ESTABLISHMENT OF AUTONOMOUS MAINTENANCE PROGRAMME TO ENHANCE EFFICIENCY OF LATHE MACHINES

RABIATUL ADAWIYAH BINTI NORAZAM

B092010104

BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (BMIW) WITH HONOURS

2023

Faculty of Industrial and Manufacturing Technology and Engineering

ESTABLISHMENT OF AUTONOMOUS MAINTENANCE PROGRAMME TO ENHANCE EFFICIENCY OF LATHE MACHINES

Rabiatul Adawiyah Binti Norazam

Bachelor of Manufacturing Engineering Technology (BMIW) with Honours

2023

ESTABLISHMENT OF AUTONOMOUS MAINTENANCE PROGRAMME TO ENHANCE EFFICIENCY OF LATHE MACHINES

RABIATUL ADAWIYAH BINTI NORAZAM

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology (BMIW) with Honours

Faculty of Industrial and Manufacturing Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

DECLARATION

I declare that this Choose an item. entitled "Establishment Of Autonomous Maintenance Programme To Enhance Efficiency Of Lathe Machines" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Rabiatul Adawiyah Binti Norazam

Date : 10/1/2024

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (BMMW) with Honours.

Signature	:	
Supervisor Name	:	Prof. Madya Ts. Dr. Wan Hasrulnizzam Bin Wan Mahmood
Date	:	10/1/2024

DEDICATION

To my beloved family especially to my parents :

Norazam Omar and Shamsiah Asat

To my respected supervisor :

Prof. Madya Ts. Dr. Wan Hasrulnizzam Bin Wan Mahmood

To my supportive friends in UTeM :

Especially for my classmates from BMIW1/1

ABSTRACT

The lathe machine is a flexible and often used tool in manufacturing and machining. It is essential for accurately and effectively shaping and machining a variety of workpieces. In FTKIP laboratory, lathe machines are frequently use for different processes with different parameters. If maintenance is neglected, it can affect the machine functionality and the safety of the machine user. This study was developed with the purpose of enhancing the lathe machine functionality by recommending OPL and SOP for abnormalities elimination for the machines. The main objective was to study and apply the best autonomous maintenance practices for abnormalities in lathe machine at FTKIP laboratory. *Fuguai* analysis was carried out to find abnormalities on the lathe machine. During the machine inspection, any *fuguai* found is marked with F-tag, meaning it required attention and further actions. The implementation of several One Point Lesson (OPL) and Standard Operating Procedure (SOP) has been carried out to eliminate the abnormalities found in the machine. This project only focuses in implementation of autonomous maintenance practices on lathe machines in FTKIP laboratory. It does not include other maintenance strategies like preventive and predictive maintenance or broader organizational changes beyond the autonomous maintenance framework within the specified manufacturing facility. This research identified that the most *fuguai* found are in physical category which is can be done by the machine user and operator. Different OPL and SOP for *fuguai* elimination is created for better guidance to the machine user. Some of *fuguai* cannot be eliminated since it required an expert technician. This type of *fuguai* is marked with red F-tag. The standardisation of OPL and SOP of a machine are crucial since it is the main guidance for the machine user in autonomous maintenance activity. Implementation of basic steps of autonomous maintenance play important roles in sustaining the machine efficiency. This project can encourage the students in FTKIP to apply autonomous maintenance when using machine in laboratory.

ABSTRAK

Mesin pelarik adalah alat yang fleksibel dan sering digunakan dalam bidang pembuatan dan pemesinan. Ia penting untuk membentuk dan memesin pelbagai bahan kerja dengan tepat dan berkesan. Di makmal FTKIP, mesin pelarik kerap digunakan untuk proses yang berbeza dengan parameter yang berbeza. Jika penyelenggaraan diabaikan, ia boleh menjejaskan fungsi mesin dan keselamatan pengguna mesin. Kajian ini dijalankan dengan tujuan untuk meningkatkan fungsi mesin pelarik dengan mengesyorkan OPL dan SOP untuk penghapusan keabnormalan untuk mesin. Objektif utama adalah untuk mengkaji dan menggunakan amalan penyelenggaraan autonomi terbaik untuk keabnormalan dalam mesin pelarik di makmal FTKIP. Analisis *fuguai* telah dijalankan untuk mencari keabnormalan pada mesin pelarik. Semasa pemeriksaan mesin, mana-mana *fuguai* yang ditemui ditanda dengan F-tag, bermakna ia memerlukan perhatian dan tindakan selanjutnya. Pelaksanaan beberapa One Point Lesson (OPL) dan Standard Operating Procedure (SOP) telah dijalankan bagi menghapuskan keabnormalan yang terdapat pada mesin tersebut. Projek ini hanya memfokuskan kepada pelaksanaan amalan penyelenggaraan autonomi pada mesin larik di makmal FTKIP. Kajian ini mengenal pasti bahawa *fuguai* yang paling banyak ditemui adalah dalam kategori fizikal yang boleh dilakukan oleh pengguna mesin. OPL dan SOP yang berbeza untuk penyingkiran *fuguai* dicipta untuk panduan yang lebih baik kepada pengguna mesin. Sesetengah *fuguai* tidak boleh dihapuskan kerana ia memerlukan juruteknik pakar. Jenis *fuguai* ini ditandakan dengan F-tag merah. Penyeragaman OPL dan SOP mesin adalah penting kerana ia merupakan panduan utama bagi pengguna mesin dalam aktiviti penyelenggaraan autonomi. Pelaksanaan langkah asas penyelenggaraan autonomi memainkan peranan penting dalam mengekalkan kecekapan mesin. Projek ini dapat menggalakkan pelajar di FTKIP untuk mengaplikasikan penyelenggaraan autonomi apabila menggunakan mesin di makmal.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform.

My utmost appreciation goes to my main supervisor, Prof. Madya Ts. Dr. Wan Hasrulnizzam Bin Wan Mahmood, Faculty of Industrial and Manufacturing Technology and Engineering (FTKIP), Universiti Teknikal Malaysia Melaka (UTeM), for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered.

Last but not least, from the bottom of my heart a gratitude to my parents for their encouragements and who have been the pillar of strength in all my endeavors. I would also like to thank my beloved partner and my friends for their endless support. Finally, thank you to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AM	-	Autonomous Maintenance
F-tags	-	*Fuguai* Tags
FTKIP	-	Faculty of Industrial and Manufacturing Technology and Engineering
JIPM	-	Japan Institute of Plant Maintenance
OPL	-	One Point Lesson
SOP	-	Standard Operating Procedure
TPM	-	Total Productive Maintenance
UTeM	-	Universiti Teknikal Malaysia Melaka

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

In the field of manufacturing, there are many types of machinery with various functions are used to carry out related tasks. The lathe machine is one of the most adaptable and popular machine tools in use today. The manufacturing, automotive, aerospace, and engineering sectors all use lathe machines extensively. They are essential in the machining and shaping of a variety of materials, such as metals, plastics, and wood. The world of machining still relies on lathe machines to produce intricate components and produce beautiful designs. Since their creation, these devices have revolutionized numerous industries, including the educational institution and they are now regarded as one of the most crucial tools.

There are various types of lathe machine with different functions and being used for different purposes. In university, most of the user are students that use the lathe machine for learning purposes. Although the lathe machine is widely used in manufacturing industry, the cost of owning it still high. To own a lathe machines, a large amount of initial investment capital is needed, as well as ongoing maintenance costs for the machine's parts and components. To overcome the high investment cost of the lathe machines, maintenance is very crucial in maintaining the machine's performance.

After a long run, many consequences such as machine breakdown can occur if proper maintenance is not carried out. In addition to safety concerns, poor maintenance can make the system deteriorate and result in quality issues, such as delays and non-conforming products that result in financial losses (Ollila & Malmipuro, 1999 cited in Holmgren, 2006). When a serious machine breakdown occurs, it requires high maintenance costs because the repairs call for highly trained workers. Maintenance is crucial because it can increase availability, prolong machine life, and maintain the machine's peak performance. To preserve the component tool life and utilize the entire expected lifespan of the machine, proper maintenance implementation is introduced. Without maintenance, equipment flaws could go unnoticed and cause harm, or worse, death. Any system flaws will be revealed by routine equipment maintenance, allowing for repairs to be made.

The concept of maintenance is expanded in autonomous maintenance. The idea behind autonomous maintenance is that machine users perform relatively straightforward maintenance tasks to maintain the machine in the best possible operational condition. Its goal is to eliminate all time-consuming activities connected to production system halts brought on by equipment failures, which invariably have a negative impact on process efficiency (Kosicka et al., 2019). The implementation of autonomous maintenance is important for the enhancement of machine efficiency as a whole and to simulate a higher awareness of machine maintenance among students. Machine's user can prevent mechanical mishaps in a secure working environment by maintaining the condition of the equipment. Zero breakdowns, zero accidents, and zero defects are the results of a successful implementation of autonomous maintenance.

1.2 Problem statement

In the faculty of industry and manufacturing technology and engineering (FTKIP) laboratory at Universiti Teknikal Malaysia Melaka (UTeM), lathe machines are frequently used. The lathe machines are frequently employed in industry for repetitive routines, however in the FTKIP laboratory, the machines are used for various procedures with various parameters and materials. If maintenance is neglected, it will have an impact on the machine's functionality. For the safety of machine users as well as to restore the lathe machines to their peak performance, proper maintenance must be performed.

The problem at hand pertains to the implementation of autonomous maintenance in the context of student learning and practical application of lathe machines. While autonomous maintenance plays a vital role in ensuring the efficient operation and longevity of these machines, students often face several challenges in understanding and applying these techniques. Insufficient practical exposure and hands-on experience hinder their ability to grasp the significance of autonomous maintenance and its practical implementation. Additionally, the scarcity of educational resources, including manuals, guidelines, and training modules specifically designed for students, further exacerbates the problem.

The lack of structured integration of autonomous maintenance into the curriculum leaves a gap between theoretical knowledge and practical application. Moreover, limited research has been conducted to evaluate the impact of incorporating autonomous maintenance techniques in student learning, hindering the assessment of its benefits. Addressing these challenges is crucial to equip students with the necessary skills and knowledge to effectively maintain and operate lathe machines autonomously, ensuring their preparedness for real-world scenarios.

1.3 Objectives

The main objectives of this study are:

a. To study autonomous maintenance practices for abnormalities in lathe machine shop.

b. To apply autonomous maintenance basic steps for selected lathe machine.

c. To recommend OPL and SOP for abnormalities elimination for the selected machine.

1.4 Scope of Project

This project will be focusing on the development of autonomous maintenance programme for lathe machines in the FTKIP laboratory in UTeM. This project is supervised by the laboratory assistant who expertise in the lathe machines. The project's primary focus is the implementation of autonomous maintenance procedures. This project started from March 2023 to January 2024. The results of this project are based on laboratory job shops conducted for educational purposes only; they are not intended for use in industry. As a result, the findings might not be relevant for other kinds of lathe machines.

1.5 Importance of Project

The importance of the project are :

a. To set up a suitable machine maintenance schedule that will allow for the early detection of abnormalities and the ability to avoid expensive repair costs.

b. To start creating a promising workplace that is safe and clean in order to reduce the likelihood of accidents.

c. To raise students' awareness of the significance of machine maintenance for academic purposes.

d. To increase machine availability and prolong machine life.

e. To improve student's knowledge of machine maintenance in order to prepare them for future industrial work environments.

1.6 Outline of the Report

The project's background, problem statement, and objectives were all introduced in Chapter 1, along with the project's importance and its defiance of the project's scope.

Chapter 2 will focus on literature review. This chapter describes the literature review on the concept of maintenance on autonomous maintenance and review on the lathe machines.

The research methodology is presented in Chapter 3. The project's design in detail as well as the technique for gathering data are presented in this chapter. With the help of flowcharts and Gantt charts, the specifics of the project design flow are shown, and this chapter goes on to discuss data collection techniques, analytical techniques, and *fuguai* investigations.

The analysis and discussion of the findings are presented in Chapter 4. This chapter presents the data collected and makes the data visually appealing using tables, charts, and graphs. Through OPL and specific steps, the countermeasures for each identified *fuguai* are shown and described.

By summarising the data and solutions used throughout the project, Chapter 5 brings the project to a close. This chapter also includes future suggestions for enhancements.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Autonomous Maintenance

The goal of autonomous maintenance is to give operators the tools they need to take care of their equipment and avoid breakdowns through regular maintenance procedures. Autonomous maintenance refers to human capital development among operators supported by technicians and engineers to perform easy daily maintenance activities aside from planned maintenance (Ahmad et al., 2011). To cut down on the requirement for maintenance personnel and increase equipment reliability, this strategy entails teaching operators how to perform simple maintenance activities including lubrication, inspection, and cleaning. In research from Gomes da Silva et al., (2019), autonomous maintenance helps operators maintain their machines, supported by the central maintenance department.

The capacity to foster a culture of ownership and accountability among operators, which can result in greater equipment performance and higher levels of productivity, is one of the key advantages of autonomous maintenance. Additionally, organizations may better understand their equipment and spot possible faults before they develop into significant ones by incorporating operators in the maintenance process. Gomes da Silva et al., (2019) states that one of the most efficient ways to convert a factory into an equipment-focused operation is through autonomous maintenance, which offers qualities such as dependability, availability, productivity, and operational safety that are crucial for quality, lead times, and production costs. A tool that comes from the eight pillars of the Total Productive Maintenance (TPM) system is autonomous maintenance (Guariente et al., 2017).

2.2 Concept of Autonomous Maintenance in TPM

Previous study by Kumar et al., (2017) have emphasized that TPM starts with 5S. A 5S framework is used to reduce waste and boost profitability by maintaining a tidy workplace and employing visual cues to produce more reliable operational results. The 5S process is typically thought of as the first step in continuous improvement techniques. 5S originated as 5 Japanese words which is *Seiri* (Sort), *Seiton* (Straighten), *Seiso* (Shine), *Seiketsu* (Standardize) and *Shitsuke* (Sustain). Table 2.1 will describe the meaning of 5S.

Table 2.1 Meaning of 5S

Japanese	English	Meaning
Seiri	Sort	To reduce clutter and boost productivity, get rid of extra items from the workplace.
Seiton	Straighten	To make it simple to find and use the remaining items when needed, arrange them in a logical and accessible manner.
Seiso	Shine	To encourage safety and a pleasant working environment, keep the workplace neat and well-kept.
Seiketsu	Standardize	Establish uniform policies and guidelines to ensure that everyone maintains the first three steps in the same way.
Shitsuke	Sustain	By consistently auditing and reinforcing the 5S practices to make them ingrained, create a culture of continuous improvement.

According to Guariente et al., (2017) the implementation of TPM requires setting up eight support pillars, one of which is autonomous maintenance. This is defined as a set of preventive and predictive maintenance activities carried out by the operator, who is involved in machine manufacturing functions and is thus responsible for its maintenance and working order. TPM offers a plan for raising production process productivity and quality for world-class manufacturing. TPM offers a method for raising production processes' productivity and quality for "World Class Manufacturing" (Vital et al., 2020). Figure 2.1 shows autonomous maintenance as the first pillars in TPM.

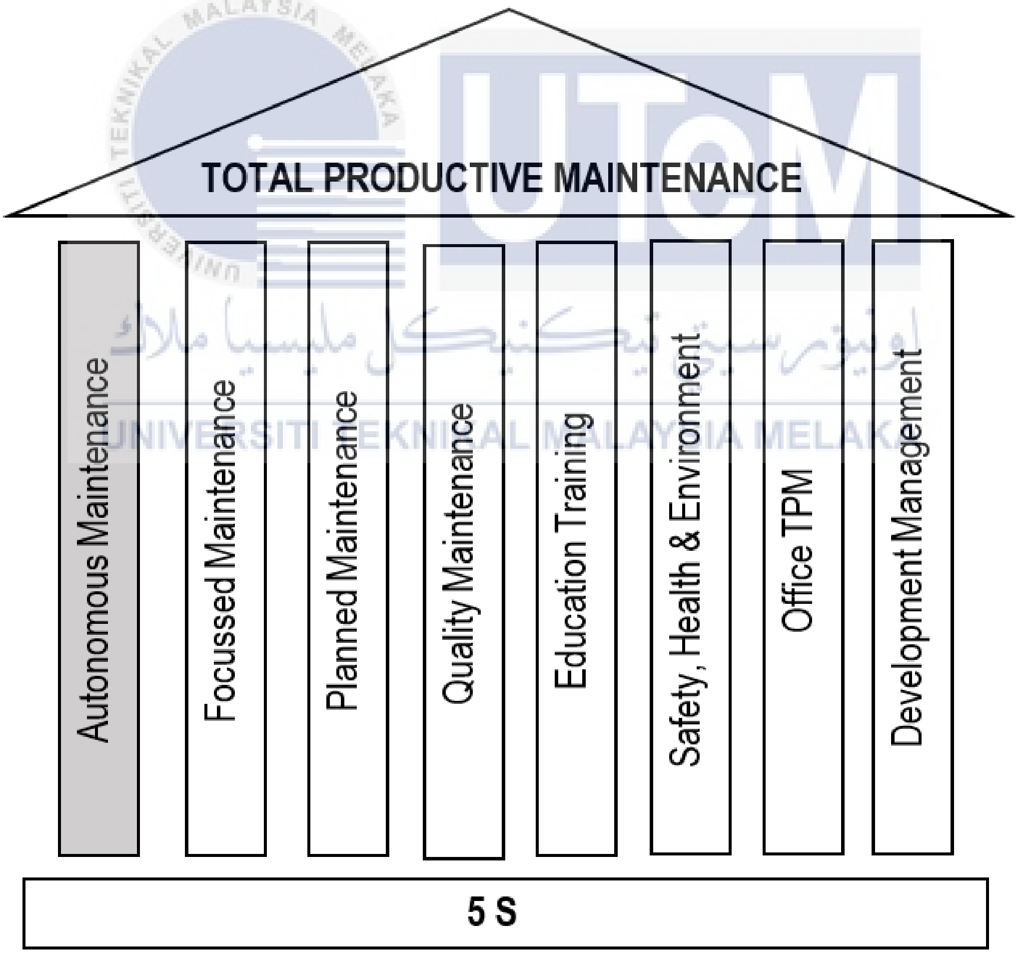


Figure 2.1 TPM pillars

Total Productive Maintenance (TPM) focuses on maximizing equipment performance, establishing a productive maintenance system that optimizes its life cycle, contributing for the continuous improvement and availability, avoiding early equipment wear, being necessary that the maintenance works on preventing with managerial focus. The TPM method is crucial for keeping the machinery in good working order and ensuring continuous production (Vital et al., 2020). In a case study by Singh et al., (2018), Total Productive Maintenance is made up of three words. Total denotes a thorough examination of all maintenance-related actions and their effects on equipment availability. Productive refers to the effort's ultimate purpose, which is efficient production rather than just efficient maintenance as is sometimes believed and maintenance represents the program's strategic focus on ensuring reliable processes and maintaining production. TPM aims to eliminate losses, reduce costs and downtime (Pinto et al., 2020).

Everyone must take care of the machines and not just rely on technicians to fix them in order to make this concept realistic. It is more of a machine prevention concept before any malfunctions occur. Because they use the machines for extended periods of time, machine operators are more accustomed to them. Operators must perform autonomous maintenance to keep the machines in their baseline conditions for optimum performance. Operators with advanced knowledge will be able to perform simple maintenance tasks, freeing up the skilled maintenance staff to perform repairs and other tasks that require more precise technical knowledge.

The same idea is expanded upon in the study by Moscoso et al. (2019), which claims that the implementation of TPM relies heavily on preventative tasks performed by operators, such as fundamental cleaning, lubrication, adjustment, and verification. Autonomous maintenance, the initial stage of TPM deployment, reduces unneeded equipment breakdowns and increases equipment productivity to give operators a sense of ownership over their equipment. The TPM maximizes productivity and equipment availability while fostering a motivating environment to encourage employee participation and outperform competitors in terms of quality, reliability, cost effectiveness, and creativity (Pinto et al., 2020).

2.3 The steps in implementation of Autonomous Maintenance

The Japanese "Institute of Plant Engineering" combined maintenance ideas from the United States and established a new standard. Autonomous maintenance was the new concept's central tenet. Machine operators who were knowledgeable and skilled were essential to its success (Poór et al., 2015). Nakamura (2016) identified the idea of setting up autonomous maintenance in a step-by-step fashion was proposed by the Japan Institute of Plant Maintenance (JIPM).

Autonomous maintenance implementation has been broken down into seven stages. By breaking the process down into phases, you can organize and streamline the implementation process while concentrating on the goals you have set for each stage. The successful implementation of autonomous maintenance is based on the efforts of ongoing teams that provide "caring" for the machines. These teams are qualified and skilled enough to develop a machine maintenance system that runs efficiently and on its own (Molenda, 2016). The seven-step autonomous maintenance methodology teaches the operator how to care for the machines using fundamental maintenance practices (Kumar et al., 2017). From the review of Ali (2019), the steps in autonomous maintenance are preparation of employees, initial clean-up of measures, take counter measures, fix tentative AM standards, general inspection, standardization, and autonomous management. Figure 2.2 shows the seven steps in autonomous maintenance.

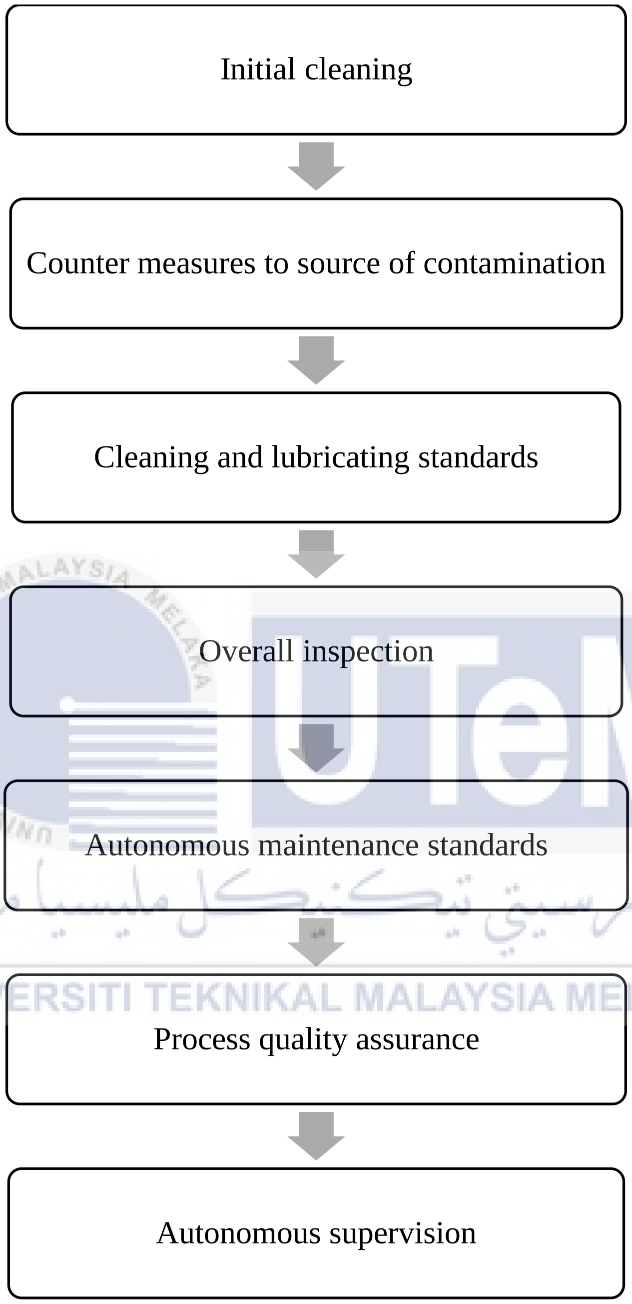


Figure 2.2 Seven steps in autonomous maintenance

Further extending of description for the seven steps in autonomous maintenance are as follows :

2.3.1 Step 1 : Initial cleaning

The purpose of this step is to thoroughly clean the equipment inside and outside (Molenda, 2016). According to a study by Vivek (2018), the first thing that needs to be done is clean the machine and its surroundings. Initial cleaning enables the operator to inspect the machines for wear and tear while also cleaning them. This is done with the goal of identifying and removing any hidden flaws. In this case, cleaning entails lubrication, dirt removal, tightening loose nuts and bolts, and other tasks. The aspects of initial cleaning process are further described as follows :

- Training and standardize cleaning process

  Operators must receive thorough training on fundamental cleaning and inspection as part of their job duties. Before beginning any cleaning tasks, safety measures must be verified to make sure they are in place. The work area, machine, and any supporting furniture like holders, trolleys, and casings all need to be thoroughly cleaned around the workstation.

- Cleaning tools and equipment

  To accomplish the cleaning goals, the fundamental cleaning process needs equipment or tools. Machine cleaning can be done with a wide variety of tools, each of which serves a specific purpose. In the first stage of autonomous maintenance, the operator must select the right tool for the cleaning task. For the convenience of cleaning accumulated grease, cleaning tools like lubricant spray, isopropyl alcohol and cleaning rag is used. Figure 2.3 shows an example of lubricant spray and Figure 2.4 shows an example of cleaning rag that commonly used for cleaning machine surface. Isopropyl alcohol is effective in cutting through and removing oils, greases, and residues that accumulate on machine parts. Its solvent properties make it excellent for cleaning and degreasing surfaces without leaving behind residue. Figure 2.5 shows an example of isopropyl alcohol.

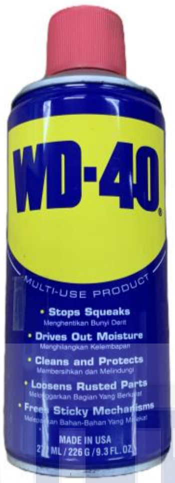


Figure 2.3 Example of lubricant spray

Figure 2.4 Example of cleaning rag

Figure 2.5 Example of isopropyl alcohol

Tools for cleaning the floor include mops, vacuum cleaners, floor scrubbers and brooms. For various cleaning tasks, there are various types of cleaning brushes, including hard brushes and soft brushes. To remove rust and debris, hard brushes like wire brushes are frequently used. For light cleaning of dust and dirt, soft brushes like jute brushes are typically used. Figure 2.6 shows example of cleaning brush.

Figure 2.6 Example of cleaning brush

- Method sensing based inspection

The primary means of finding anomalies during the cleaning process is through the use of senses. Eyesight viewing, a common sensing technique, can identify abnormalities like oil leaks, broken parts, or scratches. Smelling is a sense used to identify odd odours like abnormal burning smells or gas smells. Continuously, the hearing sense is used to listen for unusual noises like buzzing sounds or mechanical vibrations.

2.3.2 Step 2 : Counter measures to source of contamination

Implementing countermeasures to sources of contamination means controlling the sources of debris. This is done by repairing leaky pipe joints, installing shields where necessary, and making other repairs and modifications to eliminate the source of debris and keep equipment functioning properly. Kowalski et al., (2018) suggested operators are responsible for listing and countermeasure for source of contamination and hard to reach areas. As it is crucial to maintain the machine or equipment to remain in top working condition, the proper measures should be taken into consideration. The actions to be taken in this step are to prevent contamination, encourage orderliness, and encourage safe access. The approach to the source of contamination as depicted in Figure 2.7 can serve as an example of how this practice has improved.

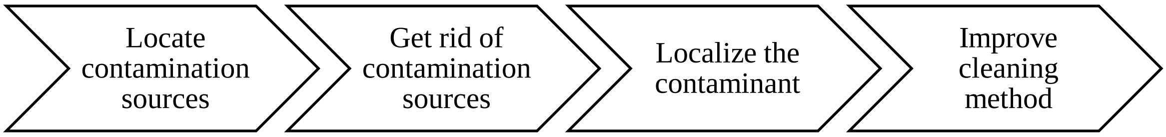


Figure 2.7 Step approach in counter measures to source of contamination

2.3.3 Step 3 : Cleaning and lubricating standards

The introduction of visual standards, cleaning, lubrication, tightening, and loosening are the goals of this step. By providing quick feedback on the current situation, this facilitates the inspection of these operations (Molenda, 2016). In the study by Cepeda et al., (2021) in the Maintenance Plan based on TPM for Turbine Recovery Machinery, standards for lubrication and cleaning activities were established during the implementation of autonomous maintenance. It is important to remember that this step can be modified as necessary depending on the available tools and the operator. All standards should be recorded once they have been finalized, whether on paper or, even better, digitally, and made available to the operators. In this step, guidelines for cleaning, lubrication, and inspections are developed to help operators follow the best practices for machine maintenance. The standards specify what needs to be cleaned, how to apply the practice, how often or when cleaning should be done, and other details that serve as operators' guidelines. Figure 2.8 shows the approach towards developing the cleaning and lubricating standards.

Figure 2.8 Approach towards development of cleaning and lubricating standards

2.3.4 Step 4 : Overall inspection

Kumar et al., (2017) reported that only the trained operator inspects the machine's internal components, such as the pneumatic system, lubrication system, fasteners, etc., allowing for the quick identification, analysis, and correction of operational abnormalities. The overall inspection or general inspection as according to Ferreira and Leite (2016), operators already obtained the training and standards to follow in the practice of maintenance of the machine. This step involves inspecting the equipment and fixing any found defective areas, putting the operators' newly acquired skills into practice. For better standard and routine adjustment and increased productivity, inspection is necessary.

2.3.5 Step 5 : Autonomous maintenance standards

Reviewing the operator's role, enhancing all activities being carried out, as well as improving maintenance and control of autonomous inspection, are the goals of this step. A system is also established. Implement standards and visual equipment inspection points at the workplace. Autonomous maintenance guidelines have been established to standardize procedures and test them on the machines to ensure that the overall inspection is carried out correctly (Sun, 2019). By performing regular maintenance to maintain the standards, additional work must be put forth to simplify the necessary task and eliminate human error. In this step, the use of visual controls is established. Visual control harmonizes autonomous maintenance in preserving each piece of equipment's integrity. By ensuring that the machinery or equipment is in reliable working order, the standards are intended to create an organized shop floor.

2.3.6 Step 6 : Process quality assurance

At this point, operations are enhanced with past actions to guarantee product quality. Management's job is to raise standards and ensure that they are being applied (Molenda, 2016). To avoid producing defective products and letting them enter downstream processes, a highly reliable process is achieved. In order to fully implement autonomous supervision, this step reviews the operators' knowledge of product quality, equipment, and methods for continuous improvement (Azizi, 2015).

2.3.7 Step 7 : Autonomous supervision

Periodically, previous assessments of the standards and practices are revised. Failure reports are kept in order to provide information for upcoming maintenance tasks and the development of better machines. monitoring the standardized procedures to identify areas for enhancement and ensuring their smooth operation. Operator feedback is essential for ongoing improvement. This makes it possible to anticipate problems.

2.4 Importance of implementation of Autonomous Maintenance

Numerous studies have shown that implementing autonomous maintenance does increase overall productivity. A case study on the development of autonomous maintenance implementation framework was presented by Min et al. (2011) and was based on four systematic stages: AM initial preparation, AM training and motivation, AM five-step execution, and AM audit. The case study shows that minimizing machine breakdown rate through the use of autonomous maintenance led to a significant improvement in production performance. A previous study by Ben (2022) in implementation of Autonomous Maintenance and its effect on MTBF, MTTR have shown that autonomous maintenance help increase machine availability and mean time between failure (MTBF) and contributed towards a significant reduction in mean time to repair (MTTR). According to the findings of this study, autonomous maintenance is a crucial program that can give machine operators the knowledge and abilities they need to identify machine abnormalities, improve equipment performance, cut downtime, and boost machine reliability.

While operators are trained on problem solving in the workplace to reduce production losses and contribute to the improvement of productivity, autonomous maintenance has an impact on the maintenance times by reducing processing and order waiting times (Morales Méndez & Rodriguez, 2017). A recent study by Molenda (2016) concluded that the implementation of autonomous maintenance in the audited company has primarily reduced failures and the amount of time it takes to fix them. Iswidibyo et al., (2019) pointed out that autonomous maintenance standardizes and enhances the operator's fundamental machine maintenance skills in addition to early detection of abnormalities on the machine before the serious machine breakdown occurs. Early detection of machine abnormalities can increase the operator's and working environment's overall safety.

2.5 Significance of Autonomous Maintenance on Lathe Machine

The significance of autonomous maintenance on machines draws deeper attention to effect towards machines, while earlier research on the implementation of autonomous maintenance is established in a wider field on overall effect. Azizi (2015) found that autonomous maintenance successfully reduced defect rates by 8.49%. Time spent on machine breakdowns has significantly decreased. Machine performance and defect rate information are interrelated. As a result, improved production productivity performance is the result of improved machine performance.

Based on the research by Ferrerira et al., (2016), the verification of effect of the autonomous maintenance is shown through increment of productivity and the stop time of the production line is decreasing. Other than that, the maintenance staff's availability to solve other issues that more crucial. A brief period of time is spent performing the maintenance on this equipment between the production of the final, high-quality product and interesting results. According to research by Filho et al., (2019), the improvement in operators' knowledge of machines and autonomous maintenance techniques, the decrease in equipment downtime, and the increase in machine availability serve as evidence of the effects of autonomous maintenance. Operator skill levels are sufficient for basic maintenance, freeing up technical maintenance staff to handle more urgent problems.

These studies findings indicated that implementing autonomous maintenance would benefit both operators and machines. The two frequently mentioned points are the increase in machine availability and the decrease in machine breakdown rate. However, far too little focus has been placed on determining the most effective method for maintaining machine components and the maintenance schedule. The specific steps taken to implement autonomous maintenance on one machine in a job shop can be used as a guide for future, more widespread applications. In order to develop a suitable standard that can be used in a mass production line to avoid unnecessary costs, preventive actions should be discovered starting from a single machine.

2.6 Lathe Machine : In Review

The autonomous maintenance program for lathe machines is the major emphasis of this project. A lathe machine is a power-driven tool that rotates a workpiece on its axis to perform various operations of manufacturing. It is an essential tool in the manufacturing industry, used for shaping and forming metal, wood, or other materials into various shapes and sizes.

The lathe machine's basic components include the headstock, tailstock, bed, carriage, and cutting tools. The headstock houses the spindle, which rotates the workpiece, while the tailstock provides support and stability to the workpiece. The bed is the foundation of the machine, providing support to all the other components. The carriage moves along the bed and holds the cutting tools that shape the workpiece. Figure 2.9 shows the schematic diagram of lathe machine.

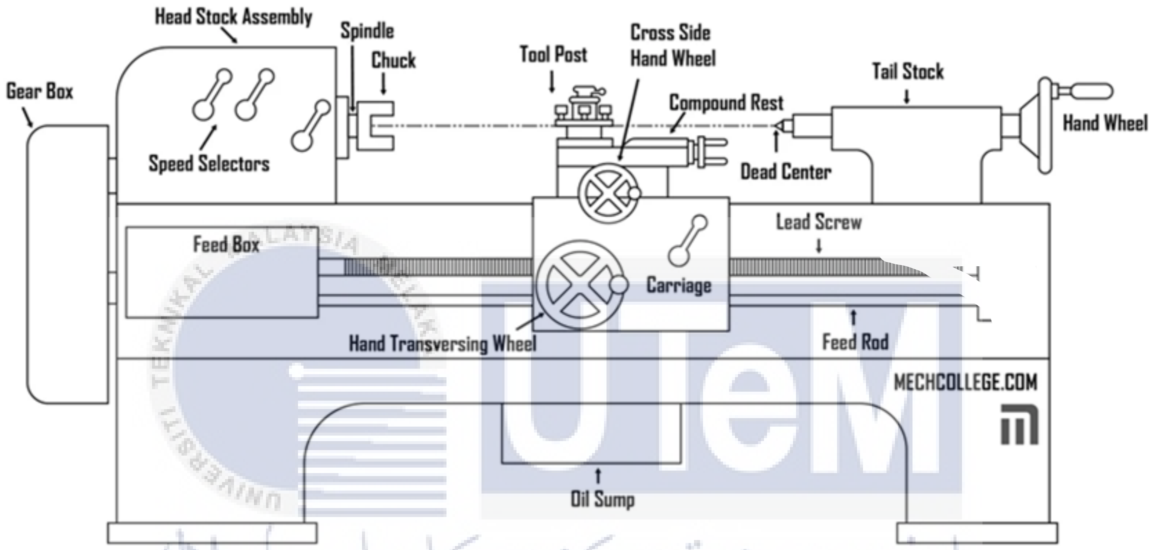


Figure 2.9 Schematic diagram of lathe machine (MechCollege, 2022)

The cutting tool is advanced along the desired cut line as the work is held and rotated on its axis. With suitable attachments, the lather may be used for turning, tapering, form turning, screw cutting, facing, dulling, boring, spinning, grinding, polishing operation. Cutting operations are performed with a cutting tool fed either parallel or at right angles to the axis of the work.

The lathe machine is a versatile tool used for various operations in the manufacturing industry. Its popularity and importance in the industry have been demonstrated by its widespread use over the years. As technology continues to evolve, the lathe machine is likely to undergo further improvements to meet the changing demands of the manufacturing industry.

2.7 Lathe for job shop operation (Process based layout)

Lathe machines are crucial to manufacturing in the realm of mechanical engineering. In order to give the workpiece desired shape and size, undesirable metals are removed using a lathe. Chauhan and Patel (2020) states that the job to be machined is held and rotated in a lathe chuck; a cutting tool is advanced which is stationary against the rotating job. This is accomplished by holding workpiece securely on the machine and turning against tool which will remove material from workpiece. To cut the material the tool should be harder than the workpiece and should be rigidly hold on the machine and should be fed in definite way relative to the workpiece. Some of the common operations performed on a lathe are facing, turning, drilling, threading, knurling, and boring etc.

From very small bench lathes used for precise work to enormous lathes used to turn giant steel shafts, lathes are produced in a range of styles and sizes. Yet, all types of lathes operate and function according to the same principles.

2.7.1 Speed lathe

The first one is speed lathe which is the simplest types of lathes. It is only included bed, headstock, tailstock, and tool post. In speed lathe, there is no food box, lead screw or carriage. With only hand control, the tool is installed on the tool post and fed into the job. This feature of the lathe allows the designer to provide high speeds in the range of 1200 to 3600 rpm. There are only two or three speeds available, and the headstock is made quite simply. It is mostly utilized for spinning, centering, and polishing. Figure 2.10 shows an example of speed lathe.

Figure 2.10 Example of speed lathe (Chauhan and Patel, 2020)

2.7.2 Engine lathe

Engine lathe, the second kind of lathe machine, are the most popular and are used extensively in workshops. Drawing into the research by Chauhan and Patel (2020), the engine lathe has all the fundamental components, including a bed, headstock, and tailstock, just like the speed lathe. However, the engine lathe's headstock is built considerably more solidly and has multiple speed mechanisms. With the aid of a carriage, the cutting tool can be fed both transversely and longitudinally with respect to the lathe axis. Engine lathes are categorized based on how power is delivered to the machine. Figure 2.11 shows an example of engine lathe.

Figure 2.11 Example of engine lathe (Chauhan and Patel, 2020)

2.7.3 Bench lathe

Typically, bench lathe is bench-mounted. It performs all the operations and has almost all the components of an engine lathe; the only distinction is size. This lathe is utilized for accurate, tiny work. To make a new object, you can cut, knurl, drill, or sand material using a bench lathe. The block will be held at two points by the lathe, which will spin it as the user shapes the material into the desired shape. The surplus material can be removed from the work area using this type of lathe's bed or horizontal beam. On the left side of the lathe is where the headstock is situated. The portion of the lathe that houses the rotating bearings is called a headstock. A spindle is attached to the bench lathe. These accessories are attached to this hollow bar that runs perpendicular to the bed. These add-ons hold the workpiece firmly in place. These lathes frequently contain a hand wheel that enable various equipment to be connected to the machine.

2.7.4 Tool room lathe

Move to another type of lathe machines, tool room lathe. It has similar features to an engine lathe and much more accurate and has wide range of speed from very low to 2500 rpm. It is known as a tool room lathe because it is used to manufacture precise components, dies, tools, jigs, and other items. Figure 2.12 shows an example of tool room lathe.

Figure 2.12 Example of tool room lathe (Chauhan and Patel, 2020)

These lathes can be used for a wider range of operations and have space to hold multiple tools. These are especially well suited for quickly producing large quantities of identical parts.

2.7.5 Capstan and turret lathe

These lathes can be used for a wider range of operations and have space to hold multiple tools. These are especially well suited for quickly producing large quantities of identical parts. Turret and capstan lathes both have advantages in terms of productivity, adaptability, and turning operations efficiency. The decision between them is influenced by various elements, including the size and complexity of the workpiece, the volume of production, and the necessary machining procedures.

Capstan lathe :

A capstan lathe is a type of machine tool used for high-speed production of small to medium-sized workpieces. It is primarily designed for turning operations, where the workpiece is rotated against a cutting tool to shape it into the desired form. The distinguishing feature of a capstan lathe is its turret.

A capstan lathe's turret houses several cutting tools, which are typically arranged in a circular or hexagonal pattern. Quick tool changes are possible during the machining process thanks to the ability of each tool to be quickly indexed into position. By decreasing the time needed for manual tool adjustments and setups, this feature increases productivity. Figure 2.13 shows an example of capstan lathe.

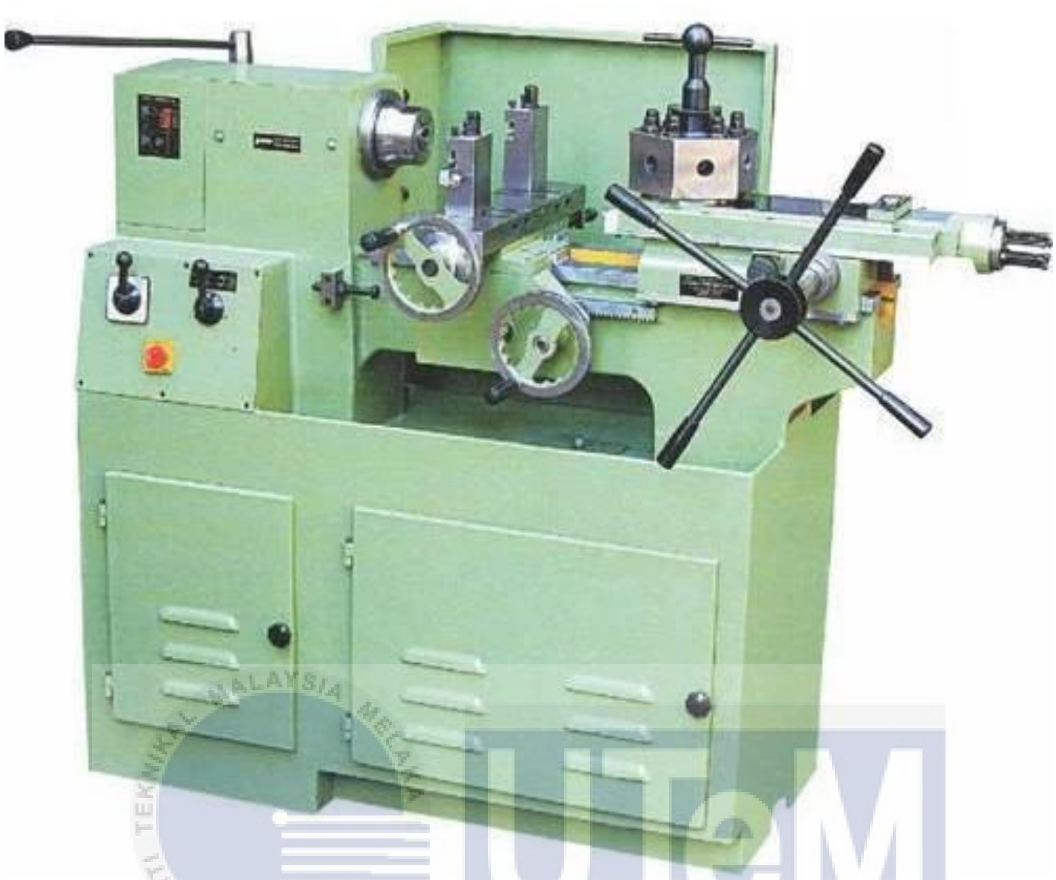


Figure 2.13 Example of capstan lathe

For producing repetitive workpieces with quick cycle times, capstan lathes are frequently used. They are especially well suited for the mass production of tiny parts like screws, bolts, and comparable parts. The lathe can carry out a variety of machining operations, such as turning, facing, grooving, threading, and drilling, without the need for significant setup changes thanks to the turret's capacity to hold multiple tools.

Turret lathe :

A turret lathe is another kind of machine tool used for turning operations, but it has a different tooling setup from a capstan lathe. Turret lathes have a stationary turret that is situated on the lathe bed, as opposed to capstan lathes, which have a movable turret. It also features numerous cutting tools that are similarly arranged in a circular or hexagonal pattern in the turret. Instead of indexing individual tools as in a capstan lathe, the entire turret rotates in a turret lathe to position the desired tool. Figure 2.14 shows a schematic diagram of turret lathe.

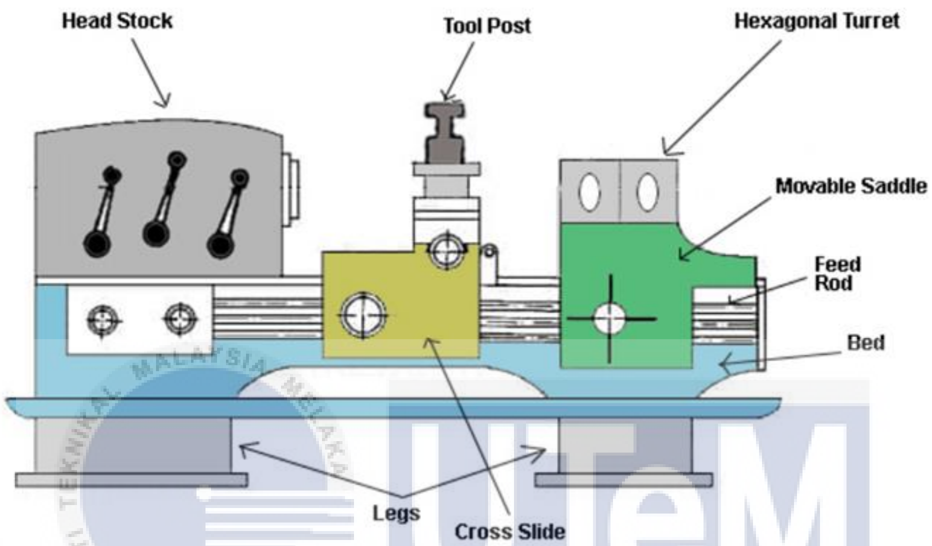


Figure 2.14 Schematic diagram of turret lathe

For medium to large sized workpieces that need a variety of machining operations, turret lathes are frequently used. They are renowned for their adaptability and are capable of a variety of tasks, including turning, boring, facing, drilling, and threading. Turret lathes are frequently used in sectors like the automotive, aerospace, and general engineering that demand intricate and varied machining operations.

2.7.6 Special purpose lathe

They are utilized for specialized tasks and jobs that a normal lathe cannot accommodate or conveniently process. Wheel lathe, gap bed lathe, T-lathe, and duplicating lathe are the four types into which it can be divided. The wheels for locomotives are made on a wheel lathe. Large diameter workpieces are machined on a gap bed lathe. The rotors for jet engines are machined on a T-lathe. Use a replicating lathe to transfer the design of a flat or rounded template onto the workpiece. Figure 2.15 shows an example of special purpose lathe.

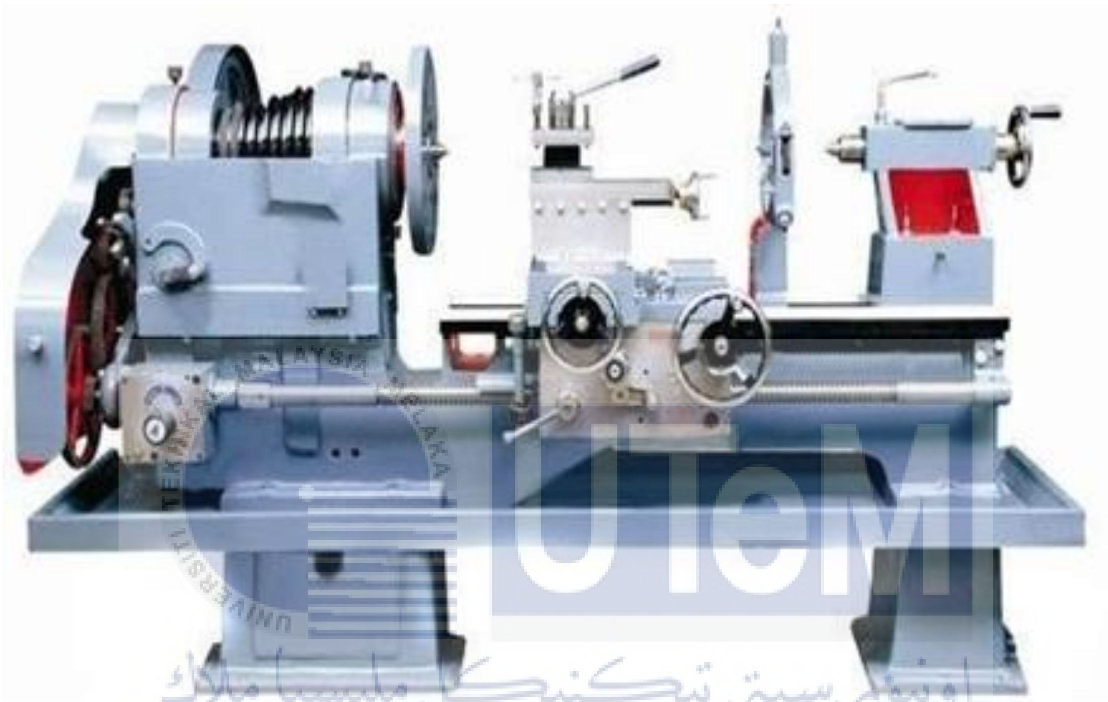


Figure 2.15 Example of special purpose lathe (Chauhan and Patel, 2020)

Special purpose lathes are made to accomplish specialized jobs or to serve certain industries or applications, as opposed to general-purpose lathes, which can handle a variety of turning operations. These lathes are frequently customized or custom-built to match the specifications of a given machining operation.

2.7.2 Type of turning process

There are numerous kinds of turning processes, each with its own functions and outcomes. Table 2.2 describe the common types of turning process.

Table 2.2 Type of turning process

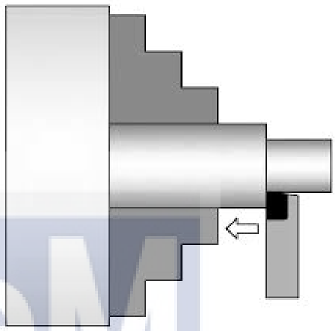
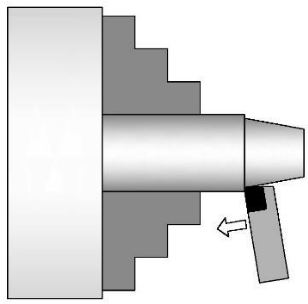
Type of turning process	Descriptions	Picture
Straight turning	The most fundamental kind of turning is straight turning, commonly referred to as cylindrical turning or outer diameter turning. In this procedure, the workpiece's outer surface is sliced away with a cutting tool to produce a cylindrical shape with a constant diameter along its length. Shafts, rods, and other cylindrical parts are often made through straight turning.	 Figure 2.16 : Straight turning process
Taper turning	Machining a workpiece into a tapered shape is known as taper turning. From one end to the other, the workpiece's diameter gradually decreases, forming a cone or tapered cylinder. By changing the tool's angle or by utilising a taper attachment, taper turning can be accomplished. Components like conical pulleys, pipe fittings, and machine tool guides can be made using this method.	 Figure 2.17 : Taper turning process

Table 2.2 Type of turning process (…continued)

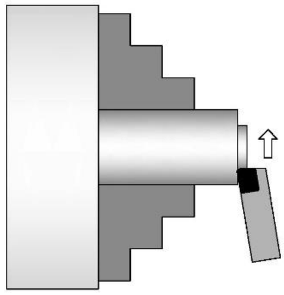
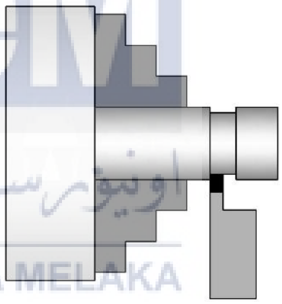
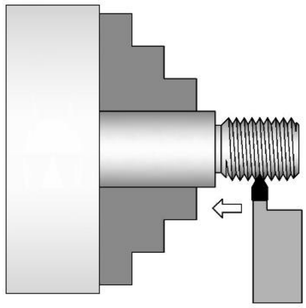
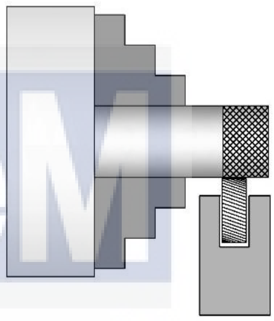
Type of turning process	**Descriptions**	**Picture**
Facing	In the turning process known as facing, the end face of a workpiece is machined until it is flat and parallel to the workpiece's axis. Usually, a single-point cutting tool is used to complete the task. Facing is frequently done to provide smooth and accurate end faces for components like flanges, valves, or bearing seats or as a preliminary step before further turning operations.	 Figure 2.18 : Facing process
Grooving	Cutting grooves or recesses into the surface of a workpiece is the process of grooving. Depending on the needs, these grooves could be straight, circular, or have other shapes. Keyways, oil channels, O-ring grooves, and other specialised profiles are examples of characteristics that are frequently included into components through grooving.	 Figure 2.19 : Grooving process

Table 2.2 Type of turning process (…continued)

Type of turning process	Descriptions	Picture
Thread cutting	Making threads on the surface of a workpiece is the process of thread cutting. It entails creating either internal (female) or external (male) threads by cutting spiral grooves around the cylinder surface. For the production of parts like bolts, screws, and nuts, thread cutting is essential.	 Figure 2.20 : Thread cutting process
Knurling	Knurling is a turning process used to indent a workpiece's surface with a pattern of ridges or diamond shaped indentations. This design improves grip and gives the surface a rough finish for easier handling. On parts like handles, knobs, or hand tools, knurling is frequently found.	 Figure 2.21 : Knurling process

2.8 Lathe machine (JET GH-1440W Metal Lathe)

In the FTKIP laboratory, there are only one type of lathe machine. The model of lathe machine is JET GH-1440W Metal Lathe. This project focus on this lathe machine as the project scope is based on the routine and usage of this lathe machine model. Figure 2.22 shows JET GH-1440W metal lathe.

Figure 2.22 JET GH-1440W Metal Lathe

The JET GH-1440W metal lathe has a wide range of machining capabilities for metal workpieces. It is commonly used in workshops, industrial facilities, and educational institutions. The system in this lathe machine is same as the other lathe machine in the industry. The type of this lathe machine is engine lathe. The hardened and ground gears are featured in the headstock and gearbox. The headstock also constantly oiled during the operation and it has independent leadscrew and feed rod. In order to shape a workpiece, this lathe machine uses rotational force and a stationary cutting tool. Typically, the workpiece is made from metal or wood. The cutting tool is pressed against the rotating workpiece. This lathe machine can produce faces, threads, holes, and other patterns desire by the user. There are some key components and mechanisms found in this metal lathe. Table 2.3 describes the functions of lathe machine component.

Table 2.3 Functions of lathe machine component

No	Type of component	Function
1.	Bed	The main parts of the lathe are supported and aligned by the bed, a heavy, rigid base. It gives solidness and guarantees exact machining by limiting vibrations.
2.	Headstock	The main motor, gears, and spindle assembly are all housed in the headstock. It gives rotational movement to the workpiece by pivoting the shaft, which is mounted with a hurl or other holding gadgets.
3.	Spindle	The workpiece is held in place by the spindle, a rotating shaft. A motor and gearbox arrangement in the headstock typically powers it. The axle speed can be changed in accordance with oblige various materials and cutting activities.
4.	Carriage	The carriage is the moving stage that conveys the cutting devices and is mounted on the bed. The saddle, cross-slide, and compound rest are among its many components. The carriage can move longitudinally along the bed (known as the Z-pivot) and cross across the bed (known as the X-hub).
5.	Apron	Mechanisms for controlling the carriage's movement can be found in the apron, which is on the carriage's front. It houses the lead screw, which converts rotary motion into longitudinal movement, as well as the feed and threading gears.

Table 2.3 Functions of lathe machine component (…continued)

No	Type of component	Function
6.	Tailstock	The headstock and the tailstock are on opposite sides of the lathe. It can be clamped in place and moved along the bed. The tailstock frequently contains a plume, which can be stretched out or withdrawn to help the workpiece during machining.
7.	Tool post	The tool post is mounted on the carriage and holds the cutting instruments. It considers simple and exact change of the instrument's position comparative with the workpiece. Various kinds of cutting devices, like turning instruments, drilling bars, and bores, can be embedded into the apparatus post.
8.	Chuck	The workpiece is held firmly by the chuck, which is connected to the spindle. Depending on the need, it comes in a variety of forms, including three-jaw, four-jaw, and collet chucks.

2.9 Safety precautions for lathe process

When employed in manufacturing and machining procedures, lathe machines are strong and possibly dangerous tools. If not operated correctly, metalworking machines can be deadly. As a result, the following notes as well as the pertinent general technical regulations must be followed. Hence, safety measures must be implemented to safeguard the operator's safety as well as the safety of any nearby workers. According to a study by Barua et al. (2021), safety training, maintenance, and machine guarding were found to be beneficial in lowering the incidence of incidents connected to lathe machine operations. To protect the safety of everyone involved in the lathe machine process, specific safety procedures and requirements must be followed. The following describes the safety operation, hazards, and precautions on lathe machine.

2.9.1 Training for safe operation

Before utilizing the lathe machines, operators must have adequate training on topics such potential machine dangers, control measures, operating procedures, emergency procedures, and safety precautions. Operators must fully understand on the use of personal protective equipment (PPE) such as safety glasses, hearing protection and safety shoes to ensure their own safety.

2.9.2 Hazards

Machine hazards are the possible causes of harm or danger that could result in accidents or damage to people, property, or the environment. Lathe machine has rotating parts like chucks, spindles and workpiece that can cause the operator entangled or crushed by them. If the workpieces are not properly secured of have defects that can be ejected from the lathe and cause serious injuries. Furthermore, operator can be burned by hot workpieces, hot chips, or cutting fluids. According to a study by Mukherjee et al. (2021), these types of hazards are the most frequent risks connected with lathe machines. In order to reduce accidents involving lathe machine operations, the study stressed the significance of appropriate training, maintenance, and usage of personal protective equipment.

2.9.3 Safety precautions

The basics for safe operation of lathe machines are described as follow :

1. Wear appropriate PPE such as safety glasses, face shields, gloves, and hearing protection to prevent injuries from flying debris, sparks, or noise.
2. Read the manufacturer's instructions and understand the various parts of the lathe machine, including the controls, chucks, tool holders, and tailstock.
3. Inspect the workpiece for defects or irregularities and ensure that it is properly secured to prevent movement or displacement during the operation.
4. Ensure that the cutting tools are properly installed and secured in the tool holder, and adjust the tool height, angle, and feed rate according to the specifications of the workpiece.
5. Use proper techniques such as avoiding excessive force or speed, monitoring the cutting tool for signs of wear or damage, and using cutting fluids to prevent overheating and fires.
6. Once the operation is complete, turn off the machine, remove the workpiece, and properly store the cutting tools and accessories.

2.10 Standard operation procedure of lathe machine

The process of lathe machine starts with switching on the main power supply that is located at the electric box at the rear of the machine. To guarantee safe and effective use, using a lathe machine requires following number of standard procedures. The operating procedure of the lathe machine is as shown in Figure 2.23 and Table 2.4 will describe the steps.

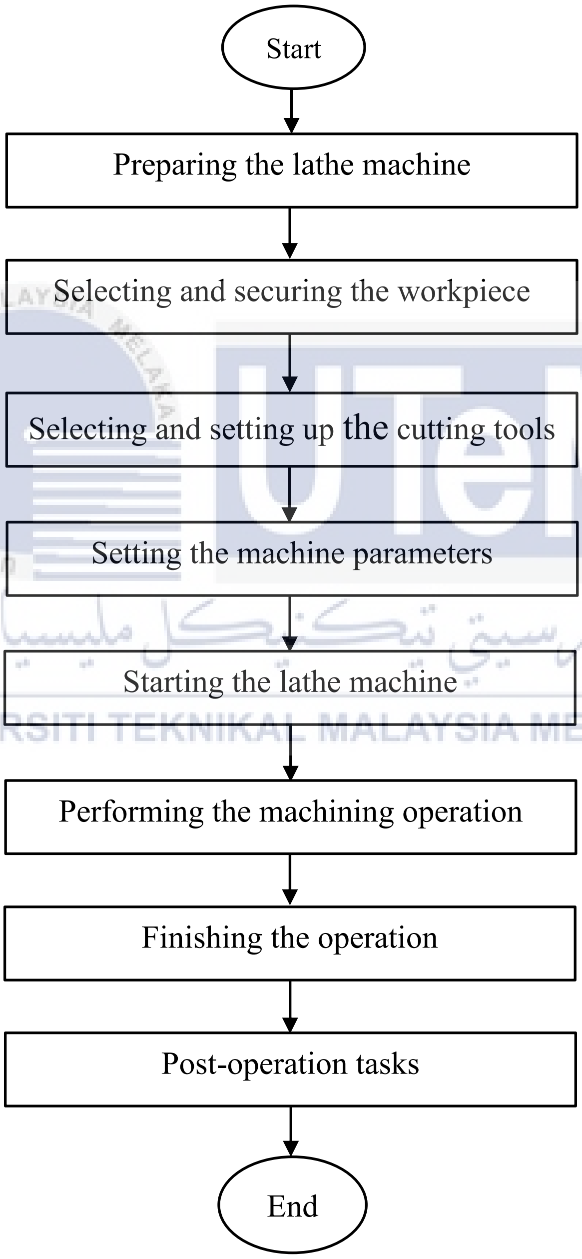


Figure 2.23 Flowchart for lathe machine operating procedure

Table 2.4 Lathe machine operating procedure explanation

No.	Operating Procedure	Description
1.	Preparing the lathe machine	• Make sure the lathe machine is clean and clear of any debris or obstructions before starting to prepare it. • Verify whether the necessary measuring tools, work holding devices, and cutting tools are available. • Make sure the machine is adequately lubricated and that the coolant system (if necessary) is filled.
2.	Selecting and securing the workpiece	• When choosing and securing the workpiece, consider its size, material, and the machining operations that will be needed. • Based on the needs of the workpiece, choose the proper work holding device, such as a chuck, collet, or faceplate. • Carefully insert the workpiece into the work holding system of your choice, making sure it is centered and tightened.
3.	Selecting and setting up the cutting tools	• Based on the machining operation and the material being machined, select the proper cutting tools. • Tighten and securely mount the chosen cutting tool in the tool holder, making sure it is correctly aligned. • Position and height of the cutting tool should be set in accordance with the necessary machining dimensions and cutting parameters.
4.	Setting the machine parameters	• Based on the specifications of the cutting tool and the material being machined, adjust the spindle speed and feed rate of the lathe. • Make the necessary adjustments to the tool slide and compound slide of the lathe machine to obtain the desired cutting angles and depths.

Table 2.4 Lathe machine operating procedure explanation (…continued)

No.	Operating Procedure	Description
5.	Starting the lathe machine	• Verify that all security measures are in place and active. • Turn on the lathe machine's motor and wait until the desired operating speed is reached. • Slowly activate the feed system to let the cutting tool contact the workpiece.
6.	Performing the machining operation	• Use the handwheels on the lathe machine or a CNC control system to direct the cutting tool's movement. • Keep an eye on the cutting process, paying attention to any unusual sounds or vibrations, chip formation, and the quality of the surface finish. • If necessary, adjust the cutting parameters, tool placements, or workpiece positioning to produce the desired effects.
7.	Finishing the operation	• After finishing the machining process, stop the feed mechanism and remove the cutting tool from the workpiece. • Switch off the lathe's motor and wait for it to completely stop. • Take steps to prevent any injury when you carefully remove the machined workpiece from the work holding mechanism.
8.	Post-operation tasks	• Cleaning the lathe machine of any chips, coolant residues, or other debris is the first post-operational chore. • Check the cutting tools for damage or wear; replace or regrind them as necessary. • If necessary, lubricate the lathe machine's parts, and carry out any regular maintenance procedures advised by the manufacturer.

2.11 Maintenance activities for Lathe machine

Maintenance should be conducted on a regular basis to avoid unwanted difficulties and downtime. Machine must be clean regularly and defective safety devices must be replaced immediately. Table 2.5 describes annual lubrication inspection items and measures, and Table 2.6 describes lathe machine inspection items and measures.

Table 2.5 Annual lubrication inspection method and measures

Type of Maintenance	**Inspection item**	**Inspection methods and measures**
Annual Lubrication	Headstock	• Fill oil by pulling plug located on top of the headstock underneath the rubber mat. • Oil must be up to indicator mark in oil sight glass.
	Gearbox	• Fill oil by lifting off thread chart cover and removing plug. • Oil must be up to indicator mark in oil sight glass
	Apron	• Fill oil by removing plug • Oil must be up to indicator mark in oil sight glass
Weekly Lubrication	Rack, Change gears	• Weekly inspect the oil sight glasses, fill oil on demand. • Apply the grease on entire length of the rack and coat all gears with grease.
Daily Lubrication	Carriage	Lubricate 4 ball oilers
	Top slide	Lubricate 1 ball oiler
	Cross slide	Lubricate 4 ball oilers
	Lead screw and feed rod	Apply oil on entire length
	Tailstock	Lubricate 2 ball oilers
	Lead screw/feed rod hub	Lubricate ball oiler

Table 2.6 Lathe machine inspection items and measures

No.	Inspection Item	Inspection Method and Measures
1.	Slide adjustments	• Loosen the rear gib screw by one turn. • Tighten front gib screw approximately a quarter turn. • Try and repeat until slide moves freely without play. • Gently tighten the rear gib screw.
2.	Shear pin replacement	• If a shear pin breaks it must be replaced by knock out the broken pin and line up the holes, then fit the new pin.
3.	Coolant system	• Remove rear access cover on tailstock end of machine stand. • Pour 15 liters of coolant mix into dip pan. • Follow coolant manufacturer's recommendations for use, care, and disposal.

2.12 Types of *fuguai*

The word *fuguai* is from the Japanese word that means abnormalities. The concept of *fuguai* is often associated with the Japanese management philosophy known as Total Productive Maintenance (TPM). Autonomous maintenance is one of the pillars of TPM, focused on empowering operators to take responsibility for the routine care and maintenance of their equipment. Following the examination of potential breakdown issues that lathe machines can experience, we will now learn more about the many kinds of irregularities that will result in the machine breaking down.

Total Productive Maintenance (TPM) classifies irregularities into seven categories, including small flaws, inaccessible places, unfulfilled basic conditions, inaccessible locations, sources of contamination, defective sources, unneeded goods, and unsafe locations (Thorat & Mahesha, 2020). Excessive vibration is one of the potential irregularities or problems that operators may run across while performing autonomous maintenance on a lathe machine. Excessive vibration in a lathe machine may be a sign of alignment problems, workpiece imbalance, worn-out bearings, or spindle problems. Vibration can result in uneven surfaces, decreased precision, and more wear on machine parts.

Minor flaws include aberrant conditions like contamination, cracks, scratches, and part deformation. Several abnormalities can be identified by unusual noise, excessive heat, vibration, or off-putting odours. Figure 2.24 shows an example of scratches on a lathe machine surface.

Figure 2.24 Example of scratches

Unfulfilled basic conditions, typically connected to cleaning, lubricating, and tightening are the abnormal state on not satisfying the basic machine function. Moving parts can experience accelerated wear due to friction and heat buildup brought on by insufficient or improper lubrication. Inadequate lubrication can lead to higher energy costs and lower machine productivity. Figure 2.25 shows an example of lubrication issues on a machine parts.

Figure 2.25 Example of lubrication issues

Areas of the machine that operators cannot reach for cleaning, lubricating, or inspection are referred to as inaccessible places. Furthermore, sources of contamination include things like product leaks, spills, or overflows of liquids, gases, or lubricants. Sources of contamination include non-conforming goods and scrap materials like cutting burrs. Figure 2.26 shows the example of sources of contamination which are cutting scraps.

Figure 2.26 Example of cutting scrap from the turning process

Additionally, defective sources are the foreign particles like dust, scraps, chips, or incorrect machining parameters can cause defects in product quality. The term "unnecessary items" refers to non-essential items that are unnecessary at the workstation and will impede progress. Finally, dangerous locations like crevices, slick surfaces, uneven working surfaces, poor lighting, or working stations without emergency stop devices are dangerous for operators while they work and may cause accidents.

2.13 *Fuguai* tag (F-tag)

Fuguai in the context of autonomous maintenance refers to deviations or abnormalities from a machine or piece of equipment's normal operating parameters. These abnormalities can appear as breakdowns, malfunctions, defects, or any other irregularities that impair the machine's functionality or produce subpar results. *Fuguai* are abnormalities that are discovered on a machine while it is being cleaned for the first time as part of autonomous maintenance (Suryawanshi & Buktar, 2015). F-tag is a visual cue used in autonomous maintenance that indicates a problem or malfunction with the machine's functionality. The F-tag alerts operators and maintenance staff that the equipment needs maintenance or repair. The F-tag's primary purpose is to encourage preventive maintenance procedures and provide operators more control over the equipment's condition. F-tag is applied to the machine to draw attention to any issues they find during routine inspections by the operator. Operators are taught to recognize and take proactive measures to address abnormalities in their equipment when autonomous maintenance is implemented.

Operators can avoid bigger problems like breakdowns or decreased equipment effectiveness by spotting and fixing these abnormalities early on. To keep the machine clean and orderly, *fuguai* are identified during the initial cleaning process, and F-tags are placed on the locations where abnormalities are discovered so that the proper analysis and preventative measures can be taken (Kumar et al., 2017). A recent study by Manish Raj et.al., (2018), said that during the initial cleaning of autonomous maintenance, operators were trained to recognize *fuguai* such as leakages, vibration, inaccessible places, and unsafe places. F-tagging, which is placed directly on the area of the machine where abnormalities are present, is used to apply *fuguai* mapping. F-tags come in three different colours: safety (yellow), operator (blue), and maintenance (red). Figure 2.27 shows an example of F-tag.

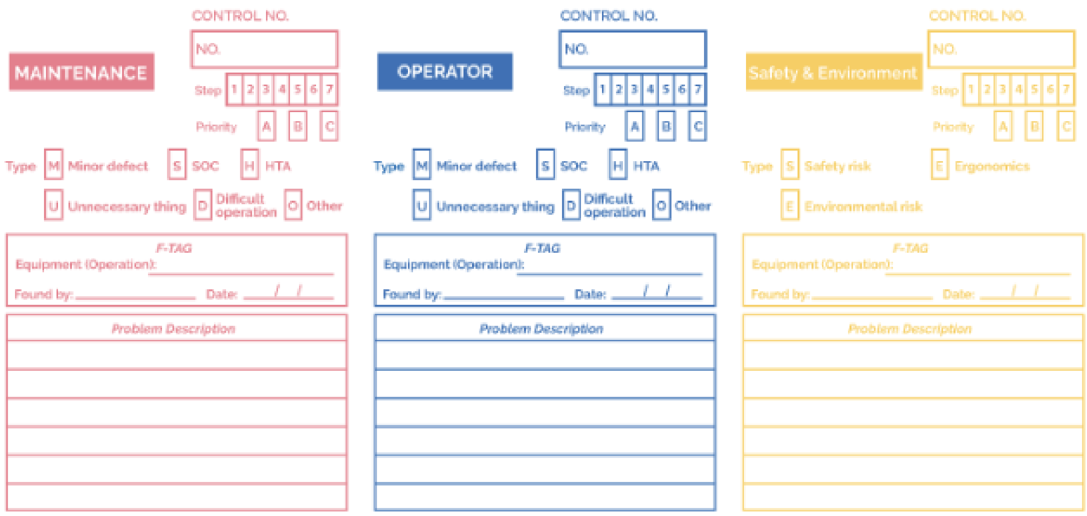


Figure 2.27 Example of F-tags (Source : leanmanufacturing.online)

The red tag indicates the machine's abnormality requires the attention of a technical mechanic in order to be fixed, while the blue tag indicates normal operators can fix the issue. The yellow tag indicates mechanics and operators to solve the abnormalities. The f-tags display the specifics, such as the date, the type of abnormalities, and the problems in detail. A study by Mahmood et al., (2008) have revealed that *fuguai* are divided into three categories; safety, physical and function. The *fuguai* status is clarified using these categories. Safety is regarded as the area of greatest potential danger to machine users. Additionally, the safety hazard may result in a factor that is dangerous and at odds with laboratory rules and regulations.

The physical column indicates that machine irregularities are visible and can be safely ignored. The function column indicates that the machine may malfunction as a result of abnormalities on the machine. The safety column warns that machine abnormalities are dangerous and could endanger the machine operator. The F-tag in autonomous maintenance serves a critical role in supporting proactive maintenance practices, facilitating effective communication, and cultivating a culture of shared responsibility for the maintenance.

2.14 Effects on Machine Without Proper Maintenance

The term "maintenance" refers to tasks that are done to maintain or quickly improve the systems, components, and structures of a plant in order to ensure that they will perform better than intended when called upon (Mahmood et al., 2008). It is very crucial to have a proper maintenance towards the machine since it can bring an impactive effects to the machine if it is not well maintained. Equipment can suffer from a variety of problems that can affect its performance, dependability, and lifespan. One of the effects is an increase in equipment operation costs as operation efficiency declines and component functional failures are more likely to occur (Zhang et al., 2016).

Inadequate maintenance can result in decreased productivity, more unplanned downtime, and a shorter lifespan for the machine. Components or safety features that are not working properly can put people at risk. Poor maintenance can also have negative effects on other connected equipment, lower product quality, higher repair costs, and non-compliance with regulations. For minimizing these effects and ensuring optimum machine performance and longevity, regular preventive maintenance programs, adherence to manufacturer's specifications, and having trained personnel dedicated to maintenance activities are essential (Ramere et al., 2021).

According to a study by Buica et al., (2019), neglecting maintenance has consequences such as resulting in work equipment defects, shortening the technical lifespan of equipment, and creating a hazardous work environment. The study also shows that maintenance activities influence worker health and safety because failure to carry out preventive maintenance can result in damage and disruption as well as more serious workplace accidents and illnesses. Machine may break down or fail without warning if maintenance is neglected. Unexpected downtime while awaiting repairs or replacement parts can result from this. The impact on productivity and project timelines increases with the amount of time the machine is idle. Reviewing the importance of autonomous maintenance on lathe machine is crucial because small issues that could cause a machine to fail are frequently disregarded. When issues go unattended, hidden factors like grease, dust, or debris that have accumulated in processing areas can cause significant losses.

2.15 Summary

To summarize, the findings suggest that creating autonomous maintenance can allow the equipment to work at its best. The concept and approach to achieving autonomous maintenance are explored throughout the chapter. The consequences of unsuccessful autonomous maintenance highlight the need and significance of implementing autonomous maintenance. Autonomous maintenance enables consistent, dependable, and cost-effective operating while also extending machine life. The discussion of the lathe process, machinery, safety precautions, and maintenance list is ongoing. The *fuguai* (abnormalities), f-tags, and losses caused by inappropriate maintenance are examined further.

However, majority reviews on lathe machines mostly concentrated on the final product's influencing factors and process flow. There are few reviews of the lathe machine maintenance procedure. The performance of the equipment will be impacted by the easily overlooked maintenance task. Small issues that are ignored and compounded over time may result in serious equipment failure and irreparable harm. Where it can impact product quality, machine availability, and total cost, the maintenance procedure is just as crucial as the process parameters. To enable a sustainable operation that leads to the next chapter, it is crucial to perform a thorough analysis on the establishment of an autonomous maintenance programme for lathe machine workstations. The research methodology for creating the autonomous maintenance plan for lathe machines is covered in following chapter.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Design of the project

The achievement of the goal and the desired project outcome depend on a well-defined project plan. To make sure the project's outline is in the right direction for reaching the milestones, the design of the project should adhere to a few rules. This project's outline is organised into a few stages. Throughout this project, each stage's planning and application are covered in detail.

The first stage of the project is the process of identification of problem. After identifying the problem, the objectives are then stated to picture the goal of the project next providing the solutions to the stated problems. The project's scope is then determined to make sure that the facilities, equipment, and personnel required for it are available. In order to learn more about the subject and gain a clearer perspective, data collection is done in the project design's next stage. Primary data and secondary data are the two categories into which data can be divided. Through the use of case studies, literature searches, and quantitative and qualitative analysis, data were gathered and analysed. In this project, both varieties of data collection techniques are used. There are four methods for gathering primary data: observation, interview, *fuguai* research, and focused group discussion. The methods used to collect secondary data include *fuguai* tags, manual machine operation, analytical techniques, and internet resources.

On the autonomous maintenance, *fuguai* detection, and lathe machines, additional data collection and information gathering is carried out. To create the ideal autonomous maintenance programme for the lab's lathe machines, the data gathered is then combined and compared with earlier research. In order to create the best autonomous maintenance programme for lathe machines, the combined data are further examined and revised for justification. This project's design flow is shown in Figure 3.1.

The 5 steps involved in implementing autonomous maintenance in a student laboratory are explained in Table 3.1. Each steps represents specific work and, in some steps, we used 9 types of *fuguai* to determine which abnormalities were present, which contributes to the overall maintenance and repair of the laboratory equipment. This project uses a Gantt chart as a project management tool. A Gantt chart is an effective tool for showing the project's tasks and timeline. In the Gantt chart for this project, each task is represented by a bar, and the length of the bar denotes the task's duration. The task timeline for planned and actual planning for the entire project is shown on the Gantt chart. Figure 3.2 shows how the Gantt chart for this project is organised.

Table 3.1 Steps for implementing autonomous maintenance in laboratory

Steps	Description
Step 1 : Preparation	In the laboratory, gather the tools, equipment, and information needed for autonomous maintenance activities. Ensure that cleaning chemicals, lubricants, inspection checklists, and necessary information are easily accessible. Mark any tools or materials that require replenishment or replacement with an F-Tag.
Step 2 : Initial Machine Cleaning And Inspection	Clean the laboratory equipment and its surroundings thoroughly to remove dirt, dust, and debris. This step helps maintain a clean and safe laboratory environment. During this step, we apply 9 types of *fuguai* to determine which type of *fuguai* is involved, and we use F-Tag to mark the areas or equipment that require attention.
Step 3 : Counter measures to source of contamination	Inspect the equipment on a regular basis for leaks, loose connections, and symptoms of excessive lubrication. Repair these problems as soon as possible to avoid contamination and potential defects.
Step 4 : Cleaning and lubricating standards	Develop and document standard operating procedures (SOPs) for cleaning, inspection, and maintenance tasks. These SOPs provide specific instructions to maintain consistency and effectiveness in maintenance activities.
Step 5 : Overall inspection	To detect problems, conduct visual examinations with an OPL or specialised equipment. Record any findings and submit them to the lab assistant for future action.

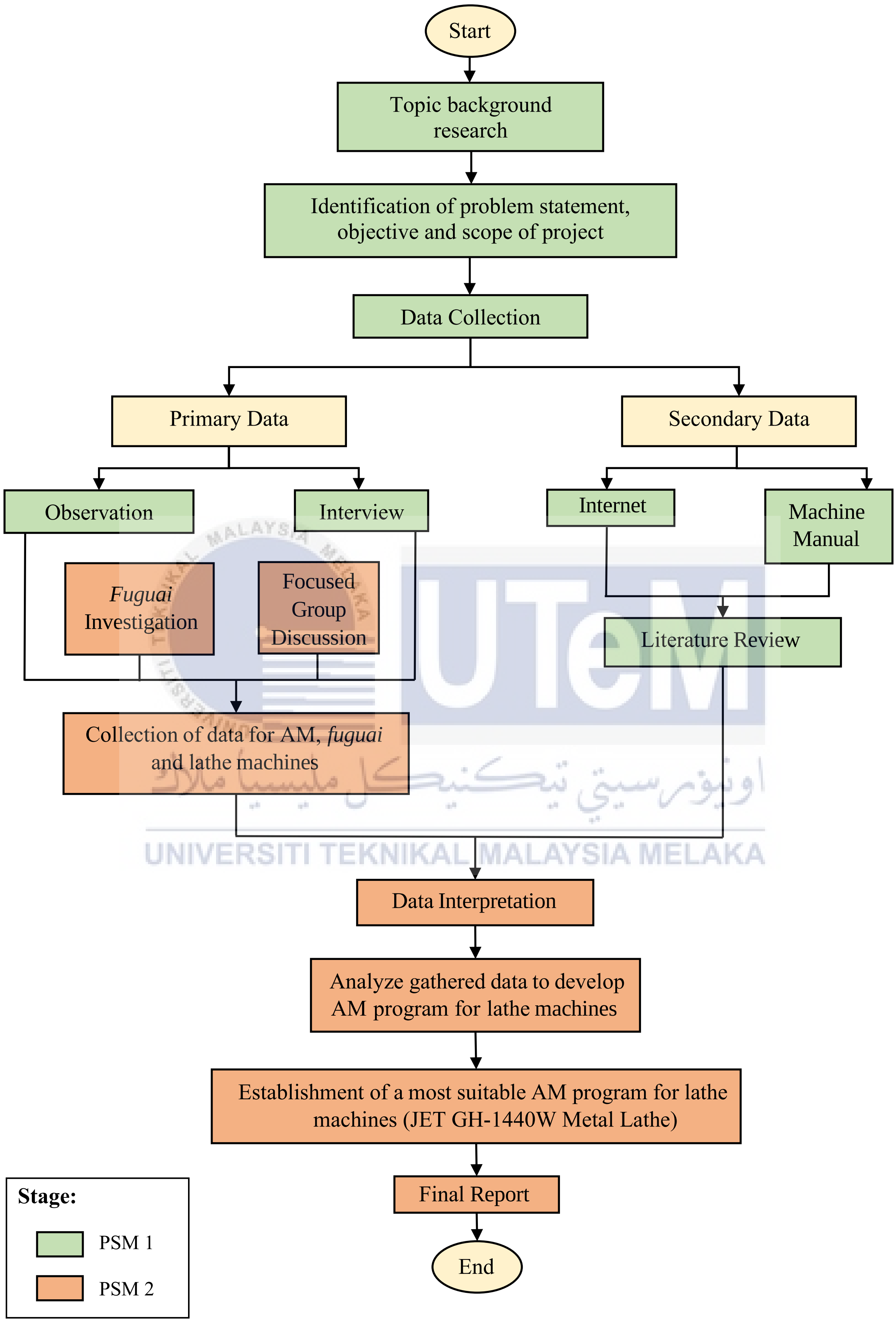


Figure 3.1 Project design flow

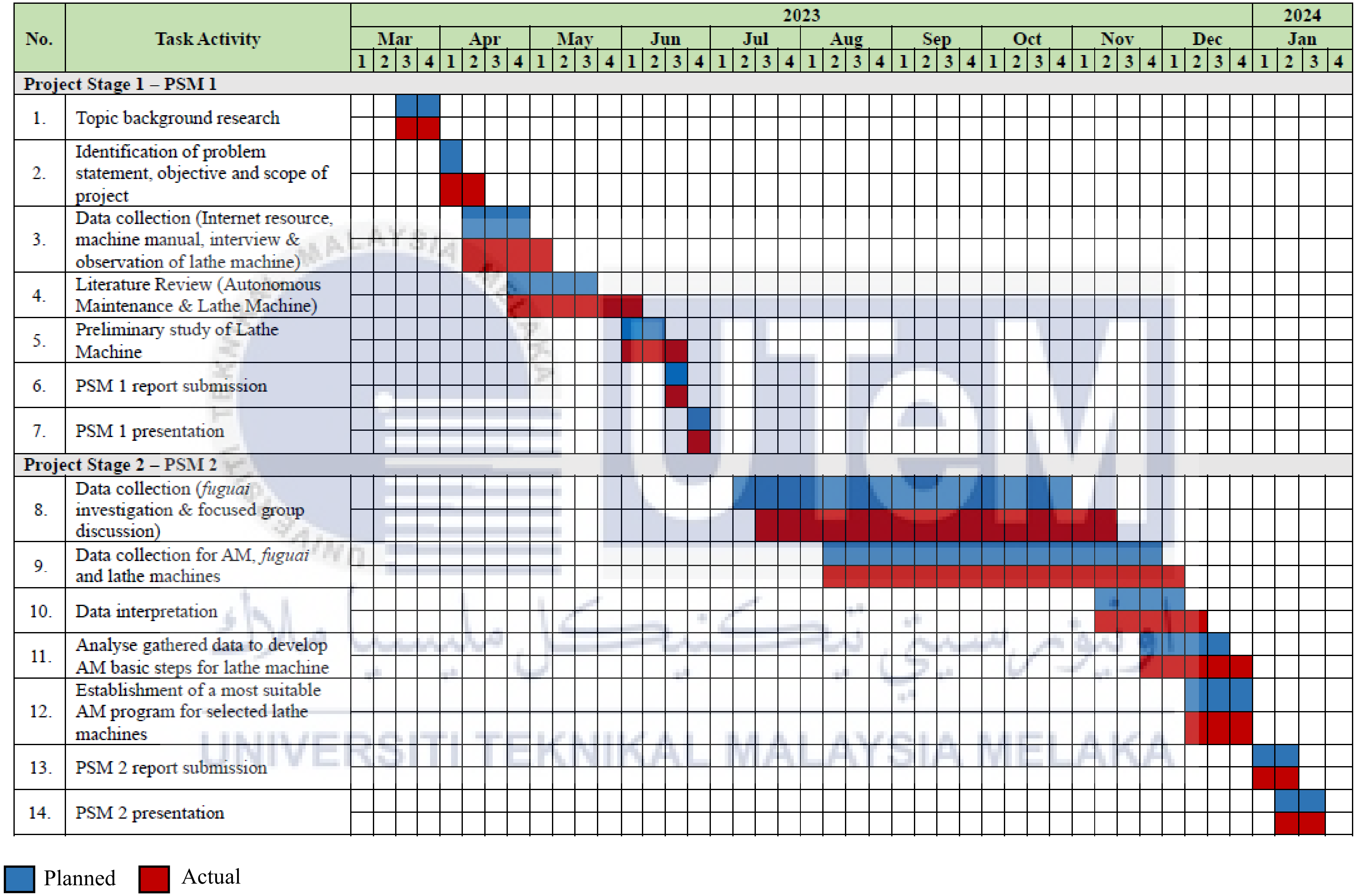


Figure 3.2 Gantt Chart for the project

3.2 Data collection

There are two types of data in data collection which are primary data and secondary data. Primary data is information that has been gathered directly from original sources with the specific aim of the current research or study while secondary data is information that has already been gathered by another party for a different purpose. This project applying both types of data to collect relevant data.

3.2.1 Primary data

Primary data is unprocessed information that has been gathered from a reliable source and directly relates to the research problem. Numerous techniques, including surveys, interviews, observations, experiments, and focus groups, can be used to collect primary data. The primary data collection for this project were focused group discussions, interviews, observations, and *Fuguai* investigations.

3.2.1.1 Observation

Observations are a typical way to gather primary data. Through the process of recording data or information from what we hear and see, observation enables us to interpret that data. Observation method is applied in this project to collect data and information of lathe machine (JET GH-1440W Metal Lathe) in the FTKIP laboratory. Maintenance procedures, tools used during maintenance, and machine condition are all noted in the information and data.

3.2.1.2 Interview

Interviews are conducted to obtain in-depth data, viewpoints, and insights from specific people or groups. Asking and responding to questions about the specifics of the topic are required during the interview process. In this project, interview is conducted with the laboratory engineer who is responsible for the operation of lathe machines (JET GH-1440W Metal Lathe). Information about machine procedure, daily maintenance, machine tools and problems student encounter during lathe process.

3.2.1.3 *Fuguai* investigation

Fuguai investigation is a systematic process of identification and addressing abnormalities found on lathe machines. Three categories which is physical, function, and safety will represent different sections of the abnormalities found in the investigation. The machine parts that need maintenance have *fuguai* tags attached to them.

3.2.1.4 Focused group discussion

With the assistance of an advisor, a focused group discussion is held within a small group to simulate discussion about the study. As there are 3 students working on projects with a similar title that discussing autonomous maintenance programmes for various machines and focus group discussions are used in this project to gather data. Members of the group conduct idea exchanges and information sharing among themselves.

3.2.2 Secondary Data

Secondary data are those that have been collected based on information from earlier studies. The available information is compiled and examined as a review for the chosen subject. Secondary data are gathered from a variety of sources, including academic journals, books, magazines, and online databases.

3.2.2.1 Internet resources

Using internet resources is one of the main ways to collect data because there is a lot information can be found online. Online resources are used to compile e-books, research journals, articles, conference proceedings, and other relevant data. Major internet databases like Google Scholar, Mendeley, Science Direct, and Emerald are used to find research journal findings. Various websites can be used to find additional information about autonomous maintenance and lathe machines.

3.2.2.2 Machine operation manual

Data gathering from the JET GH-1440W Metal Lathe operation manual to gain a better understanding of lathe machines. The machine operator's manual gives detailed information about the lathe machines, including specifications, problems to be solved, and standard operating procedures. The specifics and information are helpful for establishing a benchmark during the creation of an autonomous maintenance programme.

3.2.2.3 Analytical techniques

a. Column chart

In a column chart, also referred to as a vertical bar chart, the category of data is represented by a rectangle, and the values being plotted are shown as the height of the rectangle. Typically, column charts are used to compare values between categories. The use of a column chart is for the data visualization of *fuguai* frequency in relation to *fuguai* category and *fuguai* frequency in relation to the distribution of F-tags. Figure 3.3 shows the prototype model for column chart.

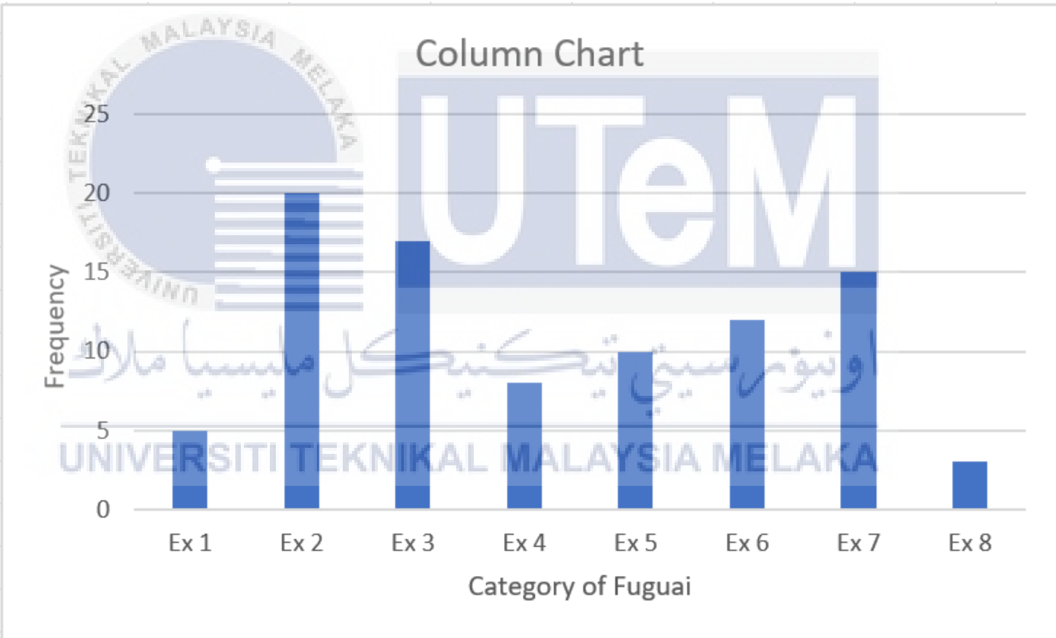


Figure 3.3 Column Chart Prototype Model

b. Pareto chart

Pareto chart is a bar graph with the longest bars on the left and the shortest on the right. The lengths of the bars represent frequency. The graph illustrates which circumstances are more important. Pareto chart is used to analyse the frequency and issues with the data and it concentrates on the important issue. In this project, a pareto chart is used to illustrate the frequency of *fuguai* occurrences, as well as their types and geographic distribution. Figure 3.4 shows the prototype model for pareto chart.

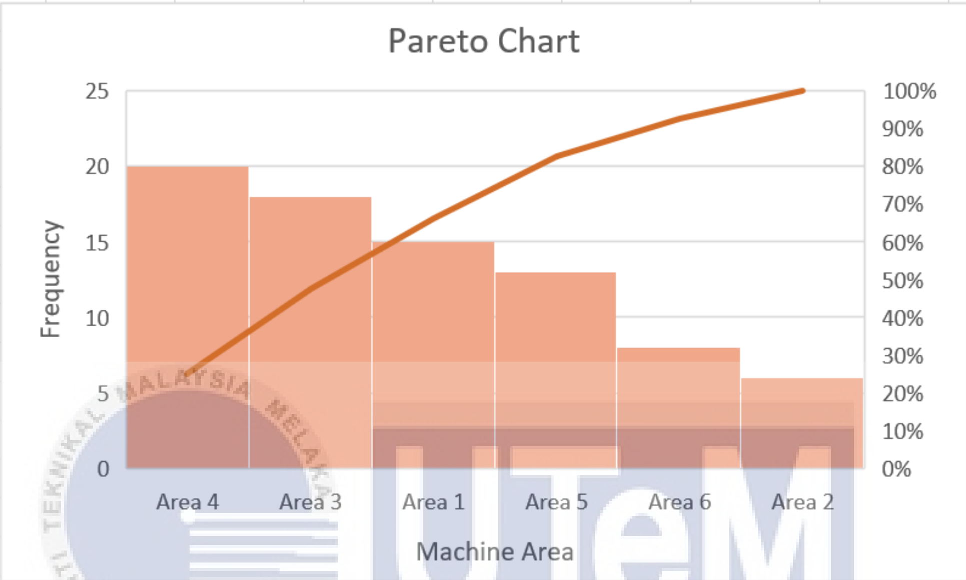


Figure 3.4 Pareto Chart Prototype Model

c. Pie Chart

The breakdown of data into categories for each segment is represented by a pie chart. While the divided segments show the data proportion, the entire circle represents all of the data. Pie charts are used in this project to categorise and analyse the various *fuguai* types. Figure 3.5 shows the prototype model for pie chart.

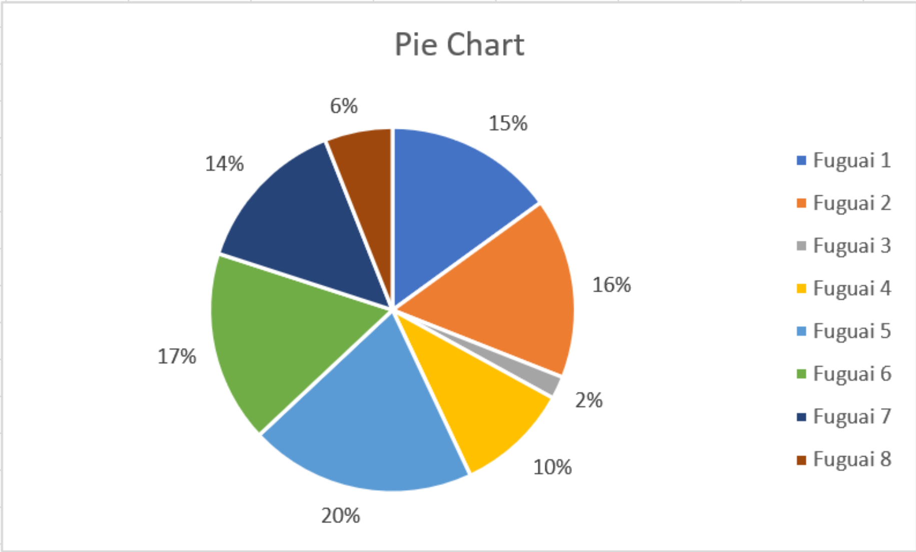


Figure 3.5 Pie Chart Prototype Model

d. One Point Lesson (OPL)

A One Point Lesson (OPL) is a brief instructional piece that focuses on explaining a particular skill or idea in a clear and understandable way. It explains how a task should to be completed. An OPL is a brief document that is created using images, symbols, and simple text. The main idea behind OPL is to make instructions for tasks simple to learn and comprehend. OPL is used in this project to give students a visually appealing document that is simple to understand. Table 3.2 shows the example template of one point lesson used in this project.

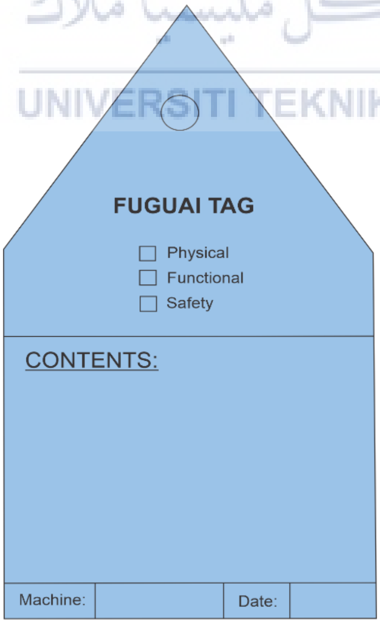
Table 3.2 One Point Lesson template

One Point Lesson	
Part:	Ref No:
	Date:
Classification: Physical Function Safety	
BEFORE	AFTER

3.2.2.4 *Fuguai* tags

Fuguai tags (F-tags) act as a visual cue to draw attention to deviations or abnormalities found during equipment inspections. It was used to mark the locations of abnormalities discovered on the machine during the initial cleaning process. F-tags come in a variety of colours to help identify the various levels of abnormalities so that the appropriate course of action can be taken. There are two distinct colour F-tags with distinct indication purposes. F-tags come in two colours: red and blue. Table 3.3 describes the details of F-tags.

Table 3.3 F-tags colour and function description

F-tags	Descriptions
 Figure 3.6 : Red F-tag	Red conveys the idea of danger. A technical mechanic with extensive knowledge of maintenance is required to address the abnormality indicated by the red f-tag in order to resolve the issue. As abnormal incidents may occur during the process, maintenance personnel with deeper technical knowledge are required to handle the maintenance.
 Figure 3.7 : Blue F-tag	The abnormalities found could be corrected by operators or anyone with the right instructions and guidance, according to the blue colour f-tag. The task listed on the blue f-tag could be completed by someone with only the most basic training or maintenance knowledge. The issues indicated by the blue f-tag don't require advanced maintenance expertise because they can be resolved with simple maintenance techniques like cleaning or repositioning the component.

F-tags in different colours enable operators or anyone else who sees the tag to address the issue right away with a clear view of the problem's specifics, including the problem's category, location, and discovery date. The elements on the F-tags are as described in Table 3.4.

Table 3.4 F-tags elements with descriptions

Elements	**Descriptions**
Fuguai category	On the f-tag, there are three categories of *fuguai*, each of which stands for a different function. a. Physical abnormalities are those that can be seen with the naked eye, such as dust or oil stains on a machine. b. Function denotes the possibility that the machine's discovered abnormalities will malfunction. c. Safety implies that abnormalities may create hazardous conditions for the operators.
Contents	Detail explanation about the *fuguai*.
Date	In order to ensure that the issue is not overlooked, the date the tag was issued is kept on file.
Machine	The indication of a particular machine type.

3.3 Summary

This chapter has discussed the project's design flow and offered a research approach for gathering and analysing data. A flowchart is used to present the project's design, while a Gantt chart is used to show its timeframe. This chapter describes the procedures for gathering primary and secondary data. Primary data come from interviews, concentrated group discussions, observations, and *fuguai* investigations. Internet sources, machine operation manuals, analytical methods, and *fuguai* tags are examples of secondary data. Column charts, pareto charts, pie charts, and one-point lessons are examples of analytical approaches. Prototype models and example templates are used to illustrate each analytical technique in detail. The *fuguai* tags used for this project are shown, along with more explanations of their details. The flow of further findings and the analysis of results in this project are both dependent on the design of the research approach.

CHAPTER 4

ANALYSIS AND DISCUSSIONS

4.1 *Fuguai* Analysis

Fuguai are the abnormalities found on the machines. *Fuguai* analysis refers to the process of identifying, investigating, and understanding anomalies in the machine. The collected data on the *fuguai* are analyzed based on the data collection methods as discussed in the previous chapter. *Fuguai* analysis serves to condense and categorize gathered anomalies, linking data points for simplified identification and pattern recognition within the dataset.

The machine's state is assessed and observed prior to the initial cleaning phase. Any *fuguai* found at various machine parts during this initial cleaning are sorted into distinct *fuguai* types. Investigating these anomalies involves gathering data about the machine's abnormalities through F-tagging and chart analysis methods.

4.1.1 Machine Area

The lathe machines are divided into smaller sections for easier identification of *fuguai* around the machine. The lathe machines are divided into 4 main areas which are front area (FRONT), back area (BACK), left side (SIDE A), right side (SIDE B). The machine area of lathe machine is illustrated as shown in Figure 4.1.

Front view (FRONT)

Back view (BACK)

Left view (SIDE A)

Right view (SIDE B)

Figure 4.1 Lathe machine area layout

4.1.2 Types of *fuguai*

The identified *fuguai* surrounding the lathe machines can be classified into 9 main category which are dust (F1) , dirt (F2) , leftover items (F3) , disorganized items (F4), rusty parts (F5), missing components (F6), broken parts (F7), loosen components (F8) and scratch component (F9). The identified *fuguai* types of each *fuguai* category are as described in Table 4.1.

Table 4.1 List of *fuguai* identified

Ref.	*Fuguai* types	*Fuguai* identified on machine	Description
F1	Dust	Dusty machine surface	Visible grey deposition on the surface of machine which are made of fine particles of dry solid matters.
F2	Dirt	Oil spillage	Machine lubricating oil leakage which caused by seal or fittings failure.
		Dirty surface	Working fluid residue deposited on the worktable.
F3	Leftover items	Leftover workpieces	Unwanted metal pieces and metal wire removed during cutting process.
		Leftover scraps between unreachable areas	Unwanted metal chips and powder dust remained after cutting process.
F4	Disorganized items	Disorganized tubes	Disorganized tubes overlapping.
F5	Rusty parts	Rusty worktable	Reddish brown substance deposited on the worktable due to action of water and air.
		Rusty handle	Handle not moving smoothly due to rusty joint which affect the function.

Table 4.1 List of *fuguai* identified (…continued)

Ref.	***Fuguai* types**	***Fuguai* identified on machine**	**Description**
F6	Missing components	Missing screw	Mislaid screw after dismantling of the machine parts.
		Missing label	Instruction or safety labelling on the machine fell off.
		Missing cover	Mislaid machine part cover.
F7	Broken parts	Broken cover	Broken cover such as broken switch cover cannot serve the protection purpose to the switch.
		Dented filter cover	Dented filter cover which may affect the function.
F8	Loosen components	Loosen screw	Unfastened screws on machine parts after dismantling.
		Loose labels	Instruction or safety labelling on the machine is not in original position.
F9	Scratch component	Scratch worktable or handle	A visible mark on machine component cause by the presence of debris between the workpiece.

4.1.3 Identification of *fuguai* on machine areas

The process of *fuguai* identification is conducted by tagging different colour of F -tags with the detailed description on the F-tag on each *fuguai* found. Different *fuguai* are identified on each 15 lathe machines. Each side of the lathe machine was analyzed to find any *fuguai*. Figure 4.2 shows *fuguai* on lathe machine.

Figure 4.2 *Fuguai* on Lathe Machine

4.2 Data analysis of *fuguai*

Data visualization is the graphical representation of information and data. It can represent the characteristic and patterns in a data set typically used with large data sets and its purpose is to identify key characteristics and patterns in a data set in preparation for statistical analysis and decision making (Krok, 2021). From the raw data of *fuguai* recorded through *fuguai* tagging process, the collected *fuguai* data are analyzed by using statistical tools such as graphs and charts. The *fuguai* found surrounding the machine are analyzed based on machine area, f -tags distribution, *fuguai* category and types. The data are inter-related and are displayed through statistical graph selected for this analysis which are pie chart, pareto chart and column chart. Decision making on resolving the *fuguai* are made based on the presented data.

4.2.1 Analysis of *fuguai* types

Table 4.2 shows the *fuguai* types identified on each machine.

Table 4.2 Data collected for *fuguai* types

***Fuguai* types**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**L10**	**L11**	**L12**	**L13**	**L14**	**L15**	**Total**
F1	5	5	3	2	6	7	6	11	4	9	8	5	6	10	4	91
F2	7	14	7	9	6	8	13	4	2	8	11	12	15	13	13	142
F3	0	2	1	2	2	3	1	3	2	1	2	2	4	2	2	29
F4	1	1	1	1	1	0	0	0	0	1	0	1	1	2	1	11
F5	11	6	6	5	3	4	5	4	3	4	3	6	5	9	5	79
F6	0	1	0	0	0	1	4	2	0	1	0	1	0	4	3	17
F7	1	1	0	2	1	0	0	1	3	1	0	2	1	1	4	18
F8	3	4	3	4	3	2	2	3	6	4	6	6	3	4	5	58
F9	3	1	1	4	3	1	4	3	3	1	1	2	1	1	0	29

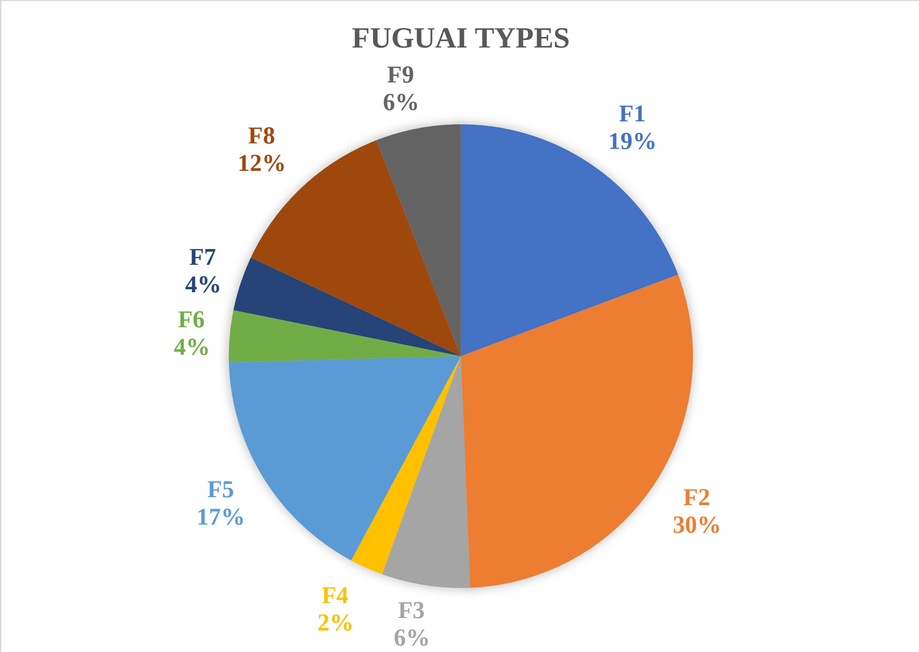


Figure 4.3 Pie chart for *fuguai* types

The *fuguai* types are analyzed by using pie chart as shown in Figure 4.3 to show the highest *fuguai* occurrence among the machines. From the pie chart analysis, dirt (F2) contributed the highest percentage of 30% among all 9 types of *fuguai*. The machine surface and worktable are dirty due to lack of cleaning activities after using the machine. Disorganized items (F4) have percentage of 2% which is the lowest percentage among all *fuguai*. This *fuguai* is the least contributor since disorganized items rarely occur.

4.2.2 Analysis of F-tags distribution

Table 4.3 shows the *fuguai* types identified according to the distribution of f-tags.

Table 4.3 Analysis based on F-tags colour

***Fuguai* types**	**F-tags colour**	
	Blue	**Red**
F1	91	0
F2	134	8
F3	23	6
F4	7	4
F5	65	14
F6	0	17
F7	0	18
F8	48	10
F9	24	5

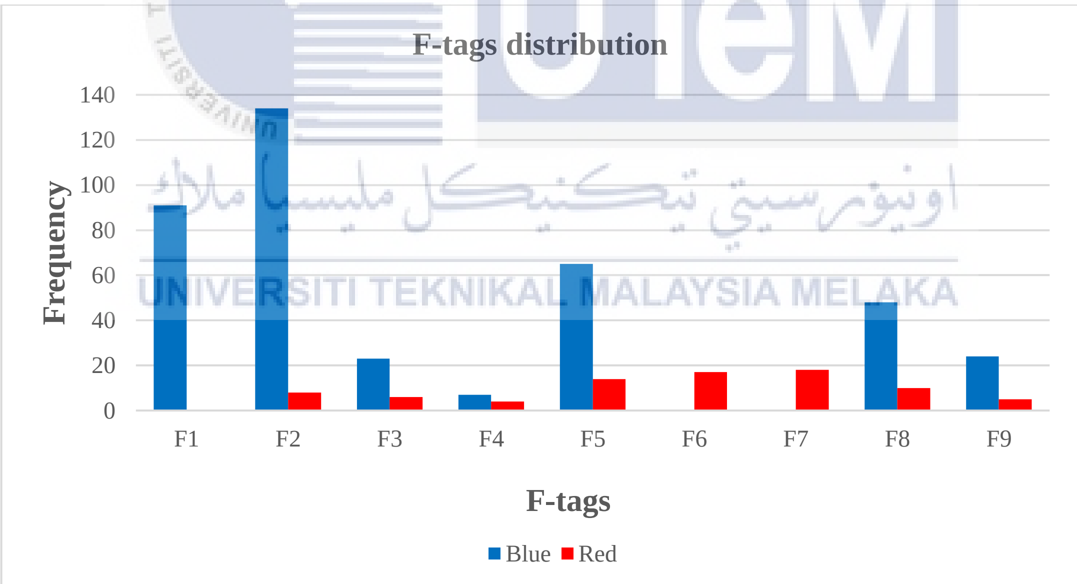


Figure 4.4 Column chart for F-tags distribution

Figure 4.4 shows the distribution of blue and red f-tags on the types of *fuguai* found. The highest blue tagged *fuguai* type is the dirt (F2) with a frequency of 134. The dirt is tagged by blue f-tags as the *fuguai* can be counter measured by machine operator without the help of high technical skilled personnel. On the other hand, the highest red tagged *fuguai* is the loosen components (F8) with a frequency of 18. Loosen component such as loosen screw are tagged by red f -tags to indicate the stated *fuguai* requires the attention of higher knowledge skilled technician to resolve the *fuguai* as it can affect the functionality of the machine and the safety of the operator. Most of the identified *fuguai* are tagged by blue f-tags which indicates the *fuguai* can be resolved by machine operator independently.

4.2.3 Analysis of machine area

Table 4.4 shows the *fuguai* data collected around the EDM machine area.

Table 4.4 Data collected of *fuguai* on machine area

Machine Areas	Front	Back	Side A	Side B
L1	22	5	2	2
L2	22	8	2	3
L3	17	2	1	2
L4	18	8	2	1
L5	16	6	1	2
L6	17	7	1	1
L7	25	5	1	4
L8	21	6	1	3
L9	18	2	1	3
L10	22	5	2	1
L11	22	4	4	1
L12	26	5	3	3
L13	26	5	2	3
L14	29	6	4	2
L15	26	7	1	3
TOTAL	327	81	28	34

Table 4.5 shows the cumulative frequency of occurrence of *fuguai* around the machine area.

Table 4.5 Cumulative frequency of *fuguai* collected on machine area

Machine Area	Frequency	Cumulative Frequency	Cumulative Percentage (%)
Front	327	327	69.57
Back	81	408	86.81
Side A	28	436	92.77
Side B	34	470	100

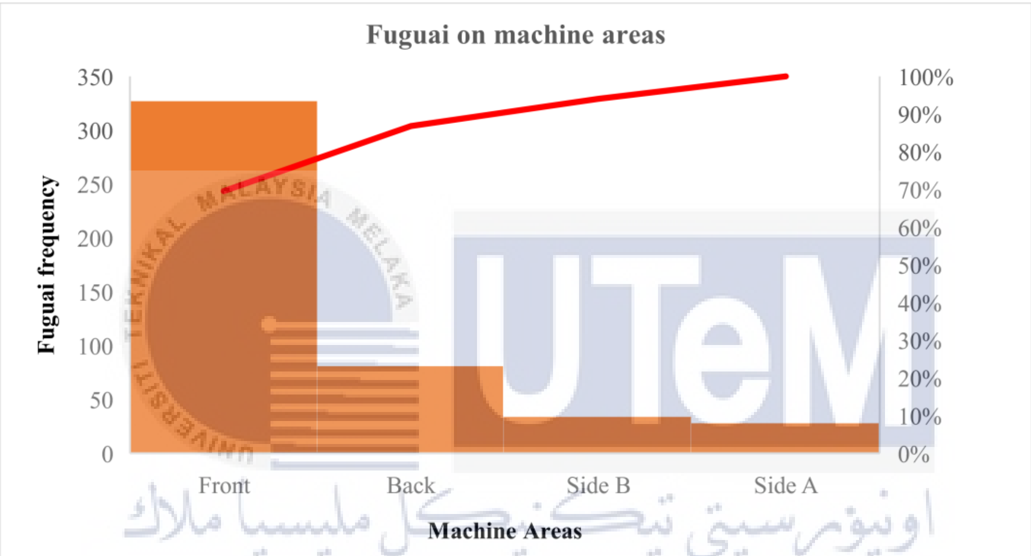


Figure 4.5 Pareto chart for *fuguai* identified on machine areas

Pareto chart in Figure 4.5 is constructed to analyze the most frequent occurrence of *fuguai* at the machine area. The most critical part of *fuguai* occurrence on the machine is determined through pareto chart. From the pareto chart, the most critical *fuguai* occurrence area is around the front area with a frequency of 327 followed by back part of machine with a frequency of 81. The least *fuguai* identified area is side A with a frequency of 28.

4.2.4 Analysis of *fuguai* category

Table 4.6 shows the *fuguai* data collected around the lathe machine area according to *fuguai* category.

Table 4.6 Data collected for *fuguai* category on machine area

Machine Area	*Fuguai* Category		
	Safety	Physical	Function
FRONT	25	253	49
BACK	8	68	5
SIDE A	0	28	0
SIDE B	6	19	9

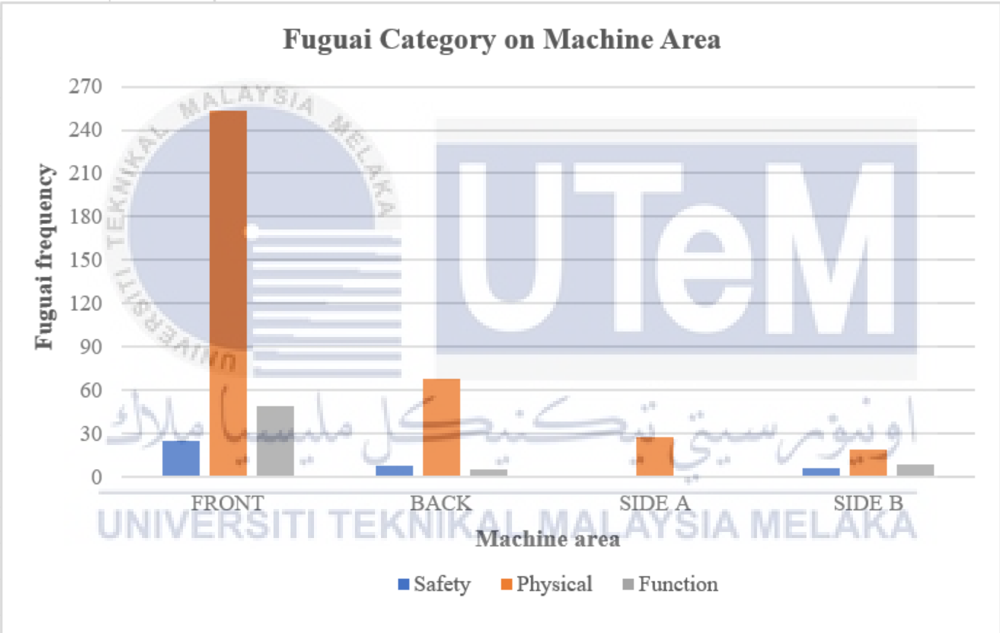


Figure 4.6 Column chart for *fuguai* category on machine area

4.3 Standard Operational Procedure for *Fuguai* elimination

One Point Lesson (OPL) serves to address a process issue or improve an existing method in a machine or procedure. Operators or team leaders use OPLs to instruct their teams or peers on specific tasks. OPL is selected for *fuguai* elimination due to their simplicity, basic nature, and brevity. Each OPL outlines a countermeasure to eliminate *fuguai* after thorough illustration.

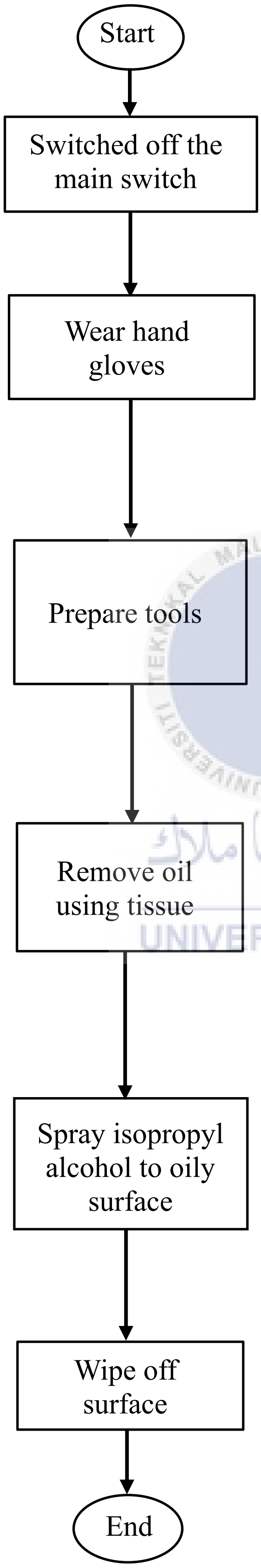
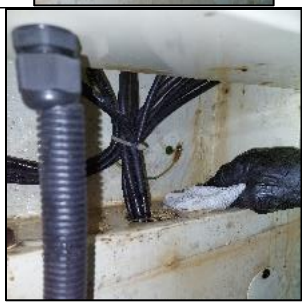
Fuguai are classified into three categories, physical, function and safety. The *fuguai* type and classification are stated in the OPL. In the OPL, the condition of the machine before and after the cleaning process is shown according to each *fuguai* identified to allow the machine user to understand the normal condition of the machine. Although the *fuguai* classification are same, the procedure to clean or fix the *fuguai* are different for ach *fuguai*.

Table 4.7 shows the OPL for oily and dirty surface. There is no overall lathe machine cleaning after the machining activities by students, which results in an oily and dirty surface. The lathe machine has a high utilization rate, however there is lack of daily maintenance activity by students or machine users after use, resulting in accumulated oil and dirty surface. The steps in *fuguai* elimination for oily and dirty surface is as described in Table 4.8.

Table 4.7 OPL for oily and dirty surface

***Fuguai* : Oily and dirty surface**	
Classification : Physical	
Before	**After**
	
Inside the back part of machine was covered with oil stain and dirty.	Clean and dry with no oil stain inside the back part of the machine

Table 4.8 Steps in *fuguai* elimination (oily and dirty surface)

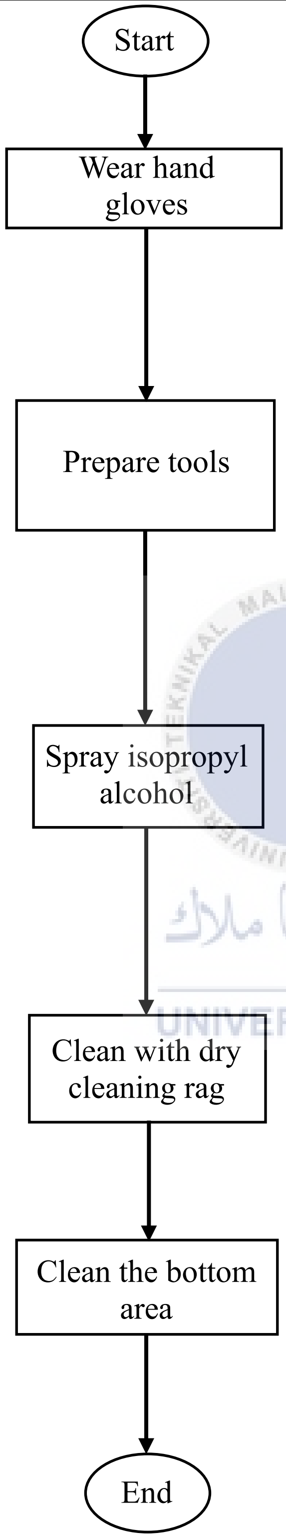
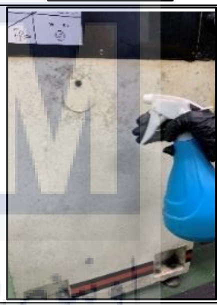
Cleaning process flow	**Description**	**Images**
	1. Make sure the main switch is switched off before cleaning process to ensure safety.	
	2. Wear hand gloves to protect the hands during cleaning process.	
	3. Prepare tools such as isopropyl alcohol, spray container and cleaning rag.	
	4. Remove the oil inside the back of machine using cleaning rag.	
	5. Spray the isopropyl alcohol to the oily surface.	
	6. Wipe the surface using cleaning rag.	

Machine user always overlooked this area of lathe machine and does not do the cleaning after using the machine. There is no rules or procedure that require machine user to clean this area and by time, dirt accumulated on the machine surface. This *fuguai* can be prevented if the machine user always cleans the area after using the machine. Table 4.9 shows the OPL of dirty surface and the steps in *fuguai* eliminations for dirty surface is described in Table 4.10.

Table 4.9 OPL for dirty surface

***Fuguai* : Dirty surface**	
Classification : Physical	
Before	After
	
Dirty machine surface	Clean machine surface

Table 4.10 Steps in *fuguai* elimination (dirty surface)

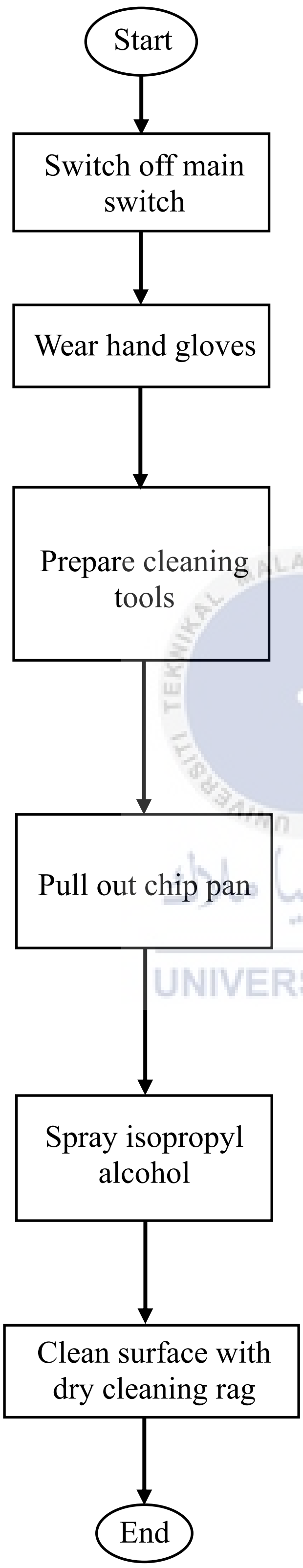
<table>
<tr><th>Cleaning process flow</th><th>Description</th><th>Images</th></tr>
<tr><td rowspan="5">
</td><td>1. Wear hand gloves to protect the hands during cleaning process.</td><td></td></tr>
<tr><td>2. Prepare an isopropyl alcohol, spray container and cleaning rag.</td><td>  </td></tr>
<tr><td>3. Spray the dirty surface with isopropyl alcohol.</td><td></td></tr>
<tr><td>4. Clean the surface with dry cleaning rag.</td><td></td></tr>
<tr><td>5. Clean the bottom area with cleaning rag.</td><td></td></tr>
</table>

Chip pan in lathe machine is functioning to collect metal chips and oil from the turning process. Oil and metal chips collected can be mixed with dust and debris that lead to dirty surface. Lack of regular machine cleaning can result to this *fuguai*. Table 4.11 shows OPL for oily and dirty surface and the steps in *fuguai* elimination for oily and dirty surface is as described in Table 4.12.

Table 4.11 OPL for oily and dirty surface

***Fuguai* : Oily and dirty surface**	
Classification : Physical	
Before	After
	
Inside of chip pan is oily and dirty.	Inside of chip pan is clean.

Table 4.12 Steps in *fuguai* elimination (oily and dirty surface)

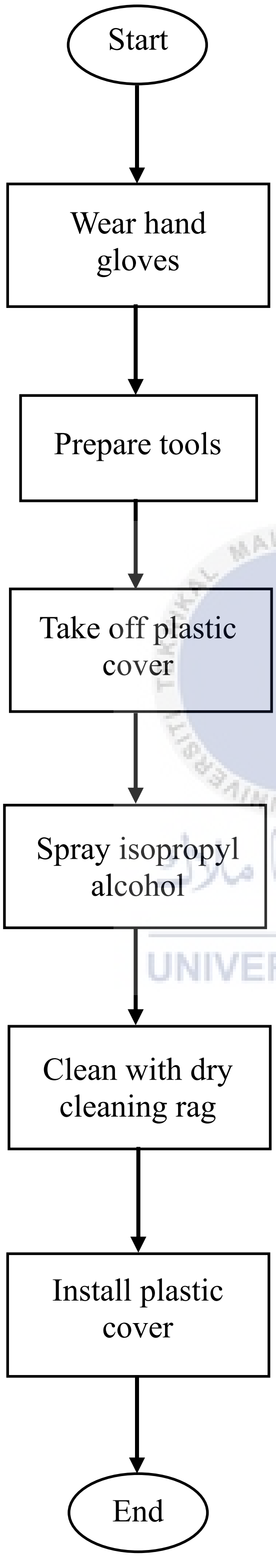
<table>
<tr><th>Cleaning process flow</th><th>Description</th><th>Images</th></tr>
<tr><td rowspan="6">
</td><td>1. Make sure the main switch is switched off before cleaning process to ensure safety.</td><td></td></tr>
<tr><td>2. Wear hand gloves to protect the hands during cleaning process.</td><td></td></tr>
<tr><td>3. Prepare tools such as isopropyl alcohol, spray container and cleaning rag.</td><td></td></tr>
<tr><td>4. Pull out the chip pan.</td><td></td></tr>
<tr><td>5. Spray isopropyl alcohol to the surface.</td><td></td></tr>
<tr><td>6. Clean the surface with dry cleaning rag.</td><td></td></tr>
</table>

Dust can accumulate over time on all machine surfaces. It can influence the machine's appearance and condition. For monitor cover, machine user cannot see the monitor clearly because of the dusty cover. Table 4.13 shows the OPL for dusty surface on machine's monitor cover and the steps in *fuguai* elimination of dusty surface is as described in Table 4.14.

Table 4.13 OPL for dusty surface

***Fuguai* : Dusty surface**	
Classification : Physical	
Before	After
	
The monitor plastic cover is dusty	Clean monitor plastic cover

Table 4.14 Steps in *fuguai* elimination (dusty surface)

Cleaning process flow	Description	Images
	1. Wear hand gloves to protect the hands during cleaning process.	
	2. Prepare tools such as isopropyl alcohol, spray container and cleaning rag.	  
	3. Take off the plastic cover.	
	4. Spray isopropyl alcohol to the cover.	
	5. Clean the cover with dry cleaning rag.	
	6. Install the monitor plastic cover.	

The area of foot brake pedal is the component that machine user using their foot to press the brake. The function is to quickly stop the rotation of the spindle and the chuck where the workpiece is mounted. The foot brake pedal is an integral safety feature in lathe machines, providing operators with a convenient and efficient way to stop spindle rotation swiftly and securely when needed. The dirt or oil from the machine's operation and safety shoes can accumulate over time and causes dirty surface. Table 4.15 Shows the OPL for dirty and oily surface and the steps in *fuguai* elimination for dirty and oily surface is as described in Table 4.16.

Table 4.15 OPL for dirty and oily surface

***Fuguai* : Dirty and oily surface**	
Classification : Physical	
Before	After
	
The surface of foot brake pedal is dirty and oily	Clean foot brake pedal without oil stain

Table 4.16 Steps in *fuguai* elimination (dirty and oily surface)

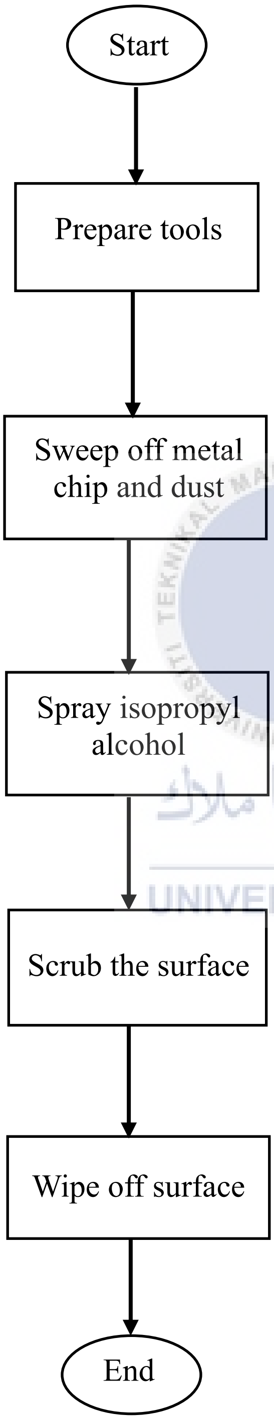
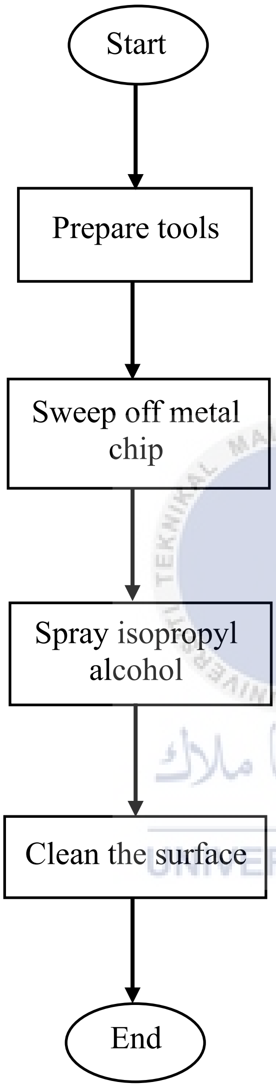
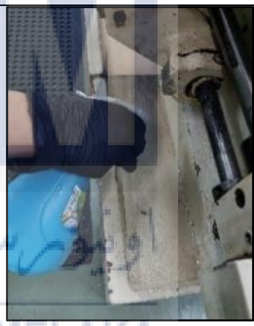
Cleaning process flow	Description	Images
	1. Prepare a brush and dustpan, small brush isopropyl alcohol, spray container and cleaning rag.	   
	2. Sweep off the metal chip and dust on the foot brake pedal surface	
	3. Spray the isopropyl alcohol to the surface.	
	4. Scrub the surface using small brush.	
	5. Wipe the surface using dry cleaning rag.	

Table 4.17 shows the OPL for dirty surface. There are scraps scattered around this area of machines and it also can be oily if it not cleansed right away. There are no strict rules that required the machine user to clean this area and the surface can be dirty over time. The steps in *fuguai* elimination for dirty surface on worktable is as described in Table 4.18.

Table 4.17 OPL dirty surface

***Fuguai* : Dirty surface**	
Classification : Physical	
Before	After
	
Dirty and dusty worktable	Clean worktable without dust and debris

Table 4.18 Steps in *fuguai* elimination (dirty surface)

Cleaning process flow	**Description**	**Images**
	1. Prepare a brush and dustpan, isopropyl alcohol, spray container and cleaning rag.	   
	2. Sweep off the metal chip and dust on the surface.	
	3. Spray the isopropyl alcohol to the surface.	
	4. Clean the surface using cleaning rag.	

Dust can accumulate over time on all machine surfaces. It has no effect on the machine's operation, but it does influence the machine's appearance and condition. Table 4.19 shows the OPL for dirty surface on the machine surface and the steps in *fuguai* elimination of dirty surface is as described in Table 4.20.

Table 4.19 OPL for dirty surface

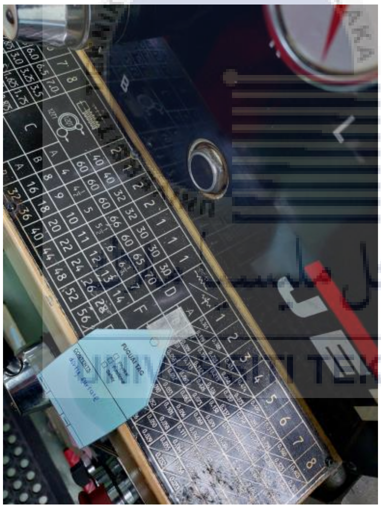
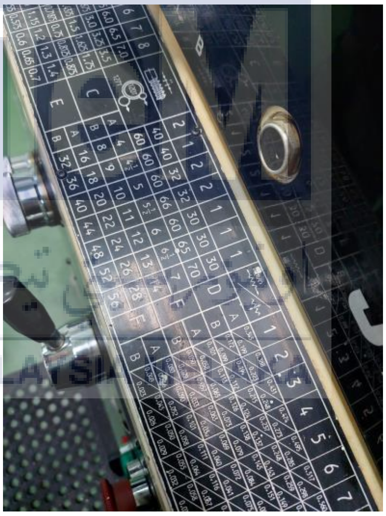
<table>
<tr><td colspan="2">Fuguai : Dirty surface</td></tr>
<tr><td colspan="2">Classification : Physical</td></tr>
<tr><td>Before</td><td>After</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Surface of thread and speed chart dirty</td><td>Surface of thread and speed chart in a clean condition</td></tr>
</table>

Table 4.20 Steps in *fuguai* elimination (dirty surface)

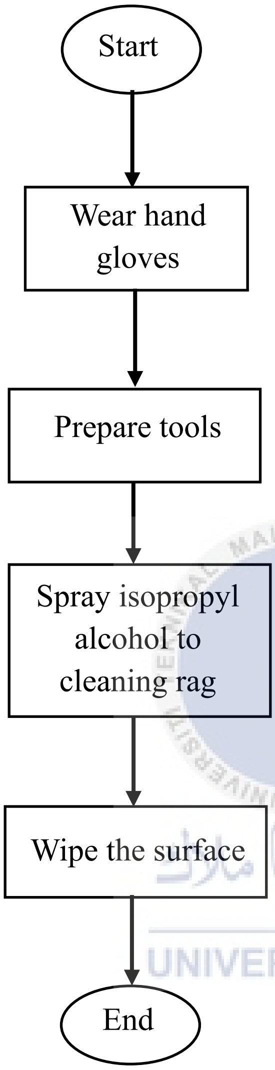
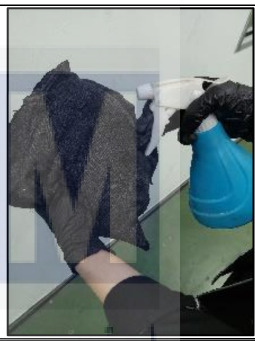
<table>
<tr><th>Cleaning process flow</th><th>Description</th><th>Images</th></tr>
<tr><td rowspan="4">
</td><td>1. Wear hand gloves to protect the hands during cleaning process.</td><td></td></tr>
<tr><td>2. Prepare isopropyl alcohol, spray container and cleaning rag.</td><td>  </td></tr>
<tr><td>3. Spray the isopropyl alcohol to the cleaning rag.</td><td></td></tr>
<tr><td>4. Wipe the surface with the cleaning rag.</td><td></td></tr>
</table>

Table 4.21 shows the OPL for dirty surface on the chuck cover. Area under the chuck cover can be dirty because of the machine's operation. The metal chips are scattered around because of the turning process from the lathe machine and accumulated under the chuck cover over time. The steps in *fuguai* elimination of dusty surface as described in Table 4.22.

Table 4.21 OPL for dirty surface

***Fuguai* : Dirty surface**	
Classification : Physical	
Before	After
	
Dirty and dusty chuck cover	Chuck cover in clean condition

Table 4.22 Steps in *fuguai* elimination (dirty surface)

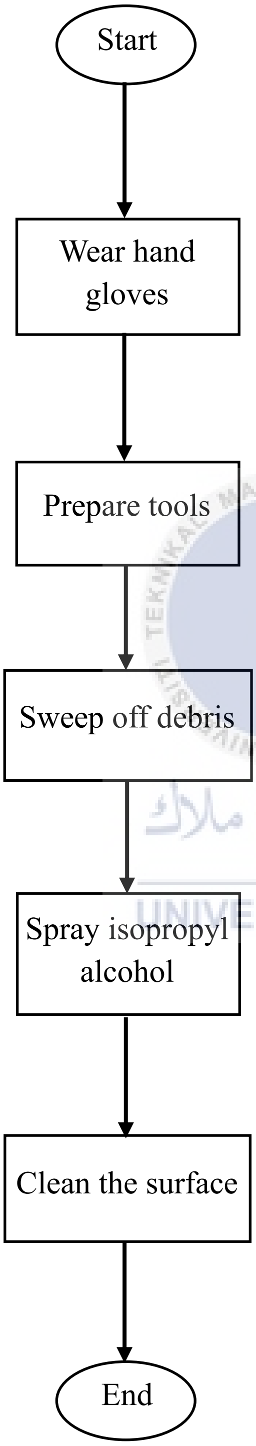
Cleaning process flow	Description	Images
	1. Wear hand gloves to protect the hands during cleaning process.	
	2. Prepare a brush, isopropyl alcohol and cleaning rag.	   
	3. Sweep off all the debris on the part.	
	4. Spray the isopropyl alcohol to the surface.	
	5. Clean the surface using dry cleaning rag.	

Table 4.23 shows the OPL for excess sticker. Excess sticker on the machine surface happen because of the label is not remove properly and left stain. The excess sticker has not been removed because there are no explicit rules to alert the machine user to the presence of *fuguai*. The steps in *fuguai* elimination for excess sticker is as described in Table 4.24.

Table 4.23 OPL for excess sticker

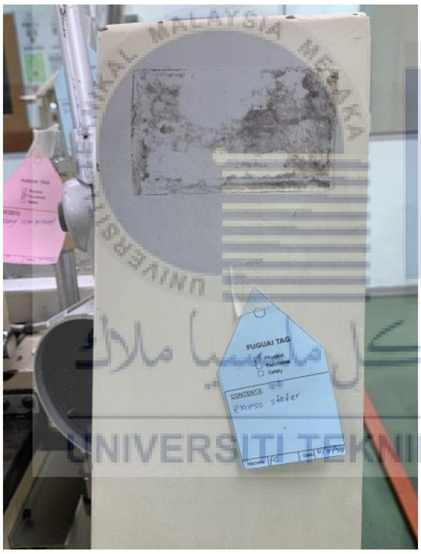
***Fuguai* : Excess sticker**	
Classification : Physical	
Before	After
	
The machine surface has stain from the sticker label	Clean surface with no stain visible

Table 4.24 Steps in *fuguai* elimination (excess sticker)

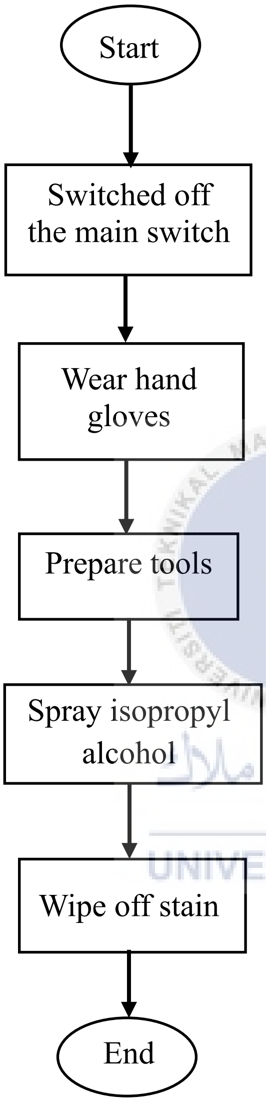
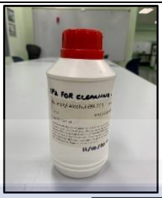
<table>
<tr><th>Cleaning process flow</th><th>Description</th><th>Images</th></tr>
<tr><td rowspan="5">
</td><td>1. Make sure the main switch is switched off before cleaning process to ensure safety.</td><td></td></tr>
<tr><td>2. Wear hand gloves to protect the hands during cleaning process.</td><td></td></tr>
<tr><td>3. Prepare the isopropyl alcohol, spray container and cleaning rag</td><td>  </td></tr>
<tr><td>4. Spray the excess sticker stain with isopropyl alcohol.</td><td></td></tr>
<tr><td>5. Wipe off the stain with cleaning rag.</td><td></td></tr>
</table>

Table 4.25 shows OPL for disorganized tubes. There are ma tubing and wiring surrounding the machines. Proper arrangement is needed to prevent the tubes from scattering and overlapping. The steps of *fuguai* elimination of disorganized tubes are as described in Table 4.26. The same countermeasure can be applied to all disorganized tubes or wires around the machines.

Table 4.25 OPL for disorganized item

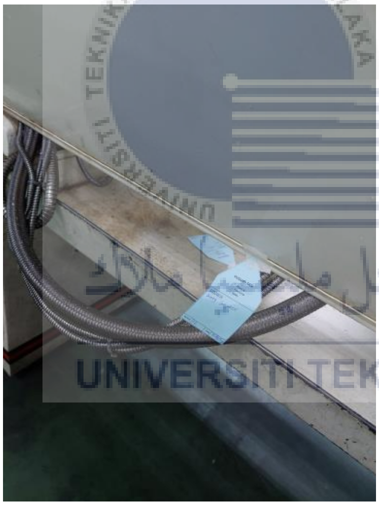
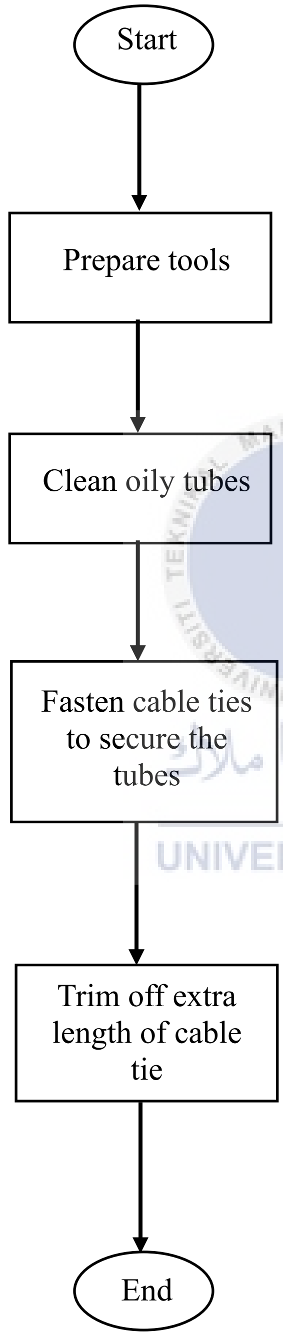
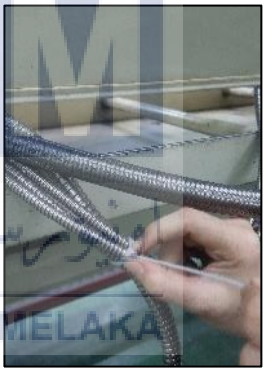
***Fuguai* : Disorganized tubes**	
Classification : Physical	
Before	After
	
Tubes is outside of the chip pan	Tubes is inside the chip pan and organized

Table 4.26 Steps in *fuguai* elimination (disorganized tubes)

Cleaning process flow	Description	Images
	1. Prepare a cleaning rag and cable tie.	 
	2. Clean the oily tubes with cleaning rag.	
	3. Fasten the cable ties to secure the position of the tubes.	
	4. Trim off the extra length of cable tie to make it neat.	

Functional *fuguai* need to be resolve to prevent it affecting the regular operation of the machines. Daily maintenance is needed to fix the functional *fuguai* to ensure the machine's proper functioning and avoiding significant machine component failure. Rusty handwheel on lathe machines are result of continuous use and a lack of lubrication, which prevents the internal joint of the handwheel from functioning properly and making noise. Table 4.27 shows the OPL of rusty handle and the steps in *fuguai* elimination for rusty handle is as described in Table 4.28.

Table 4.27 OPL for rusty handle

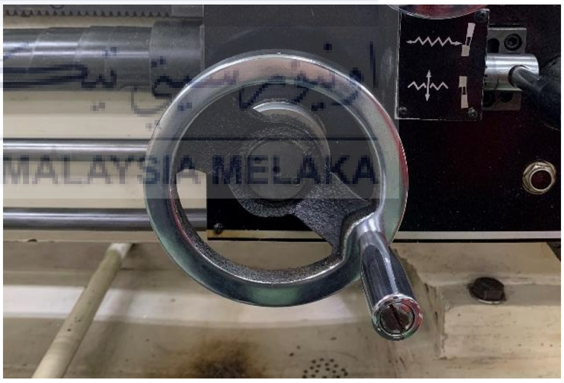
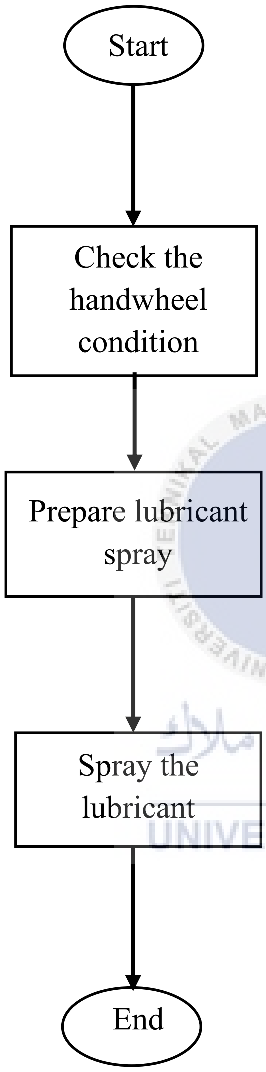
***Fuguai* : Rusty handle**	
Classification : Function	
Before	After
	
Handwheel making noise because of rusty handle	Handwheel not making noise

Table 4.28 Steps in *fuguai* elimination (rusty handle).

Cleaning process flow	Description	Images
	1. Check the conditions of handwheel and identify rusty handles.	
	2. Prepare a lubricant spray.	
	3. Spray the lubricant at the joint of the handwheel.	

The adhesive on the labels deteriorates and no longer holds the label in precise position, the labels may loosen and slide off over time. Table 4.29 and Table 4.30 shows two types of OPL for loose label. The steps in *fuguai* elimination for loose labelling is as described in Table 4.31.

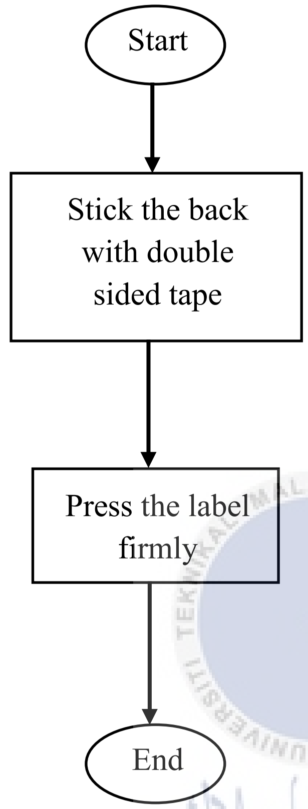
Table 4.29 OPL for loose label (Category 1)

Fuguai **: Loose label**	
Classification : Physical	
Before	After
	
Machine label loosen	Machine label in secured correct position

Table 4.30 OPL for loose label (Category 2)

Fuguai **: Loose label**	
Classification : Physical	
Before	After
	
Machine label loosen	Machine label in secured correct position

Table 4.31 Steps in *fuguai* elimination (loose label)

Cleaning process flow	Description	Images
	1. Stick the back of label with double sided tape.	
	2. Press the label firmly on to the spot.	

Fuguai that are classified under safety are those that may pose a threat to the surrounding environment or people. To avoid injuries and to ensure the machine operator's and user's safety, safety *fuguai* must be encountered. To prevent injuries and to make sure the machine operator's and user's safety, safety *fuguai* must be encountered. A machine is made up of many tiny components such as screws, nuts, and bolts that are used to secure the machine's components such as in place. After dismantling, screws are discovered to be unfastened due to incorrect installation. Table 4.32 shows the OPL for loosen screw and the steps in *fuguai* elimination for loosen screw is as described in Table 4.33.

Table 4.32 OPL for loose screw

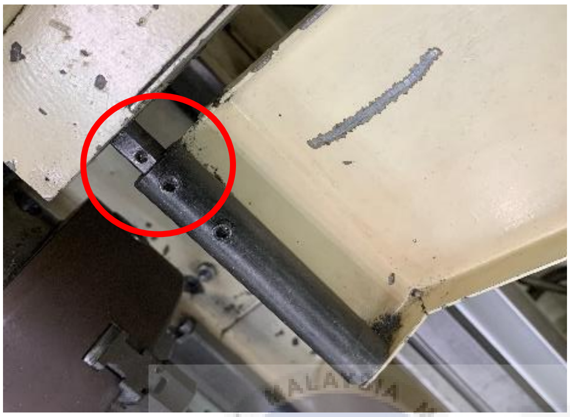
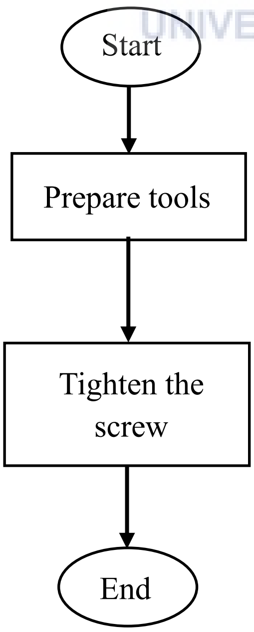
***Fuguai* : Loosen screw**	
Classification : Physical	
Before	After
	
Loosen chuck cover screw	Chuck cover in secured position

Table 4.33 Steps in *fuguai* elimination (loose screw)

Cleaning process flow	**Description**	**Images**
	1. Prepare an allen key.	
	2. Tighten the screw using allen key.	

4.4 Summary

The scale of *fuguai* data collection is not as extensive as the data collection in industrial environments. This is because the machines in labs typically operate under less critical conditions compared to their industrial counterparts, where machines endure significantly heavier workloads and prolonged operation times.

Most of recognized *fuguai* are eliminated but there are a few that cannot be done because it requires advanced technical expertise. The *fuguai* that are not being eliminated are those with red F-tags. This includes broken parts, dented component, and missing cover. Although some of the *fuguai* is not being eliminated, the condition of the lathe machines has improved and the number of *fuguai* is significantly reduced. In comparison to the condition of lathe machines prior to the deployment of autonomous maintenance, the condition of lathe machines is substantially better. The parts of machine that has been identified with *fuguai* can now run more smoothly that before. As a result of implementing autonomous maintenance, the lathe machines appeared cleaner, and the safety of the machine users is ensured.

The countermeasure towards the recognized *fuguai* is demonstrated through One Point Lesson (OPL). One Point Lesson's primary purpose is to effectively communicate instructions or focused knowledge about a single aspect of a task, process, or skill. OPL will provide a clear image of how to deal with *fuguai* and it can be understood by all machine users or operators. It allowing the establishment of a standard guideline for all machine users to refer if the same *fuguai* happen in future. In addition to the data generated by the *fuguai* removal, the autonomous maintenance produces non-measurable outcomes as well. The machine user and operator now have a deeper understanding of machine maintenance, and by consulting the OPL going forward, they will be better equipped to handle *fuguai*. The awareness on the importance of autonomous maintenance is successfully raised among machine users and operators.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Among all 9 types of *fuguai*, dirt (F2) is mostly discovered with the greatest percentage of 30%, whereas disorganized items (F4) had the lowest percentage of 2%. The most critical machine area is also identified through the analysis which is the front area (FRONT). Physical and functional *fuguai* were mostly found around the front area of the machine with a value of 253 physical *fuguai* and 49 functional *fuguai* are identified. The majority of the *fuguai* discovered on the machine are being removed. Only a limited number of *fuguai* required more advanced technical abilities to solve.

Throughout the project, there are few limitations and challenges encountered. One of the problems is that the machines don't have a routine maintenance schedule. Failure to execute routine maintenance on the machine can result in major problems such machine component failure, which can impair process functionality. Small flaws are usually ignored and discarded. These problems shouldn't be ignored, though, as even small ones can have a big influence on the functionality of the machine and the workflow. Establishing appropriate standards for *fuguai* removal as part of autonomous maintenance is essential for the future use of inexperienced or seasoned operators. Based on each *fuguai*, the appropriate parameters for the *fuguai* elimination are established. Depending on the situation and need for *fuguai* eradication, various strategies are used to address the various *fuguai* types. Every *fuguai* has a One Point Lesson (OPL) that is shown, and each phase of the *fuguai* elimination process is well explained. Placing the OPL and the illustrated *fuguai* elimination steps close to the machine maintenance checklist will make them easily accessible. Daily cleaning and inspections are done in accordance with a schedule to guarantee proper upkeep, self-control, and the operator's duty towards the machinery.

Lastly, the project objective of establishing autonomous maintenance programme of lathe machine is well accomplished. *Fuguai* are investigated and analysed as a preventative measure to enhance the efficiency of the lathe machine. Autonomous maintenance enhances machine performance and need to be applied to machinery and industry because there are significant studies showing that implementation of autonomous maintenance can improves the machine efficiency and responsibility if the machine user. The standardisation of OPL and SOP of a machine are crucial since it is the main guidance for the machine user in autonomous maintenance activity.

5.2 Recommendations

This study discovered different One Point Lesson (OPL) and Standard Operating Procedure (SOP) for different type of *fuguai* found on the lathe machine in the laboratory. The countermeasure of *fuguai* is demonstrated in OPL and it is created for the machine user to understand the original condition of the machine. There are many types of *fuguai* categories in one machine and for the *fuguai* elimination, it requires a specific step to be followed by the machine user. Different SOP was created for every *fuguai* found on the lathe machine based on machine inspection and cleaning activities.

However, this project highlighted on lathe machines in the FTKIP laboratory and there is only one type of lathe machine. Most of the machines in the laboratory operating when students are having laboratory activity and using limited parameters. Project can be conducted on implementation for industrial application as this project only focus on machine that use for educational purpose in university. The autonomous maintenance for industrial machine can lead to a deep review since they are using various type of workpiece and parameters. Identification of *fuguai* can be compared between the same processing nature but different type of machines. Furthermore, there are variety of OPL and SOP can be created and relevant for autonomous maintenance activity in industry.

In this project, there were only 5 steps for implementation of autonomous maintenance was conducted. Starting from preparation, initial machine cleaning and inspection, counter measures to source of contamination, cleaning and lubricating standard and lastly, overall inspection. These steps are taken from the 7 steps in implementation of autonomous maintenance according to the objectives of this study. Further study should include all the 7 steps to ensure the application of AM towards the machine operator and to sustain the autonomous maintenance activity in the laboratory. Autonomous maintenance is not the only way to enhance the machine efficiency. Further study might explore deeply in autonomous maintenance topic such as preventive maintenance and predictive maintenance.

REFERENCES

Acharya, A.S.E.E.M., Garg, D.H.A.I.R.Y.A., Singh, N.A.V.N.I.D.H. and Gahlaut, U.T.K.A.R.S.H., 2018. Plant effectiveness improvement of overall equipment effectiveness using autonomous maintenance training:—A case study. *Int. J. Mech. Prod. Eng. Res. Dev*, *9*, pp.103-112.

Azizi, A., 2015. Evaluation improvement of production productivity performance using statistical process control, overall equipment efficiency, and autonomous maintenance. *Procedia Manufacturing*, *2*, pp.186-190.

Barua, S., Banik, S., & Bari, S. (2021). Analysis of lathe machine accidents in manufacturing industries. *IOP Conference Series: Materials Science and Engineering,* 1138(1), 012020. doi: 10.1088/1757-899x/1138/1/012020

Buica, G., Antonov, A.E., Beiu, C., Remus, D., Pasculescu, D. and Ahmad, M.A., 2019. Some Features of Non-Safety Costs in Maintenance of Work Equipments: Maintenance of Work Equipment's. *International Journal of Science and Engineering Invention*, *5*(02), pp.39-to.

Correia Pinto, G.F., José Gomes da Silva, F., Octávio Garcia Fernandes, N., Carla Barros Casais, R., Baptista da Silva, A. and Jorge Vale Carvalh, C., 2020. Implementing a maintenance strategic plan using TPM methodology. *International Journal of Industrial Engineering and Management*, *11*(3), pp.192-204.

Ferreira, C.W.T. and Leite, J.C., 2016. Applied autonomous maintenance in the improvement of production quality: A case study. *ITEGAM-JETIA*, *2*(7).

Guariente, P., Antoniolli, I., Ferreira, L.P., Pereira, T. and Silva, F.J.G., 2017. Implementing autonomous maintenance in an automotive components manufacturer. *Procedia Manufacturing*, *13*, pp.1128-1134.

Holmgren, M., 2006. *Maintenance-related incidents and accidents: aspects of hazard identification* (Doctoral dissertation, Luleå tekniska universitet).

Iswidibyo, D.R., Nugroho, G., Al Imam, A., Junianto, H., Astutik, R.I., Hadi, T. and Puspasari, K., 2020. Developing Autonomous Maintenance through FMEA-RCM Models to Reduce% Machine Breakdown in Food and Beverages Industry.

Kosicka, E., Gola, A. and Pawlak, J., 2019. Application-based support of machine maintenance. *IFAC-PapersOnLine*, *52*(10), pp.131-135.

Kowalski, A., Królikowski, S. and Szafer, P., 2018, August. Methods and techniques for evaluating the productivity of production processes in the automotive industry. In *IOP Conference Series: Materials Science and Engineering* (Vol. 400, No. 6, p. 062017). IOP Publishing.

Krok, E. (2021). Visualization on charts – manipulations and distortions. Procedia Computer Science, 192, 3932–3944. https://doi.org/10.1016/j.procs.2021.09.168

Kumar, P., Chauhan, P., Chaudhary, R. and Juneja, D., 2017. Implementation of 5s And Kobetsu Kaizen (TPM Pillars) In A Manufacturing Organization. *International Research Journal of Engineering and Technology (IRJET)*, *4*(07), pp.2987-2991.

Kumar, S., Raj, B. and Shubham, S., 2017. Study of total productive maintenance & it's implementation approach in steel manufacturing industry: A case study of equipment wise breakdown analysis. *International Research Journal of Engineering and Technology (IRJET)*, *4*(8), pp.608-613.

Lima, O., 2019. Impact of autonomous maintenance on a PIM production line. *International Journal for Innovation Education and Research*, *7*(12), pp.385-398.

Lozada-Cepeda, J.A. and Buele, J., 2021, May. Maintenance Plan Based on TPM for Turbine Recovery Machinery. In *Journal of Physics: Conference Series* (Vol. 1878, No. 1, p. 012034). IOP Publishing.

Mahmood, W.H.W. and Ab Rahman Mahmood, I.A., 2008. Autonomous Maintenance Program For Job Base In Technical University.

Meca Vital, J.C. and Camello Lima, C.R., 2020. Total Productive Maintenance and the Impact of Each Implemented Pillar in the Overall Equipment Effectiveness. *International Journal of Engineering and Management Research*, *10*.

Min, C.S., Ahmad, R., Kamaruddin, S. and Azid, I.A., 2011. Development of autonomous maintenance implementation framework for semiconductor industries. *International Journal of Industrial and Systems Engineering*, *9*(3), pp.268-297.

Mohamed, A., Ben, J. and Muduli, K., 2022. Implementation of Autonomous Maintenance and Its Effect on MTBF, MTTR, and Reliability of a Critical Machine in a Beer Processing Plant. In *Applications of Computational Methods in Manufacturing and Product Design: Select Proceedings of IPDIMS 2020* (pp. 511-521). Singapore: Springer Nature Singapore.

Molenda, M., 2016. The autonomous maintenance implementation directory as a step toward the intelligent quality management system. *Management Systems in Production Engineering*, *24*(4), pp.274-279.

Morales Méndez, J.D. and Rodriguez, R.S., 2017. Total productive maintenance (TPM) as a tool for improving productivity: a case study of application in the bottleneck of an auto-parts machining line. *The International Journal of Advanced Manufacturing Technology*, *92*, pp.1013-1026.

Moscoso, C., Fernandez, A., Viacava, G. and Raymundo, C., 2020. Integral model of maintenance management based on TPM and RCM principles to increase machine availability in a manufacturing company. In *Human Interaction and Emerging Technologies: Proceedings of the 1st International Conference on Human Interaction and Emerging Technologies (IHIET 2019), August 22-24, 2019, Nice, France* (pp. 878-884). Springer International Publishing.

Mukherjee, S., Chakraborty, S., & Kumar, V., 2021. Identification of hazards associated with lathe machine operations: a case study. *International Journal of Occupational Safety and Ergonomics*, 1-7. doi: 10.1080/10803548.2021.1908555

Nakamura, T., 2016. History of TPM and JIPM: The TPM Awards From the Japan Institute of Plant Maintenance (JIPM). *WCOM (World Class Operations Management) Why You Need More Than Lean*, pp.169-179.

Okpala, C. and Anozie, S., 2018. Overall equipment effectiveness and the six big losses in total productive maintenance. *Journal of Scientific and Engineering Research*, *5*(4), pp.156-164.

Parmar, P.N., Mehta, N.C. and Trivedi, M.V., 2014. Investigation on automation of lathe machine. *International Journal of Emerging Technology and Advanced Engineering*, *4*(5), pp.524-529.

Poór, P., Kamaryt, T. and Simon, M., 2015. Introducing autonomous maintenance by implementing OTH hybrid positions and TPM methods in metallurgical company. *International Journal of Engineering and Technology*, *7*(3), pp.817-824.

Ramere, M.D. and Laseinde, O.T., 2021. Optimization of condition-based maintenance strategy prediction for aging automotive industrial equipment using FMEA. *Procedia Computer Science*, *180*, pp.229-238.

Singh, J., Singh, H. and Sharma, V., 2018. Success of TPM concept in a manufacturing unit–a case study. *International Journal of Productivity and Performance Management*, *67*(3), pp.536-549.

Suryawanshi, V., & Buktar, R., 2015. Leveraging Tpm for Increase in the Oee of Cnc Machine. In *www.ijmer.com* | (Vol. 5, Issue 9). www.ijmer.com

Sutoni, A., Setyawan, W. and Munandar, T., 2019, July. Total productive maintenance (TPM) analysis on lathe machines using the overall equipment effectiveness method and six big losses. In *Journal of Physics: Conference Series* (Vol. 1179, No. 1, p. 012089). IOP Publishing.

Thorat, R., & Mahesha, G. (2020). Improvement in productivity through TPM Implementation. Materials Today: Proceedings, 24, 1508–1517. https://doi.org/10.1016/j.matpr.2020.04.470

XIAOMENG, S., 2018. Implementing a Total Productive Maintenance Approach into an Improvement AT S Company. *Universidad de Western Kentucky Bowling Green, Kentucky-Bowling Green*.

Zhang, J., Huang, X., Fang, Y., Zhou, J., Zhang, H. and Li, J., 2016. Optimal inspection-based preventive maintenance policy for three-state mechanical components under competing failure modes. *Reliability engineering & system safety*, *152*, pp.95-103.

APPENDICES

APPENDIX A Turnitin similarity check report

Final Report

ORIGINALITY REPORT

17%	15%	6%	11%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Universiti Teknikal Malaysia Melaka Student Paper	1%
2	static.vdhbv.nl Internet Source	1%
3	ijari.org Internet Source	1%
4	eprints.utem.edu.my Internet Source	1%
5	Submitted to University of Sunderland Student Paper	1%
6	Submitted to Glasgow Caledonian University Student Paper	1%
7	www.riejournal.com Internet Source	<1%
8	hdl.handle.net Internet Source	<1%
9	www.meddeviceonline.com Internet Source	<1%