns will be collected, and calculation to find the machine availability, MTTR and MTBF to identify monthly maintenance KPI is achieved or not.
- All the data will be displayed in front of the maintenance office. It will be reviewed by the plant top management for the updated status of TPM implementation and any major problem that interrupt the production operation.

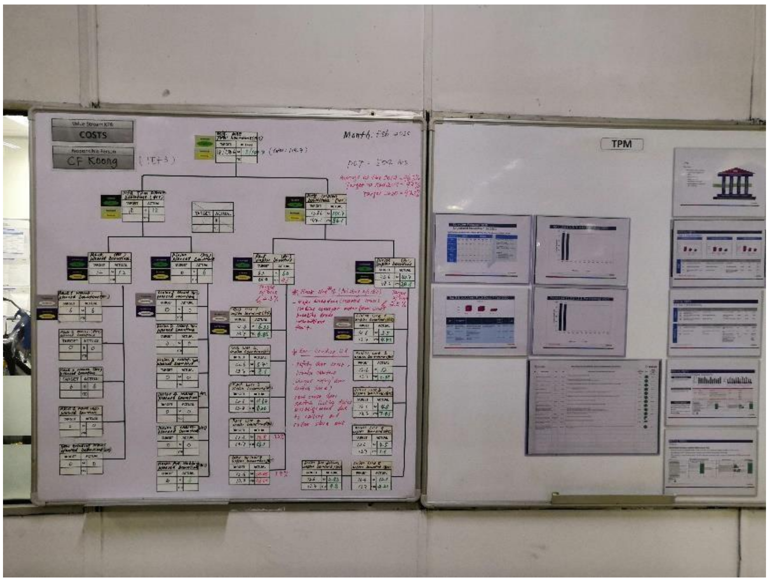
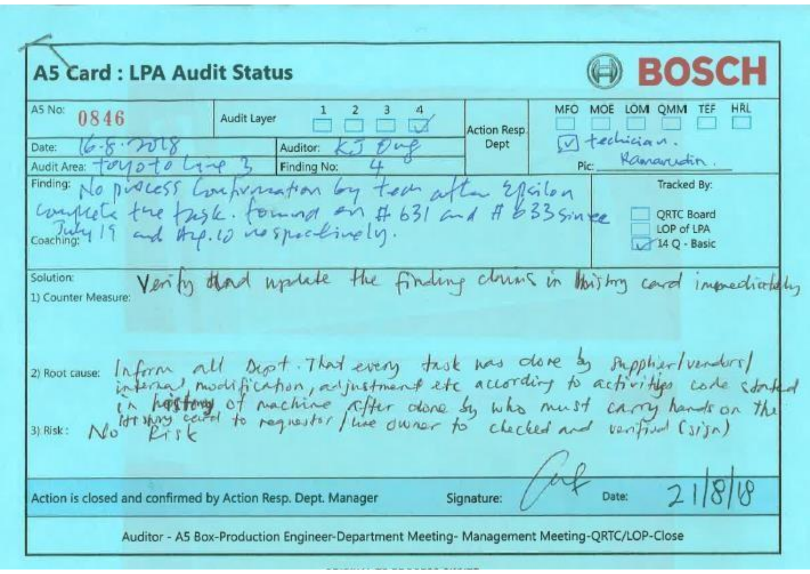


Figure 29 Maintenance KPI Review Board

iv. Layer Process audit internally by another department.

- This is a quality technique that focuses on observing and validating how process are made rather than inspecting finished goods which TPM is included as the audit item in this audit.
- During this audit process, internal auditor in different department will conduct audit for another department and NCR (non-conformance reporting) will be given for further action as shows in Figure 30 as example.
- This audit will help in identify non-conformance issues and provide procedures for documenting and correcting them.



A5 Card : LPA Audit Status

BOSCH

A5 No: 0846

Audit Layer 1 2 3 4

Date: 16.8.2018

Auditor: KJ Ong

Audit Area: Toyota Line 3

Finding No: 4

Action Resp. Dept

MFO MOE LOM QMM TEF HRL

technician.

Pic: Kamarudin.

Finding: No process confirmation by tech after Epsilon complete the task. found on # 631 and # 633 since July 19 and Aug. 10 respectively.

Coaching:

Tracked By:

QRTC Board

LOP of LPA

14 Q - Basic

Solution:

1) Counter Measure: Verify and update the finding claims in history card immediately

2) Root cause: Inform all Dept. That every task was done by supplier/vendors/ internal modification, adjustment etc according to activities code stated in history of machine after done by who must carry hands on the history card to requestor / line owner to checked and verified (sign)

3) Risk: No Risk

Action is closed and confirmed by Action Resp. Dept. Manager

Signature:

Date: 21/8/18

Auditor - A5 Box-Production Engineer-Department Meeting- Management Meeting-QRTC/LOP-Close

Figure 30 LPA Audit Status Form

v. Regular training for the operators and maintenance personnel (yearly) and attendance are recorded.

- Yearly autonomous maintenance for the operators will be conducted to refresh operator understanding and knowledges to the maintenance check point in every particular machine. All of the attendance will be recorded and updated in their training matrix.
- Maintenance personnel as well will have yearly training in safety, SOP (Standard Operation Procedure) & Work Instruction as well as On Job Training (OJT)
- Maintenance personnel also will send to outsource training for instance PLC programming, electrical and mechanical training as well to sharpen their knowledge and skills.
- All of the attendance will be recorded and documented as well as updated in their training matrix as reference.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 SUMMARY OF MAIN FINDINGS

In chapter 4, the analysis has been done in every pillar of TPM 4 Pillars to findout on how this TPM implementation able to help in improving the OEE of Maegerle Gear Grinding machine. Based on the research, using the DMAIC tools for analysis, implementation of TPM 4 Pillars are able to help in improving the OEE for that machinefrom in average 94% to 99%. It not only improves the machine availability, but able theincrease the production performance in term of part produced as well as reducing the quality defect due to the machine problem. The analysis has been conducted in variousof elements which are

- Identify the main problem that cause high downtime of that machine and the way to rectify as well as eliminate that main problem.
- Implementation of Autonomous of Maintenance for the operatorinstead of only 5S practice that controlled by the production.
- Implementation of Planned Maintenance that carry out by maintenance team to conduct periodic inspection, preventivemaintenance and corrective maintenance.
- Measure the effectiveness by collecting OEE data which found that this TPM 4 Pillars model able to help in improving the OEEfor that particular machine.
- Control measure for all of activities done to ensure that continuous practice of TPM 4 Pillars among the employees eitherblue or white collars.

Besides that, after the observation and analysis of TPM 4 Pillars done, I have summarized some of the strength and weakness of this project objectives as a benchmark for any opportunities of improvement in implementing TPM 4 Pillars for other machines.

i. To analyse and eliminate loss sources due to unplanned machine breakdown.

- Strength
  - Good documentation in every breakdown record by analysis on the high downtime breakdown and repeated breakdown.
  - Experience and knowledges of the maintenance team about that machine operation and process able to minimize the unplanned breakdown and reduce the repair time.
- Weakness
  - There have some of the breakdown need assistance from the machine maker or outsource vendor. So, it takes longer response time which made downtime become higher because of waiting time issue.
  - Tools for repair job not completed which made some modification need to be done.
  - Sometimes, no spare part for replacement made some modification need to be done that cause higher downtime.

ii. To analyse planned maintenance implementation and performance.

- Strength
  - Previous PM implementation that have similarity made easier for maintenance team to adapt with new TPM approach.
  - Cooperation of production and planner to schedule the production plan able to ensure that planned maintenance is conducted on schedule.

- Weakness
  - ➢ Inefficient and systematic previous PM check sheet. So, identification for detailed check point of maintenance job need to be done. It made revision need to be done regularly based on the analysis on breakdown record and TPM finding during maintenance job is carried out.
  - ➢ High cost for spare part inventory for part replacement during preventive, corrective or predictive maintenance is carried out.

iii. To identify and analyse improvement opportunities through TPM 4 Pillar approach.

- Strength
  - ➢ Analysis of any problem that lead to downtime is analysed in action list. It helps to ease any possibility of improvement opportunities.
  - ➢ Detailed guidelines given in TPM 4 Pillar approach easy the analysis for improvement opportunities can be done effectively.
- Weakness
  - ➢ Cooperation from the maintenance team to updating any abnormality in TPM finding.
  - ➢ Low of enforcement in TPM activities made improvement opportunities cannot be identified.

iv. To analyse machine performance and achieving machine OEE target

- Strength
  - ➢ Implementation of every pillar in TPM 4 Pillars help in improving machine OEE especially machine availability factors.
  - ➢ Enhancement of machine performance by conducting improvement activity to eliminate main problem, cooperation among operator by conducting autonomous maintenance and on time carry out planned maintenance based on schedule arranged.

- Weakness
  - Attitude of the operator to always meet the production target.
  - Data from production not tally with the maintenance department due to some breakdown are not recorded in activity form.

v. To identify the equipment-related knowledge and experience among operators (autonomous maintenance)

- Strength
  - Some of the operators are sent to technical institute to enhance their skill through HRDF Fund. So, they already have skills and knowledge about technical.
  - Cooperation from the operator to conduct the autonomous maintenance with minimal supervision.
- Weakness
  - Training matrix not updated by the supervisor which made hard to identify the level of knowledge and experience of the operator.

5.2 DISCUSSION AND IMPLICATIONS

Today, with competition in automotive industry at an all-time high, TPM may be the only things that can stands between success and total failure for some companies. Cost of product produced, cost of operation, customer demand and expectation made the companies compete each other to become as a winner and role model. But it is proven that TPM 4 Pillars approach able to help to ensure it come true. Based on the research on the case study, it shows that how every pillar in TPM 4 Pillars with good study and analysis able to help to improve in OEE to make sure the production able to meet the customer demand and expectation as well as reduce the cost of operation whichmade that lower cost with high quality of product can be produced. It the study also shows that, how the effective implementation of TPM 4 Pillars help to increase the OEE from in average 94 % to 99 % by eliminating the main problem of the machine, early detection of any abnormalities and good prevention to ensure machine in optimum availability that lead to increase the production performance and reduce the quality issueimpact of machine problem.

The are many benefits or positive implication of implementing TPM 4 Pillar approach which are:

- Involvement of all associates, independent processing of tasks, increased identification of associates with their equipment.
- Teamwork and interdisciplinary cooperation are intensified.
- Improvement in process and product quality.
- Increase in OEE (Overall Equipment Efficiency)
- Reduction in unplanned downtimes, high level of system availability.
- Planned maintenance instead of unplanned "fire-fighting".

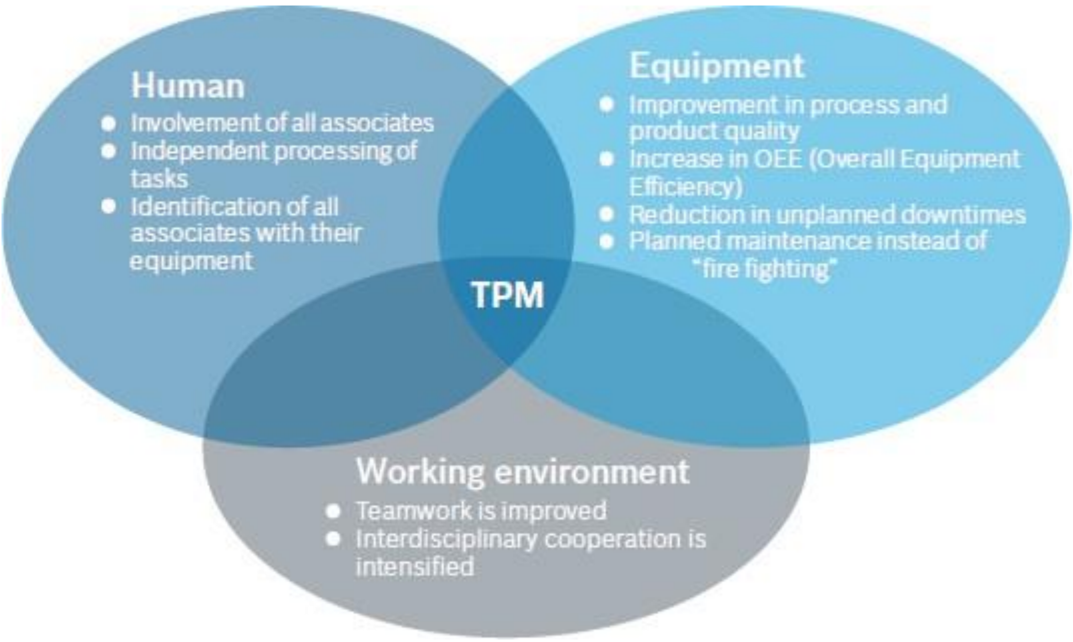


Figure 31 Triad of TPM Benefits

5.3 LIMITATION OF THE STUDY

Every research has their have their own limitation of the study including me. I having a problem in the first step of DMAIC tools which is define. The problem here is to find out the real main problem of that machine due to lack of information about the machine breakdown record. It is because, some of the breakdown is not recorded or manufacturing playing with the time of the downtime to ensure their KPI is good. So, it hard for me to get the tally downtime record when comparing the data from maintenance department and manufacturing department to calculate the accurate OEE data. Second is in implementation stage during implementing and measuring the performance of planned maintenance. Here, I found that, enforcement of carrying autonomous and planned maintenance is very weak. There still have the operator do not carry out the autonomous maintenance as well maintenance personnel who some of them not carry out the planned maintenance within the schedule given. For me, it will be affecting the result of improvement or prevention for the problem to happen again which effected the data result for the OEE. Lastly about the time constrain to complete this final report due to responsibility to family and work as well made me need to work harder to finish the final report.

5.4 DIRECTION FOR FUTURE RESEARCH

Gear grinding process like the one described through the case study are performing the first manufacturing operation to make parts within a factory. When thismachine OEE is improved, it has impacted on the whole downstream, where the line for next process of the parts should move smoothly according to the “first piece flow” approach. So, implementation of TPM 4 Pillars must enforce to all to ensure no OEE affected in every machine. After find out about the effectiveness of TPM 4 Pillars in improving the OEE, I would like to study more on MTTR (Mean Time to Repair) and MTBF (Mean Time Between Failure) in increasing the availability of machine which one of the factors in the OEE. The focus here on how to reduce the MTTR and increase the MTBF by using TPM approach based on TPM 4 Pillar Model and the significant benefits to maintenance downtime KPI as well as optimize production efficiency and effectiveness.

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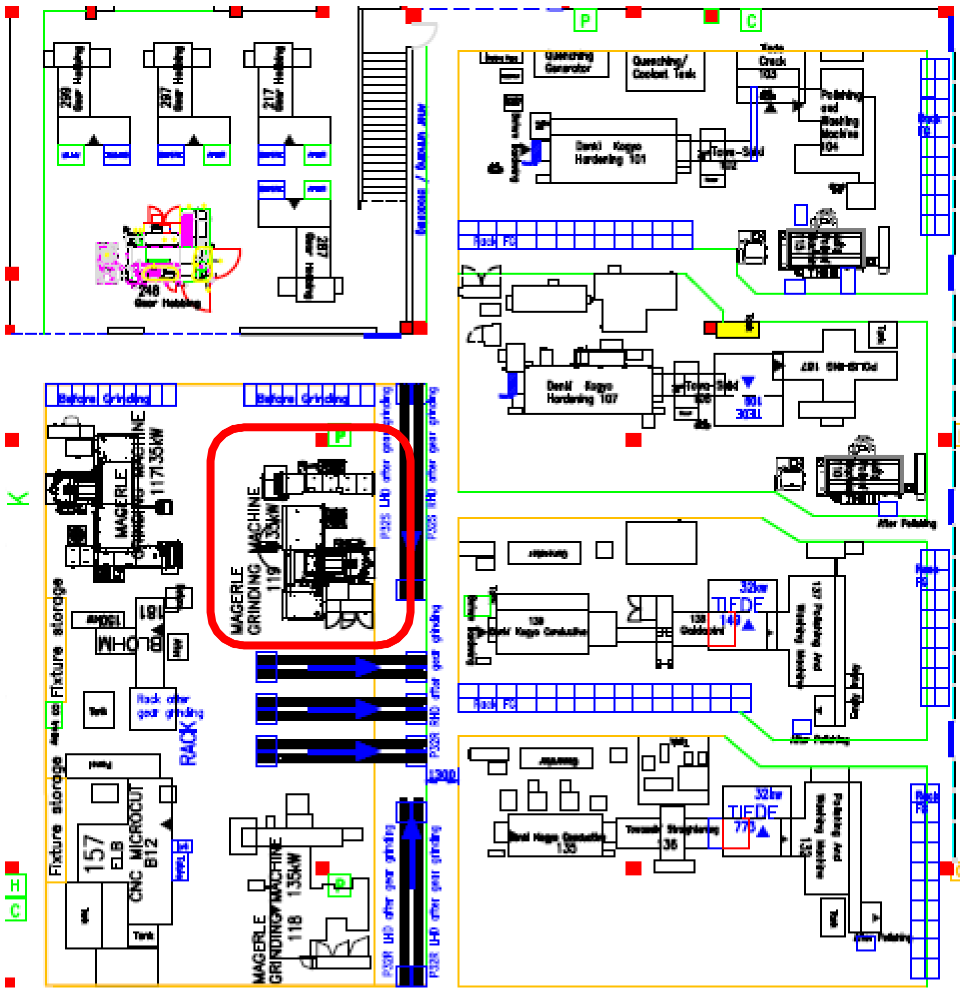
APPENDICES

APPENDICE 1

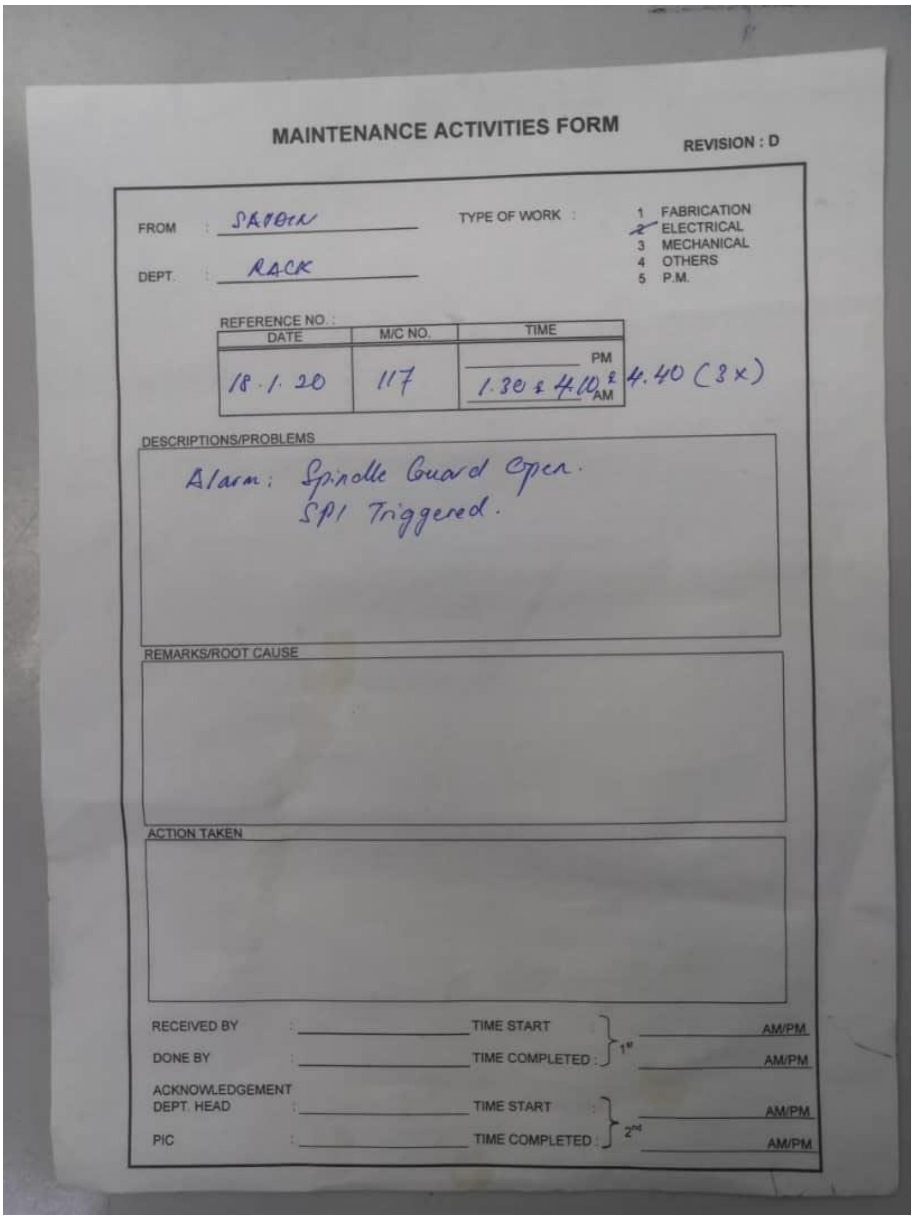


Manufacturing Machine Layout

APPENDICE 2

Rack Manufacturing Process

APPENDICE 3



MAINTENANCE ACTIVITIES FORM

REVISION : D

FROM : SAPBIN

DEPT. : RACK

TYPE OF WORK :
1 FABRICATION
2 ELECTRICAL
3 MECHANICAL
4 OTHERS
5 P.M.

REFERENCE NO. :

DATE	M/C NO.	TIME
18.1.20	117	1.30 & 4.10 & 4.40 (3x) PM/AM

DESCRIPTIONS/PROBLEMS

Alarm: Spindle Guard Open.
SPI Triggered.

REMARKS/ROOT CAUSE

ACTION TAKEN

RECEIVED BY : ______ TIME START : ______ AM/PM (1st)

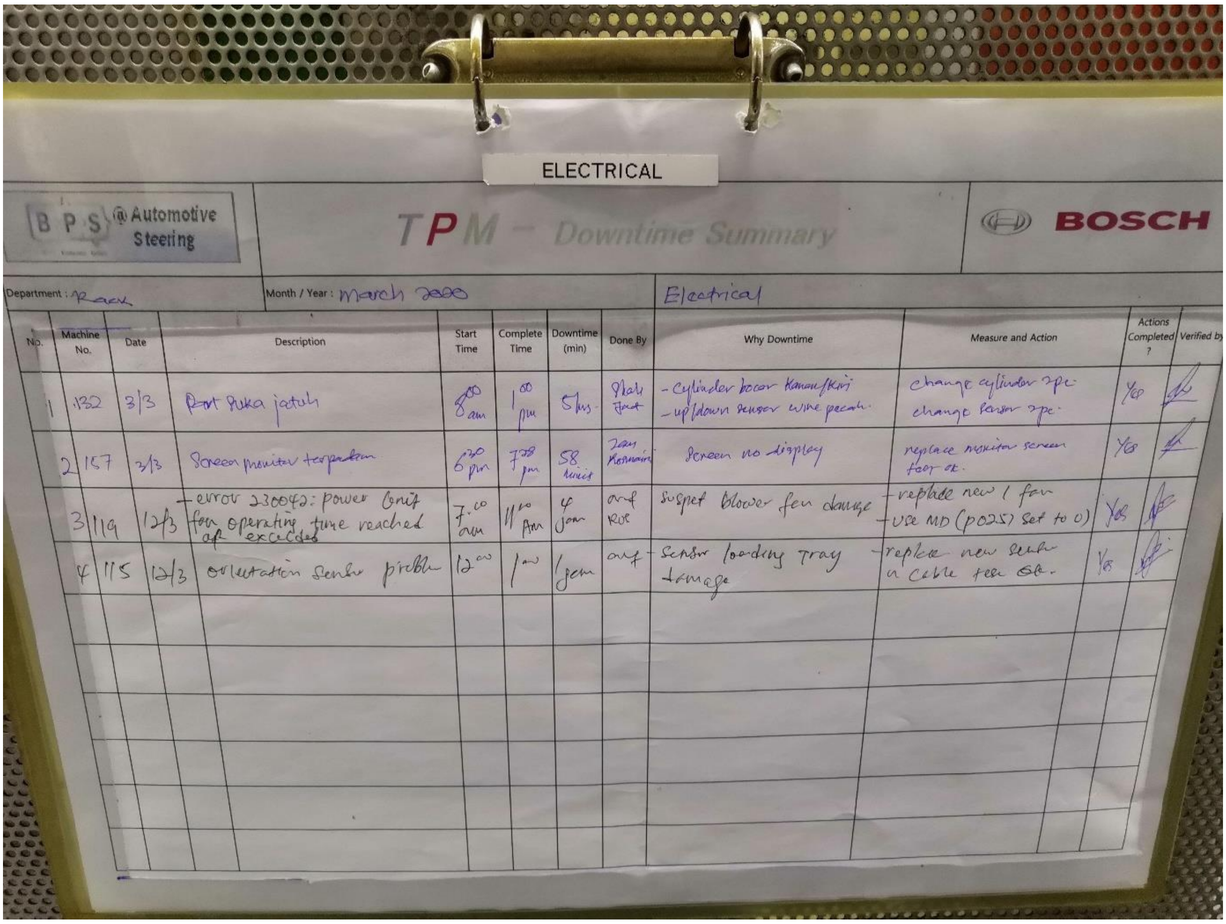
DONE BY : ______ TIME COMPLETED : ______ AM/PM

ACKNOWLEDGEMENT DEPT. HEAD : ______ TIME START : ______ AM/PM (2nd)

PIC : ______ TIME COMPLETED : ______ AM/PM

Example of Maintenance Activity Form

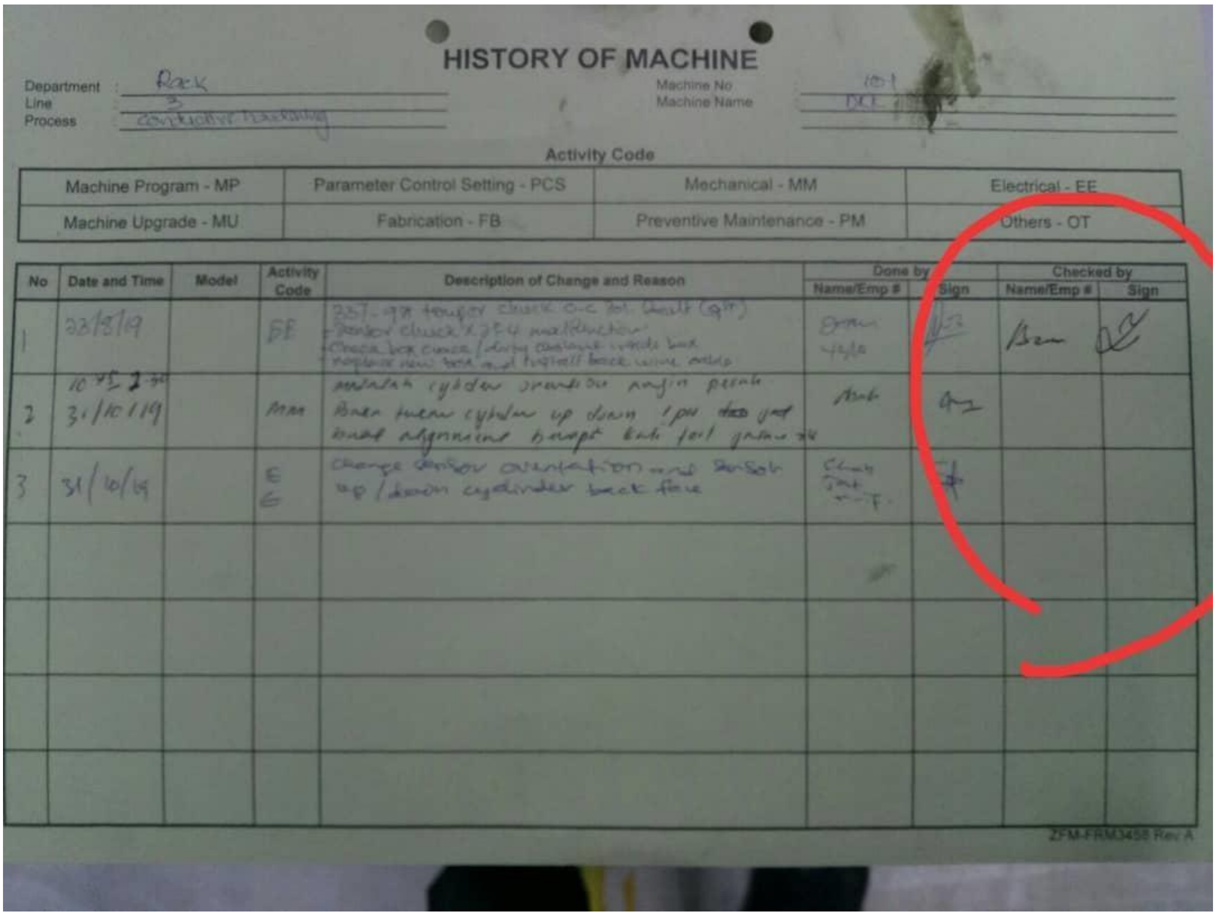
APPENDICE 4



No.	Machine No.	Date	Description	Start Time	Complete Time	Downtime (min)	Done By	Why Downtime	Measure and Action	Actions Completed ?	Verified by
1	132	3/3	[illegible] jatuh	8.00 am	1.00 pm	5 hrs	[illegible]	- Cylinder bocor kanan/kiri - up/down sensor wire pecah	change cylinder 2pc change sensor 2pc	Yes	
2	157	3/3	Screen monitor terpadam	6.30 pm	7.28 pm	58 minit	[illegible]	Screen no display	replace monitor screen [illegible] ok.	Yes	
3	119	12/3	- error 230042: power unit fan operating time reached or exceeded	7.00 am	11.00 am	4 jam	[illegible]	Suspect blower fan damage	- replace new 1 fan - use MD (p025) set to 0)	Yes	
4	115	12/3	orientation sensor problem	12.00	1.00	1 jam	[illegible]	- Sensor loading tray damage	- replace new sensor n cable [illegible] ok.	Yes	

Downtime Summary

APPENDICE 5



Example of History Card

APPENDICE 6

TPM Board at Every Machine

APPENDICE 7

MAIN PROBLEM,COUNTERMEASURE AND ACTION
M/C 118 MAEGERLE GEAR GRINDING MACHINE

Updated on 15/11/2018

BOSCH

ITEM	MONTH 2015												MAIN PROBLEM	METHOD OF ACTION (Repair/Service/Part Replacement)	STATUS (repair by tech)	ANALYSIS	DATE	PIC	COUNTERMEASURE & ACTION	ATTACH FILE / DONE ASSEMBLE	UPDATED STATUS (after counter measure)
	JAN	FEB	MAC	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC									
1		x											Splash door not fully closed and opened due to stuck with chip.	Remove all the chip and test run ok.	Done	Observing the rootcouse to find out the countermeasure.Analysis prevention method for this repeated issue.	15/02/2016	Boon & Team Member	Plan to have one periodical cleaning to remove all the chip.Input this cleaning task as a item in half year TPM.But need to modify the machine cover by making small door to ease technician while doing cleaning or checking at splash door area. On 4/5/2016,vendor came and made small door at splash door area.This modification is made at both **Maegerle m/c 118 &119**.The effectiveness of this modification is still under monitoring.	Countermeasure	DONE
2												x		Remove all the chip and test run ok.	Done						
ITEM	MONTH 2016																				
	JAN	FEB	MAC	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC									
3				x									Splash door stuck due to roller went out.Fix back the roller and remove chip residue by tech	Fix back the roller and remove chip residue by tech	Done						

STATUS

- OBSERVATION STAGE
- IN PROGRESS
- KIV
- DONE
- NEW ISSUE FROM MONTH

FRM-3162 Rev A

Example of Action List