

CHAPTER 2 - LITERATURE REVIEW

2.1 Maintenance

Maintenance is the activity of keeping, maintaining, and repairing equipment or systems in order to operate optimally. Maintenance can be done preventively to prevent damage, or correctively to repair damage that has already occurred. Furthermore, with the development of technology, we can use it to perform predictive maintenance activities that can ultimately prevent catastrophic damage.

It can be concluded that maintenance as an activity carried out to maintain, maintain, and repair an equipment or system in order to function optimally and can achieve the planned economic life (Soetrisno, 2014).

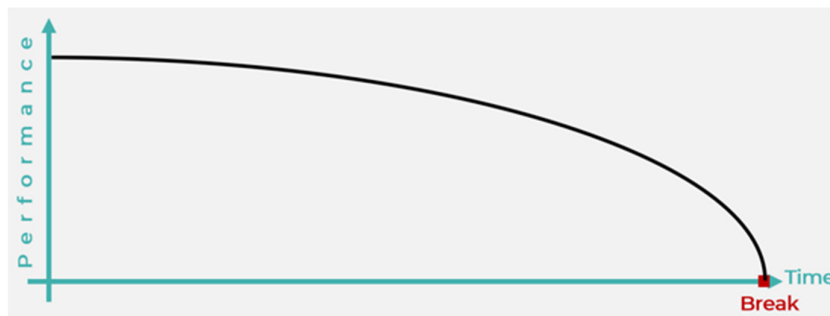


Figure 2.1. Lifecycle Condition of Equipment

Mining heavy equipment is a very important equipment in the mining process. This machine is used to perform various kinds of work, such as excavation, transportation, and material processing. Therefore, mining machines must always be in good condition in order to operate optimally and produce high productivity. By implementing a comprehensive maintenance program, mining companies can reduce equipment downtime, improve productivity, and extend equipment life (K. E. Aboagye, 2022).

Maintenance involves the activities required to keep a system or equipment functioning properly (Mobley, et al., 2008). Maintenance methods and tools include Preventive

Maintenance (PM), Corrective Maintenance (CM), and Condition-Based Maintenance (CBM). Maintenance strategies play a vital role in ensuring the optimal performance, reliability, and longevity of equipment. In choosing the right maintenance strategy, companies must consider various factors, such as cost, level of dependence on equipment or machinery and the level of risk received.

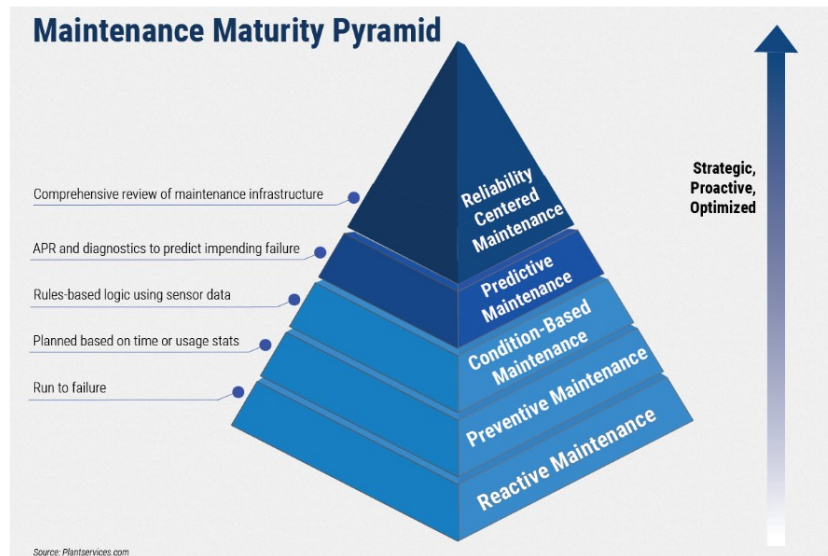


Figure 2.2. Maintenance maturity pyramid

2.1.1 Corrective Maintenance

Corrective maintenance is a maintenance activity carried out to repair damage that has occurred (Gan, Song and Zhang, 2022). On heavy equipment This activity is carried out to restore the machine to its original condition so that it can be used again.

The first step is to identify the damage that occurred to the machine (Indra Permana and Arvianto, 2020). This can be done by checking the condition of the machine, listening to engine sounds, and reading error codes The next step is to install the defective parts. The spare parts used must be in accordance with applicable standards (Zhang, Tang and Chica, 2021). Finally, the machine must be tested to ensure that the damage is resolved (Wang *et al.*, 2014).

Table 2.1. Advantage and disadvantage of Corrective Maintenance

Characteristic	Advantage	Disadvantage
Cost	Increase equipment reliability	Increase maintenance costs
Performance	Preventing workplace accidents	May cause equipment downtime

In terms of maintenance costs, corrective maintenance costs more than routine maintenance because more parts and labor are required (Wang *et al.*, 2014). This is due to damage that has already occurred must be repaired, so it requires more spare parts and labor. Equipment performance Corrective maintenance can improve equipment reliability and prevent work accidents (Andrzejczak, Młyńczak and Selech, 2018). This is because damage that has already occurred can be repaired, so that the equipment can work better and prevent work accidents caused by damaged equipment. However, corrective maintenance can also cause equipment downtime, which can interfere with company productivity (Özgür-Ünlüakın, Türkali and Aksezer, 2021).

2.1.2 Preventive Maintenance

Preventive maintenance (PM) is a maintenance activity carried out in a planned and systematic manner to prevent damage to equipment or machinery (Angeles and Kumral, 2020). PM aims to keep equipment or machines in good condition and ready for use, so as to increase the reliability, productivity, and economic life of the equipment or machine (Indra Permana and Arvianto, 2020).

Based on the time of implementation, PM can be divided into two types, namely:

- PM by time (time-based PM) (Basri *et al.*, 2017): This PM is done periodically based on a certain time, for example every 250 hours of operation, every 3 months, or every 6 months even every 1 year.
- PM By condition (condition-based PM) (Jurča, Hladík and Aleš, 2008): This PM is done based on the condition of the equipment or machine. This PM is done if the equipment or machine shows signs of damage, for example there is an increase in temperature, vibration, or sound.

From the two PM models above, there are advantages and disadvantages both in terms of cost, time and impact on equipment.

Table 2.2. Comparison of Cost, Time and Performance of Preventive Maintenance

Factor	Time-based PM	Condition-based PM
Cost	Lower	Higher
Time	Shorter	Longer
Equipment performance	More stable	More fluctuate

Time-based PM requires lower costs because it is only done based on a certain time, for example every 250 hours of operation, every 3 months, or every 6 months or even every 1 year. Condition-based PM requires higher costs because it costs for the equipment or system used to detect the condition of the equipment (Mollahassani-Pour, Abdollahi and Rashidinejad, 2014).

Then, time-based PM takes a shorter time because it is only done based on a certain time. Meanwhile, condition-based PM takes longer because it must be done periodically to detect equipment conditions (Angeles and Kumral, 2020). In terms of equipment performance, time-based PM can help keep equipment performance stable because damage can be identified and repaired before it becomes more severe. While the condition-based PM can cause equipment performance to fluctuate more because repairs are only made if the equipment shows signs of damage (Bangun *et al.*, 2022).

In general, time-based PM is better for equipment whose conditions are easy to predict, while condition-based PM is better for equipment whose conditions are difficult to predict (Li *et al.*, 2021). However, it is up to the organization in preparing its resources to choose a PM approach that suits the equipment it maintains.

2.1.3 Proactive Maintenance

Condition Based Maintenance (CBM) is a proactive maintenance strategy that uses sensors to assess the actual state of the parts and then provides recommendations to forecast potential functional failures (Maity, et al., 2011). When CBM is used, maintenance expenses are typically lowered and equipment availability is increased. Opportunistic maintenance, which is group maintenance actions for two or more

components that are monitored to lower maintenance costs, will strengthen CBM's ability to support maintenance management (Koochaki, et al., 2012).

CBM works by monitoring the condition of equipment in real-time through the use of device monitoring sensors (Tian *et al.*, 2011). These sensors collect data on pressure, temperature, levels and other parameters to assess the health of the equipment. This data is then analyzed to identify potential problems early on.

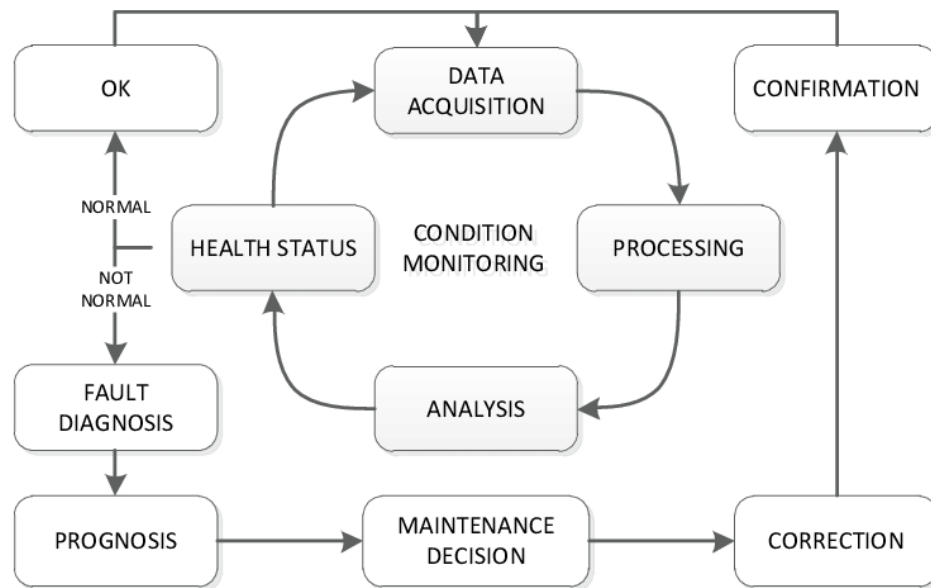


Figure 2.3. Condition-based Maintenance process (Do *et al.*, 2015)

Figure 5 above describes the condition-based maintenance (CBM) process workflow which consists of five steps:

- **Data Acquisition:** The first step is to collect data about the condition of the equipment. This data can be collected through a variety of means, including sensors, visual inspection, and document analysis.
- **Data Processing:** The second step is to process the collected data to produce valuable information about the condition of the equipment. This process is usually done using special software.

- **Condition Monitoring:** The third step is to monitor the condition of equipment to identify potential problems. This monitoring is done using information generated by the data processing process.
- **Fault Detection:** The fourth step is to detect potential problems with equipment. This process is carried out using special algorithms to detect abnormal patterns in the collected data.
- **Decision Making:** The fifth step is to make decisions about actions to be taken to address potential problems. This decision is usually based on the outcome of the fault detection process.

The process flow shows how CBM works starting with data collection. This data is then processed to produce information about the condition of the equipment. This information is then used to monitor the condition of the asset and detect potential problems. If potential problems are detected, then corrective action should be taken to prevent failures.

2.2 Computerize Maintenance Management System (CMMS)

Computerized Maintenance Management System (CMMS) is a system designed to assist organizations in managing and planning equipment and facility maintenance activities. CMMS leverages information technology to increase efficiency, optimize maintenance, and extend asset life.

CMMS brings various benefits to organizations, such as preventive maintenance planning, inventory monitoring, maintenance work management, and asset performance analysis. Research by Smith et al. (2018) shows that CMMS implementation can significantly reduce downtime and maintenance costs.

The process of implementing a CMMS and its integration with other systems is a crucial aspect. According to a study by Jones (2019), effective integration can improve operational visibility and traceability. Therefore, a deep understanding of the implementation process is the key to success in implementing a CMMS.

Despite its great benefits, CMMS implementation does not always go smoothly. Challenges often encountered include change resistance from workers, intensive

training needs, and technical problems. Research by Brown (2020) identifies that understanding and support from all levels of the organization is key to overcoming such barriers.

Data security is a significant concern in CMMS implementation. Research by White et al. (2021) highlights the importance of strict security policies and the implementation of data protection measures to prevent potential threats to companies' critical information.

Recent trends in CMMS development involve the integration of technologies such as the Internet of Things (IoT) and artificial intelligence (AI) to improve maintenance predictivity. According to Green (2022), the use of smart sensors and real-time data analysis can provide deeper insights into asset health.

2.3 Overall Equipment Effectiveness (OEE)

Overall equipment effectiveness (OEE) is a metric used to measure the effectiveness of equipment used in a production operation (Nursubiyantoro, Puryani and Rozaq, 2016). So that OEE can be used as a key performance indicator (KPI) measurement tool in a production equipment maintenance process. OEE calculates three main components: availability, performance and quality (Gianfranco *et al.*, 2022). So that the calculation can be formulated as follows.

$$OEE = Availability (\%) \times Performance(\%) \times Quality(\%) \quad (1)$$

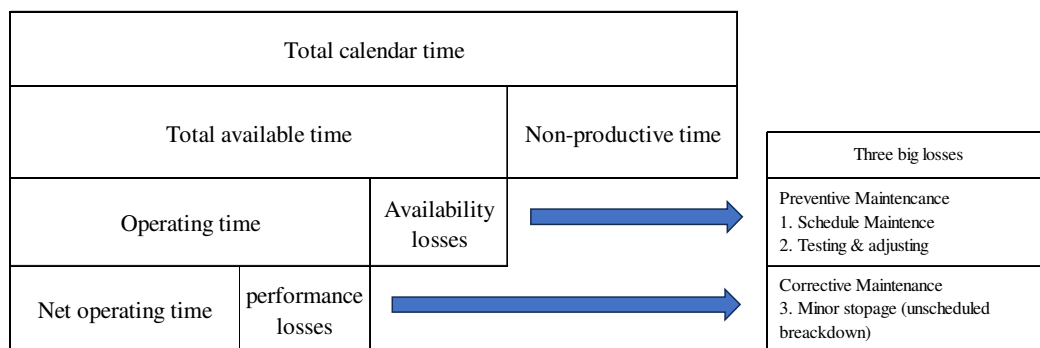


Figure 2.4. Concept of OEE Calculation

Availability is a measure often used to assess the readiness of equipment for use (Elevli & Elevli, 2010). The availability of a piece of equipment is important to measure because the availability of a high amount of equipment can increase productivity and efficiency and reduce maintenance and repair costs.

Availability is a probability that can be calculated by the following formulation.

$$Availability (\%) = \frac{uptime - downtime}{uptime} \times 100\% \quad (2)$$

Where:

- Uptime is the time that equipment is available for use (hours).
- Downtime is the time when equipment is not available for use (hours).

Downtime can be caused by various factors, such as:

- Equipment malfunction
- Equipment maintenance and repair
- Human error

Performance refers to the operational efficiency of a piece of equipment, measured based on the percentage of time in which the equipment operates optimally without interruption (Rahman *et al.*, 2022). The higher this percentage, the higher the performance of the equipment. In maintenance activities, the performance of these activities is measured from the standard time for maintenance compared to the actual maintenance work. So that the calculation can be formulated as follows.

$$Performance (\%) = \frac{Planned\ time}{Actual\ time} \times 100\% \quad (3)$$

Where:

- Planned time is the planned time for one periodical maintenance job (hours).
- Real time is the actual time it takes to complete a maintenance job (hours).

Quality refers to the quality of maintenance work, where there is no re-do after maintenance activities are carried out (Farahani, Tohidi and Shoja, 2020), It is said to

be re do if there is a failure after 72 hours of periodic maintenance work. So that quality can also be interpreted as the amount of periodical maintenance work without re-doing with the number of periodical maintenances carried out.

$$Quality (\%) = \frac{PM \text{ without re do}}{Total PM} \times 100\% \quad (4)$$

Dimana:

- PM without re do is the amount of PM work without followed breakdown afterwards for 72 hours (unit).
- Total PM is the number of PM jobs over a one-month period (unit).

2.4 Five-whys Analysis

Five Whys Analysis is a simple yet effective problem-solving technique for identifying the root cause of a problem. This technique uses repeated "why?" questions to dig deeper into the root cause of the problem (Serrat, 2009).

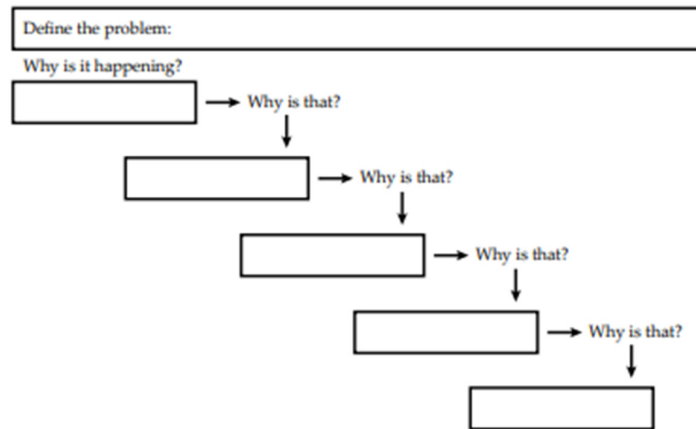


Figure 2.5. Five Whys Analysis Worksheet (Serrat, 2009)

Five Whys Analysis is a simple but effective problem-solving technique. This technique can be used to identify the root cause of a problem and develop a more effective solution to solve the problem.

2.5 P-M Analysis

P-M Analysis, or Phenomenon-Mechanism Analysis, is a comprehensive and systematic problem-solving method (Arai, 2017). Phenomenon (P) is a phenomenon or problem to be solved. Then, Mechanism (M) is the mechanism or cause of the phenomenon.

P-M Analysis aims to identify all factors that can cause the occurrence of phenomena, both physical and non-physical factors. By identifying all causative factors, problems can be solved more effectively and efficiently.

The steps in P-M Analysis consist of eight steps, namely:

a. Define the phenomenon

The first step is to define the phenomenon or problem you want to solve. The phenomenon must be clearly defined and specific, so that it can be understood by all parties involved in the problem-solving process.

Arai (2017) explains that, the phenomenon in this analysis refers to the objective reality of a situation, which includes what actually happens. It involves observations made through direct visual perception and numerical data, emphasizing the importance of concrete evidence. It excludes subjective elements such as opinions and personal feelings, focusing only on verifiable facts without any preconceived notions. In essence, the phenomenon encapsulates the empirical and measurable aspects of a scenario, ignoring individual interpretations or emotional responses.

b. Mechanism identification

The second step is to identify the mechanism or cause of the occurrence of the phenomenon. Mechanisms can be identified using a variety of methods, such as brainstorming, cause-and-effect diagrams, or fishbone diagrams.

c. Analysis of mechanisms

The third step is to analyze the mechanisms that have been identified. Analysis is carried out to understand how the mechanism works and how the mechanism can cause the phenomenon to occur.

d. Identify causative factors

The fourth step is to identify all the factors that can cause the occurrence of the phenomenon. Causal factors can be identified using a variety of methods, such as brainstorming, cause-and-effect diagrams, or fishbone diagrams.

e. Test the Hypothesis

The fifth step is to test hypotheses about the relationship between causal factors and phenomena. Hypothesis testing is carried out to ensure that the causative factors that have been identified really cause the phenomenon.

f. Developing solutions

The sixth step is to develop a solution to solve the problem. Solutions should be designed to eliminate or mitigate the causative factors that have been identified.

g. Solution implementation

The seventh step is to implement the solution that has been developed. Implementation must be done carefully and systematically, so that the solution can run effectively.

h. Solution evaluation

The eighth step is to evaluate the effectiveness of the solution that has been implemented. Evaluation is carried out to ensure that the solution has successfully solved the problem.

Another reference developed in Lean Manufacturing Online (2021) entitled "Focused Improvement – The Structure of P-M Analysis" explains that the steps of P-M analysis are as shown in the following figure.

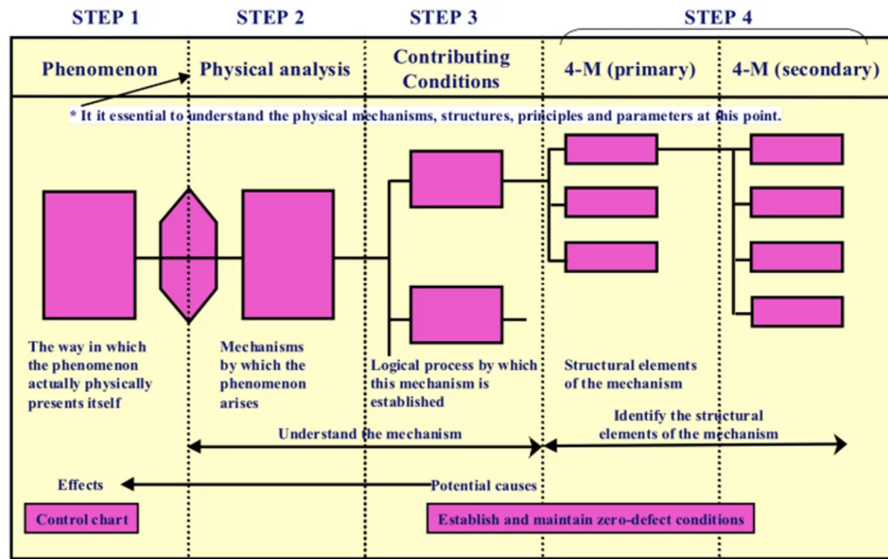


Figure 2.6. The Overall Structure of P-M Analysis

The graphical representation in Figure 11 illustrates the structure of the P-M Analysis resembling a branching tree. The diagram is arranged from left to right, aligned with the initial four steps of P-M Analysis. Step 1 involves clarifying the phenomenon, followed by Step 2, which includes performing a physical analysis of the phenomenon. Turning to the right, Step 3 focuses on identifying the conditions that contribute to the phenomenon, and Step 4 involves testing the relationship with the 4M's (People, Machines, Methods, and Materials). Although these diagrams usually include only 4-M secondary correlations, which are generally adequate, they have the flexibility to be extended further to tertiary and quaternary correlations if deemed necessary.

The process of initiating and concluding a P-M Analysis involves special considerations. As explained by Arai (2017) that the process of finding phenomena must use empirical data, this can also be done using five whys analysis. This initial identification helps in selecting one of these root causes as the starting point for the next P-M Analysis.

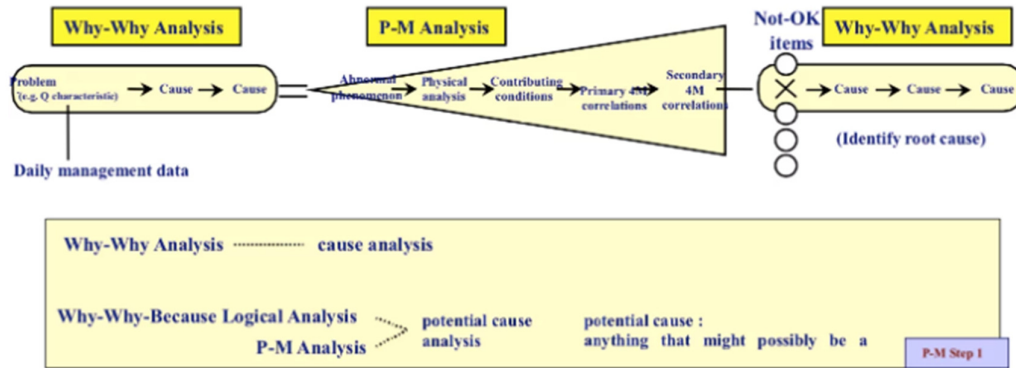


Figure 2.7. Step to begin a P-M Analysis

P-M analysis should be stopped when it reaches the level of damage to individual components, such as shaft wear or loss of spring strength. Typically, this ends at secondary 4-M correlation levels, although certain situations may require further deepening. Once modes of deterioration have been identified, it is important to investigate whether they actually occur in practice (Gnanavel, Saravanan and Chandrasekaran, 2018). The modes that are found to occur should be investigated further to understand why the individual responsible for the maintenance of the machine did not prevent it.

Further, measures should be implemented to ensure the prevention of the identified modes of damage in the future. This comprehensive approach ensures that P-M Analysis not only addresses identified issues but also proactively establishes preventive measures to improve the overall reliability and performance of the components involved (Cigolini and Rossi, 2004).

2.6 Technology Acceptance Model (TAM)

One model designed to examine and comprehend the variables influencing the acceptability of computer technology use is the Technology Acceptance Model (TAM). Fred Davis created the model in 1989, and it has since been applied to a large number of research projects on technology adoption in the fields of education, health, and information technology.

The two primary components of TAM are perceived usefulness (PU) and perceived ease of use (PEOU). The belief that technology can enhance performance or productivity is known as the user's perception of technology's benefits. Users' perception of technology's ease of use refers to how simple they think it is to understand and utilize.

According to Rafique et al., (2020), Both of these factors directly affect the user's intention to use the technology (behavioural intention). The user's intention to use the technology then directly influences the user's (actual behaviour).

Venkatesh et al (2003) Unified Theory of Acceptance and Use of Technology (UTAUT) which includes 4 factors which can be external variables, including: (1) Performance expectancy, (2) Effort expectancy, (3) Social influence and (4) Facilitating Conditions.

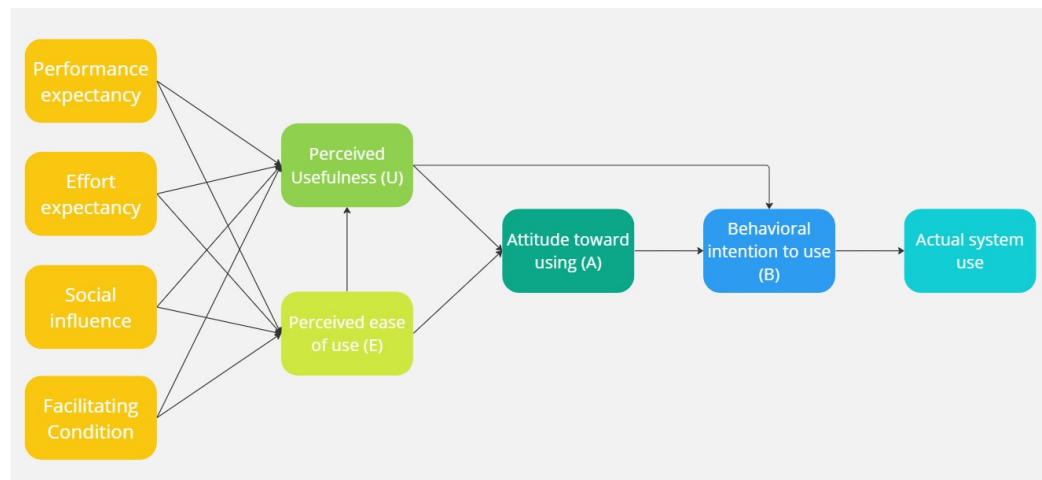


Figure 2.8. Technology Acceptance Model (TAM)

2.6.1 Perceived Usefulness (PEU)

Perceived usefulness is the user's perception that the technology can improve its performance (Gupta, Abbas and Srivastava, 2022). This perception can be influenced by factors characteristic of technology, such as the features possessed by the technology, the next factor is what tasks will be performed or completed using the

technology, and last but not least is the knowledge and skills of users of the technology, this is important because the usefulness of the new technology is often influenced by these factors.

Sorce & Issa (2021), In his research related to TAM for the construction industry, he explained that the TAM theory he studied showed that the perception factor of the ease of using technology and the perception of the usability of a technology will be related to a person's attitude towards the use of the technology. So that likes or dislikes towards the implementation of this new technology can be used to predict one's behavior in using it.

2.6.2 Perceived Ease of Use (PEOU)

Perceived ease of use is the user's perception that the technology is convenient to use (Gupta, Abbas and Srivastava, 2022). This perception can be influenced by factors Characteristics of technology, such as design and user interface and User knowledge and skills. But then, Rafique et al. (2020) from the theory they studied, they added social influence, which is the influence of people around the user and perceived behavioural control, which is the user's perception of his ability to use the technology.

Moreover, Rafique et al. (2020) also explain about changes in relationships between factors based on the development of technology and information such as changes in the relationship between perceptions of benefits and intentions to use technology, then changes in the relationship between the intention to use technology and behaviour using technology. These modifications were made to improve TAM's ability to predict technology acceptance in a variety of contexts.

2.7 Previous Study

Computerize Maintenance Management System (CMMS) have gained traction in the mining industry as tools for optimizing equipment uptime and service lead time accuracy. By centralizing maintenance data, automating workflows, and enabling data-driven decision-making, CMMS offer potential benefits for improving operational efficiency and reducing costs.

The following is a summary of the previous study of the use of CMMS in maintenance operations in the mining sector.

Table 2.3. Key Takeaways from previous study

Title	Journal	Author(s) (Year)	Research Findings
Computerized Maintenance Management System (CMMS) Implementation Challenges in the Construction Industry	Journal of Advanced Research in Dynamical and Control Systems	(Mohd Nawi <i>et al.</i> , 2019)	Identified common challenges in CMMS implementation in the construction industry, such as resistance to change, data accuracy, and integration with existing systems.
The Impact of Computerized Maintenance Management System (CMMS) on the Efficiency of Steel Manufacturing: Case Study	Competition Forum	(ElKhouly and Fadil, 2019)	CMMS implementation improved equipment uptime, reduced maintenance costs, and increased production output.
Application of Computerized Maintenance Management Systems (CMMS) for Service Fleet	Science and Technology Development Journal	Vo et al. (2011)	CMMS implementation improved vehicle availability, reduced maintenance costs, and provided better data for operational decision-making.
Preventive Maintenance Decisions through Maintenance Optimization Models: A Case Study	Procedia Manufacturing	Vilarinho, Lopes and Oliveira (2017)	Optimization models used with CMMS helped optimize preventive maintenance schedules.
Current Practices for Preventive Maintenance and Expectations for Predictive Maintenance in East-Canadian Mines	Mining	Robatto Simard, Gamache and Doyon-Poulin (2023)	Surveyed current preventive maintenance practices and expectations for using CMMS for predictive maintenance.
Information management to improve the effectiveness of preventive maintenance activities with computerized maintenance management system at the intake system of circulating water pump	Procedia CIRP	Munyensan ga et al. (2018)	CMMS improved data management for preventive maintenance of a water pump system.

Title	Journal	Author(s) (Year)	Research Findings
Analysis of building maintenance requests using a text mining approach: building services evaluation	Building Research and Information	Bortolini and Forcada (2020)	Used text mining to analyze building maintenance requests from CMMS data.
Supporting Maintenance Scheduling: A Case Study	Procedia Manufacturing	Senra, Lopes and Oliveira (2017)	Developed a system using CMMS data to support maintenance scheduling.
Availability Improvement by Implementing Customize Maintenance Strategy in Rental Operation of Indonesian Forklift Distributor Company	Proceedings of The Conference on Management and Engineering in Industry	(Mohammad Yoga Baskoro, 2021)	Implementing a customized maintenance strategy combining preventive maintenance (PM) and reliability center maintenance (RCM) based on customer requirements can improve forklift availability and optimize maintenance costs.

According to these research, Computer-Based Maintenance Management Systems (CMMS) can be a very useful tool for mining companies looking to maximize equipment uptime and repair time precision. With its capacity to monitor and evaluate operational data, CMMS can help mining companies effectively plan and schedule equipment maintenance. As a result, there may be less equipment downtime, more productivity, and more accurate servicing times. Thus, in terms of operational effectiveness and service dependability, CMMS has the potential to significantly help the mining sector.