Preventive Maintenance of Mining Heavy Equipment in an Indonesian Coal Mining Contracting Company

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Abstract

In Indonesia, one of the most important energy sources is coal. Since 2020, Indonesia's coal production has increased. This is partly due to the energy crisis in Europe. As production increases, mining companies need better equipment. To achieve production targets, reliability and availability are the most important factors. One of the factors that have an impact on mining equipment reliability is preventive maintenance. Preventive maintenance (PM) is intended to reduce the probability of failure or degradation of functioning of an item and is carried out at predetermined intervals. Maintenance performance measurement is therefore essential to ensure that maintenance objectives are achieved, and that maintenance adds value for the company. This research aims to understand preventive maintenance applied by coal mining actors in Indonesia. Questionnaire is used to collect opinions of maintenance crew about their experience in conducting preventive maintenance. It is then summarized to get preventive maintenance characteristics in Indonesian coal mining contracting company.

Keywords
Coal Mining, Heavy Equipment, Preventive Maintenance, Maintenance Characteristics and Likert Scale Survey.

1. Introduction
To be able to compete successfully both at national and international levels, production systems and equipment must perform at levels not even thinkable a decade ago. Machine maintenance is paramount to the process industry with regards to both safety and effectiveness. A poor maintenance system has a direct impact on costs, deadlines, quality, and accidents making it catastrophic to an organization in terms of both operational performance and process safety. Requirements for increased product quality, reduced throughput time and enhanced operating effectiveness within a rapidly changing customer demand environment continue to demand a high maintenance performance (Ben-Daya et al. 2009). Given the important nature of maintenance, it must be conducted in parallel with a plant's normal operations to avoid compromising the plant's productivity levels (Kobbacy and Murthy 2008). Traditionally, maintenance is studied in isolation of other functions within an organization such as operations, marketing, etc., and in isolation of other supporting and service providing organizations. Modern manufacturing is becoming more automated than ever with more flexible and reliable manufacturing technologies. The main purpose of maintenance is to ensure manufacturing asset (machine, equipment, or plant) availability and reliability.

Maintenance is defined as the set of activities, technical, administrative, and managerial, performed during the life cycle of an item, workplace, work equipment, or means of transport, to preserve the value of an asset. The value includes its reliability, availability, productivity, and market value. Activities include planning, coordination, financing, and operations. It involves multidisciplinary activities involving people machines equipment spare parts and information. Various maintenance strategies were developed over time such as preventive maintenance, condition-based maintenance, reliability-based maintenance and so forth. Maintenance can be performed in two major types: corrective or preventive. Corrective maintenance (CM), similar with repair work, is undertaken after a breakdown when obvious failure has been located. CM, can be also called reactive maintenance, only performs after failures occur during operation time, aiming to restore or recover operation conditions (Zhong et al. 2019). Preventive maintenance (PM) is intended to reduce the probability of failure or degradation of functioning of an item and is carried out at predetermined intervals, predetermined PM, or according to a prescribed condition.

Compared with CM, although PM has the advantages of effectively guaranteeing the system reliability and power output, but unnecessary inspection and maintenance activities cannot be avoided (Nguyen and Chou 2018). These strategies scored great success in eliminating unexpected failures and unplanned unavailability's which usually cause high costs of operations and restoration (Al-Turki et al. 2014). Based on health states and degradation process of equipment which are reflected by recorded data from condition monitoring systems, the potential failure occurrences can be predicted, thus maintenance performance can be scheduled in advance (Zhao et al. 2017).

Generally, maintenance activities are considered in conflict with production operations (Colledani and Tolio 2012). In fact, although preventive maintenance can slow down the equipment degradation and reduce the need for complex and expensive corrective actions, it shows a negative impact on the availability of equipment. According to this strategy, due to the dynamic behavior of the system, preventive maintenance tasks should be performed when a suitable window of opportunity is available. Opportunity windows are defined as specific time intervals generated by favorable system conditions, where preventive maintenance tasks can be performed. By taking advantage of these opportunity windows, the coordination between production and maintenance operations can be better achieved, thereby reducing the impact of maintenance on system performance.

Maintenance management is also carried out in the coal mining industry. In Indonesia, one of the most important energy sources is coal. Baskoro et al (2021) estimate that 30% of Indonesia's energy sources will come from coal by 2025. Since 2020, Indonesia's coal production has increased 7.16% from 565.69 million tons to 606.22 million tons (Figure 1). It is predicted that in 2022 the percentage increase will reach 18.8% because production in the first half of 2022 has reached 360 million tons (CNBC Indonesia 2022). This is partly due to the energy crisis in Europe which is caused by the Russia-Ukraine war (CNBC Indonesia 2022). The volume of coal exports to Europe usually is less than 1 million tons, but due to the current conditions it has increased to 4 million tons until October 2022. Coal from Indonesia substitutes the one from Russia.
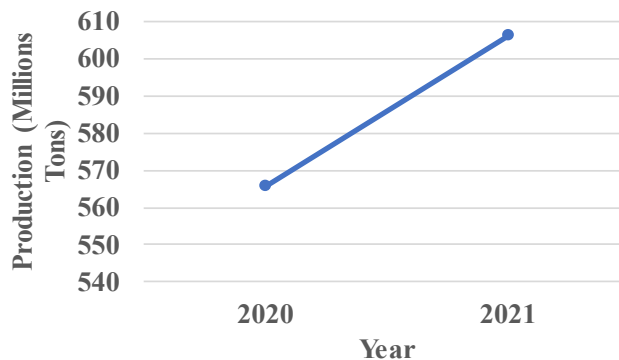

Figure 1. Coal production in Indonesia during 2020 – 2021
(source: Realisasi Produksi Batu Bara (2014-2021) Katadata, 2022)

As production increases, mining companies need better equipment. By keeping the reliability, profits can be maximized and can overcome global competition. Reliability is defined as the probability of an equipment will function properly for a certain time when used properly in specified conditions (Dhillon 2008). Dhillon (2008) states that one of the factors that have an impact on mining equipment reliability is routine or preventive maintenance. The system that usually used in open pit mines is the shovel-truck system. To achieve production targets, reliability and availability are the most important factors. In addition to production related, preventive maintenance is important to prevent accidents. Ismail et al. (2021) stated that the most common accidents occurring in mines are related to mechanical failures.

Ben-Daya et al. (2009) stated that 15 – 40% of operational costs are related to maintenance. Specifically, in mines, the cost of maintaining mine equipment ranges from around 20% to more than 35% of the total mine operating costs (Dhillon 2008). Even in Indonesia, Dhillon (2008) states that maintenance costs are more than 60% of operating costs. To control these costs, one of the things mining companies do is optimizing scheduled maintenance operations.

1.1. Objectives

To carry out mining, contractor services are usually used by coal producers in Indonesia. This decision is chosen because if they are operating by themselves, they will need a large investment, both in terms of capital to purchase heavy equipment and human resources (Dunia Tambang 2019). This business sector is a support service for mining business activities in Indonesia. The purpose of this study is to understand preventive maintenance applied by coal mining actors in Indonesia, in this case a coal mining contractor. This research selected a contractor under PT United Tractors Tbk (UT), namely PT Pamapersada Nusantara (PAMA).

2. Literature Review

2.1. Preventive Maintenance

Preventive Maintenance (PM) is an activity to repair, replace, and maintain equipment that is planned and carried out within a certain period of time to avoid unexpected failures during operation (Ben-Daya et al. 2009; Al-Turki et al. 2014; Basri et al. 2017). The possibility of downtime failure can be reduced through inspection, monitoring, cleaning, lubrication, adjustment, re-alignment, repair, replacement, and maintenance of components (Al-Turki et al. 2014; Au-Yong et al. 2014).

The main objective of Preventive Maintenance (PM) is to minimize the total cost of inspection, repair, and equipment downtime from the failure or degradation of the machine function, so that the cost of preventive maintenance is less than the cost of failure or corrective maintenance because it can prevent downtime failures (Ben-Daya et al. 2009; Ahmad and Kamaruddin 2012,;Au-Yong et al. 2014).

2.2. Preventive Maintenance Characteristics

The failure behavior (characteristics) of the equipment can be predicted (Ahmad and Komarudin 2012). Preventive maintenance characteristics are needed when planning and implementing maintenance activities, so that maintenance performance and customer satisfaction can be improved and achieved optimally (Au-Yong et al. 2014). From some literature, we have identified seven characteristics of preventive maintenance that influence the maintenance performance of a heavy mining equipment as follows:

a. Preventive maintenance management

Preventive maintenance management is a long-term strategy of carrying out maintenance at scheduled intervals (Basri et al. 2017), by allocating and coordinating resources including labor, spare parts and materials at minimum costs without disturbing the quality of the system (Chua et al. 2018). Technical and administrative changes are made to the production and maintenance processes, including to top management (Basri et al. 2017), thereby making maintenance decisions by minimizing or maximizing downtime, failure costs, maintenance costs, reliability, and availability (Ahmad and Kamaruddin 2012). Preventive maintenance management must be supported by detailed and structured standard procedures to assist in planning and scheduling the system for effective PM (Al-Turki et al. 2014; Basri et al. 2017).

b. Preventive maintenance planning

Preventive maintenance planning is an activity carried out by allocating all maintenance resources, such as material requirements, labor requirements, time assignments, and technical references related to equipment (Basri et al. 2017), including costs incurred due to the maintenance of a system (Horenbeek et al. 2012) and scheduled during planned machine stoppage (Alhourani et al. 2019). This is determined and prepared before the implementation of preventive maintenance tasks (Basri et al. 2017), namely at certain time intervals, number of operations, or mileage (Chua et al. 2018) based on a history of system failure (Ahmad and Kamaruddin 2012, Horenbeek et al. 2012) thereby reducing the risk of future failure (Chua et al. 2018). Effective and efficient preventive maintenance planning requires analysis of the plant's general machine failures and maintenance requirements to help strengthen machine efficiency, reduce failure consequences, and extend system useful life (Alhourani et al. 2019). PM planning involves predetermined maintenance tasks planned before failures occur (Basri et al. 2017). Nurcahyo et al. (2018) added that maturity of the maintenance organization will give excellence process in maintenance planning.

c. Preventive maintenance spare parts and tools

Preventive maintenance spare parts and tools are maintenance resources in optimizing company operations (Horenbeek et al. 2012) related to spare parts needed, spare parts reorder efficiency, spare parts inventory levels, and spare parts storage (Chua et al. 2018) which must be managed properly so as not to cause high inventory costs

(Horenbeek et al. 2012). The replacement process uses certain equipment, materials, people, and information (Basri et al. 2017) which are determined by an optimization approach based on the mechanism of the equipment being maintained (Ahmad and Kamaruddin 2012). In a policy of regularly scheduled shutdown and preventive maintenance, random failure replacement and demand for spare parts may occur, and the parts are used in a large system (Vaughan 2005). So as not to delay the schedule of interrelated preventive maintenance activities, providing sufficient supplies to support preventive maintenance is very important (Vaughan 2005).

d. Preventive maintenance monitoring and inspection
Preventive maintenance monitoring and inspection are maintenance activities carried out by measuring the condition of the equipment and monitoring it using various features, such as vibration and temperature measurements (Horenbeek et al. 2012) which are carried out at certain intervals according to the criticality of the system and components (daily, weekly, monthly, yearly, etc.) (Au-Yong et al. 2014), based on design estimates, and updated through experience (Basri et al. 2017). Condition monitoring (using sensors) and manual inspection (checking directly on machines) are carried out in the industry to identify systems through preventive maintenance (Wang and Wang 2015). Inspection with observation of anomalies in equipment can be carried as input for preventive maintenance scheduling (Angeles and Kumral 2020).

e. Preventive maintenance human resource
Preventive maintenance human resources is the allocation of resources that includes the workforce, including people who lead and direct the company, to make technical and administrative changes to the production and maintenance processes (Basri et al. 2017), to improve maintenance performance so as to maintain system reliability (Chua et al. 2018) and are expected to have the necessary capabilities with specific qualifications and experience as well as maintenance skills and knowledge (Au-Yong et al. 2014). To provide additional skills and knowledge, training is needed for the maintenance crew. Fatoni and Nurcahyo (2018) stated that it can improve maintenance performance and create skilled technician effectively.

f. Preventive maintenance performance
Preventive maintenance performance is an assessment to find out the strengths and weaknesses of maintenance performance in terms of cost, quality, and time (Chua et al. 2018) with certain methods to help analyze and run systematically so as to facilitate the achievement of accurate and efficient results, such as reducing unplanned system breakdowns and increasing availability of operational time (Basri et al. 2017), resulting in an assessment of the degree of maintenance in determining the level of improvement in returning the system to a like new condition or condition as before the repair (Horenbeek et al. 2012). The efficiency and quality of the maintenance need to be measured through maintenance performance indicators and key performance indicators to assist and predict future actions and performance based on past data (Parida et al. 2013).Machines and maintenance information need to be reevaluated frequently and updated (Alhourani 2019).

g. Preventive maintenance information management
Preventive maintenance information management is the process of collecting a sufficient set of failure data and influencing maintenance factors (such as time spent on repairs and replacements, time lost due to failure, time allocation for collecting spare parts, shifts, and time for system operation) that can be used for modeling in planning future actions such as determining the optimal time interval for PM, making decisions related to PM, and taking corrective actions (Basri et al. 2017). The process takes time and may be expensive to collect (Ahmad and Kamaruddin 2012). The unavailability of relevant data and information is a major problem for decision-making in PM. Optimizing the preventive maintenance needs to be supported by an integrated information system (Parida et al. 2013).

2.3 Geometric Mean and Cronbach's Alpha
A geometric mean is used for data that has a different weight among the data. The geometric mean minimizes theinfluence of extreme values. One of the geometric mean requirements is that no data element has a negative valuebecause it is a process of calculating the root of the power. Equation (1) shows the geometric mean formula.

$$G = \sqrt[n]{x_1 \times x_2 \times x_3 \times \ldots x_n} \quad (1)$$

G represents geometric mean of a sample, x_n represents value of the nth data, while n represents amount of data in a sample.

In general, reliability testing is a research instrument to obtain reliable information as a data collection tool. A reliability test can be used to test some questionnaires used in a study to determine whether the questionnaire used can be said to be reliable or not. Questionnaires can be reliable if someone's answer to the statement is consistent from time to time.

Reliability testing can use the Cronbach's Alpha method to test the reliability of the questionnaire using a Likert scale. Provisions indicate the high and low reliability, empirically indicated by a number called the reliability coefficient value. The reliability coefficient value ranges from 0 to 1, indicating that high reliability is a reliability coefficient value close to 1. Equation (2) shows the Cronbach's Alpha formula.

$$\alpha = \left(\frac{n}{n-1}\right)\left(1 - \frac{\sum \sigma_t^2}{\sigma_t^2}\right) \quad (2)$$

α represents the reliability coefficient, n for number of items tested, $\sum \sigma_t^2$ for total score variance for each item, and σ_t^2 represents the total variance.

3. Methods

An empirical quantitative study was conducted and data were collected by questionnaire. Supported by an extensive literature review of journals, references, supporting libraries, and theoretical sources for the writing process related to preventive maintenance, maintenance surveys, and maintenance in coal companies. Seventeen questions were developed based on the criteria obtained from the literature review and the target to be known, which contains questions that can explain these factors. The questionnaire consists of seven characteristics of preventive maintenance. Those are:
1. Preventive maintenance management
2. Preventive maintenance planning
3. Preventive maintenance spare parts and tools
4. Preventive maintenance monitoring and inspection
5. Preventive maintenance human resource
6. Preventive maintenance performance
7. Preventive maintenance information

This research was conducted at the Indonesian coal mining contracting company, PAMA. PAMA has fifteen sites across Indonesia (PT United Tractors Tbk 2022). In 2021, it utilizes 4.280 units of equipment. They consist of 2.940 dump trucks, 464 excavators, 359 bulldozers, 257 graders, 84 wheel loaders, 82 drilling machines, 79 prime movers, and 15 crushers (PT United Tractors Tbk 2022). Respondents for the questionnaire were Plant Department Heads, Plant Section Heads, and Plant Engineers. Specifically for Plant Section Heads, they consist of Plant Planner Section Heads and Plant Operational Section Heads.

The preventive maintenance criteria were measured based on their responses to a five-point Likert scale. The Likert scale is used to convert some qualitative responses into quantitative data analysis (Ugwu et al. 2018). The five points are scaled as: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. Table 1 shows the Likert scale and its explanations used in the questionnaire. The assessment was conducted to determine the opinions and perceptions of employees on preventive maintenance at PAMA by using the list of questionnaires in Table 2.After that, the geometric mean and Cronbach's alpha statistical test were carried out in this study. The geometric mean is used to find a compromise between the data sets provided, giving the same results, while Cronbach's alpha calculates the consistency between items in the test which is the internal consistency of the test (Christmann and Van Aelst 2006).

Table 1. Likert scale definition

Scale	Description
1	Very Important (the criterion is very unimportant in maintenance management)
2	Not Important (the criterion is not important in maintenance management)
3	Neutral (the criterion is neither agree nor disagree important in maintenance management)
4	Important (the criterion is very important in maintenance management)
5	Very Important (these criteria are important in maintenance management)

Table 2. Questionnaire of preventive maintenancecharacteristics

Criteria	Sub Criteria
A. Preventive Maintenance Management	A1. There are policies that regulate the planning, implementation, and monitoring of preventive maintenance
	A2. Preventive maintenance policies are made in accordance with the operating conditions of heavy equipment in the company
B. Preventive Maintenance Planning	B1. Preventive maintenance is carried out at certain intervals according to the agreed schedule
	B2. There is a budget allocation that is devoted to preventive maintenance activities
C. Preventive Maintenance Spare Parts and Tools	C1. Spare parts are prepared during preventive maintenance
	C2. Purchase of spare parts based on the history of preventive maintenance
	C3. Auxiliary equipment is available during preventive maintenance activities
D. Preventive Maintenance Monitoring and Inspection	D1. Periodic checks are carried out during preventive maintenance
	D2. The inspection process during preventive maintenance is carried out with diagnostic tools
E. Preventive Maintenance Human Resource	E1. There is a separation of technical and managerial work functions in preventive maintenance activities
	E2. Mechanics receive regular training related to preventive maintenance
	E3. Staff (managerial level) receive regular training related to preventive maintenance management
F. Preventive Maintenance Performance	F1. There are KPIs that measure preventive maintenance performance
	F2. Periodic evaluation is carried out on preventive maintenance performance that is not achieved
G. Preventive Maintenance Information	G1. Accurate recording of the history of operations and preventive maintenance
	G2. Heavy equipment preventive maintenance data is digitally recorded and integrated
	G3. Digitally recorded data is used to evaluate the effectiveness of preventive maintenance that has been carried out

4. Data Collection

Data is then collected from sixteen sites, namely ABKL, ARIA, ASMI, BAYA, BEKB, BRCB, BRCG, BTSJ, INDO, KIDE, KPCB, KPCS, KPCT, MTBU, SMMS, and TCMM. Most respondents came from BAYA, BEKB, KPCB, and MTBU locations with a total of 3 respondents (Figure 2). Total respondents are thirty-two persons, consisting of three positions,namely Plant Department Head, Plant Section Head, and Plant Engineer. Plant engineering is the position of most respondents with a total of 34.4% of all respondents (Figure 3). Their experience is shown in Figure 4. Most of them have worked for 5 – 15 years with a total of 37.5% of all respondents (Figure 4).The respondent's last education consisted of 3 levels, namely SMA, D3, and S1. Most of them have been graduated from D3 level with a total of 43.8% of all respondents(Figure 5).
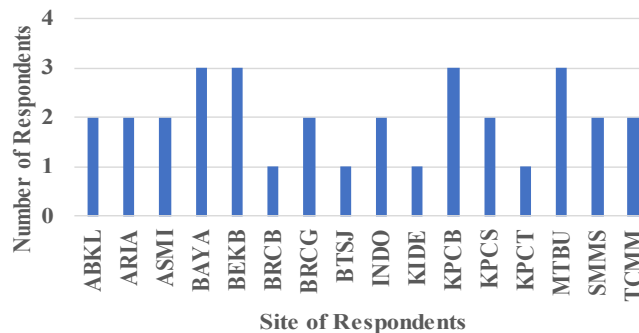

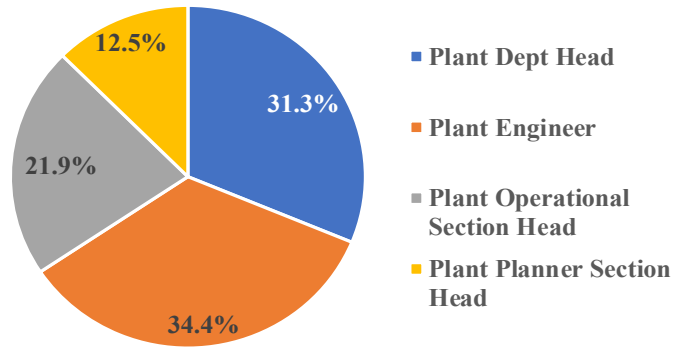
Figure 2. Respondents' workingbranch
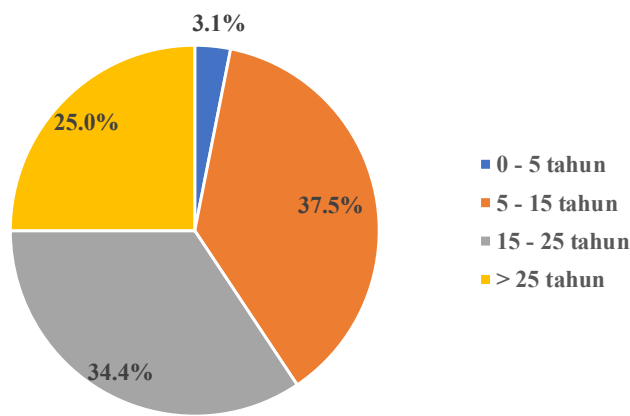
Figure 3. Respondents' working position

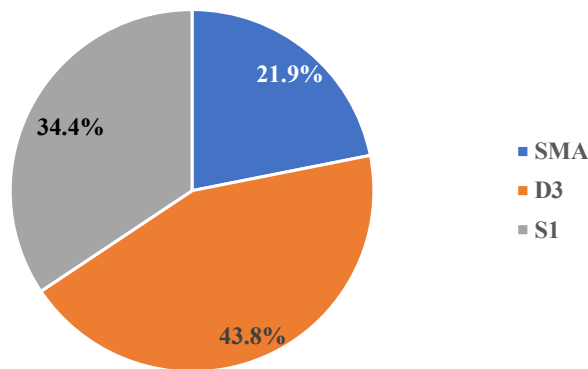Figure 4. Respondents' years of work

Figure 5. Respondents' last education

5. Result and Discussion

Based on the survey, we can get Likert scale distribution as shown in Figure 6. Above 60% of the total respondents rated point 5 on all preventive maintenance characteristics, namely all preventive maintenance characteristics are very important (this criterion is important in maintenance management). They are 76% of total respondents and the detail is shown in Table 3. It means that maintenance personnel in mining have the same definition about preventive maintenance. Consistency of score is then measured by using Cronbach's alpha. For the questionnaire, the Cronbach's alpha coefficient is 0.856. It means that the internal consistency reliability of the questionnaire is good

(Oktavia et al. 2018). Summary of this responses is shown at Table 4 as a geomean score of Likert scale. The highest score is questions regarding performance of preventive maintenance (F) with an average Geomean score is 4.88, and the lowest one is regarding monitoring and inspection (D)with an average Geomean score is 4.42.
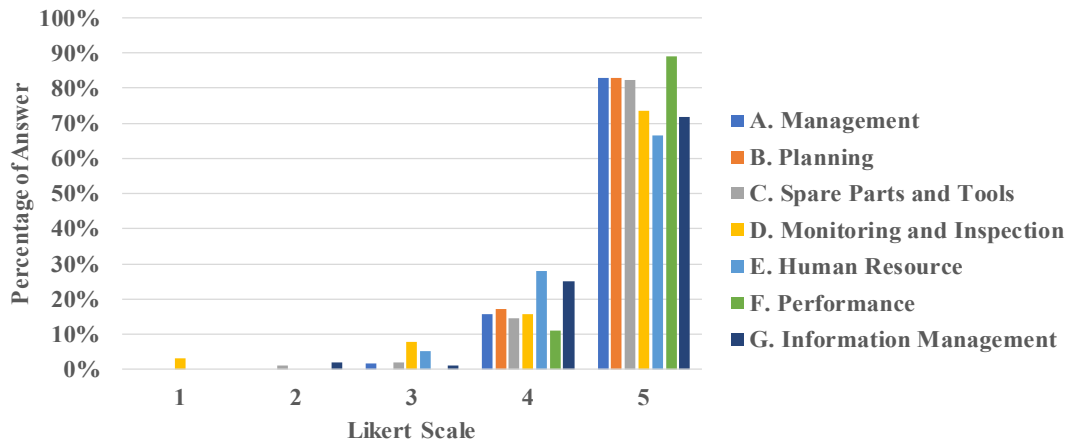

Figure 6. Likert scale distribution of preventive maintenance characteristics

Table 3. Responses of preventive maintenance sub criteria

Sub Criteria	Responses in Likert Scale				
	1	2	3	4	5
A1	0%	0%	0%	9%	91%
A2	0%	0%	3%	22%	75%
B1	0%	0%	0%	19%	81%
B2	0%	0%	0%	16%	84%
C1	0%	0%	0%	9%	91%
C2	0%	3%	6%	9%	81%
C3	0%	0%	0%	25%	75%
D1	3%	0%	3%	6%	88%
D2	3%	0%	13%	25%	59%
E1	0%	0%	6%	31%	63%
E2	0%	0%	0%	19%	81%
E3	0%	0%	9%	34%	56%
F1	0%	0%	0%	3%	97%
F2	0%	0%	0%	19%	81%
G1	0%	3%	0%	16%	81%
G2	0%	3%	3%	34%	59%
G3	0%	0%	0%	25%	75%

Preventive maintenance activities in mining contractor are regulated by management. The regulation covers planning, execution, and monitoring area (A1) in accordance with operating condition of heavy equipment (A2). In the planning area, it is scheduled on a specific interval (B1) with certain budget allocation (B2). Before carrying out the maintenance, spare parts are prepared (C1) and purchased according to the history (C2). If needed, maintenance crew are also equipped with special tools to assist their works (C3). Beside replacing spare parts, they also carry out inspections during preventive maintenance (D1). The inspections are mostly carried out using visual check rather than diagnostic tools (D2). They are accurately recorded as operation and maintenance history (G1). To be aligned with current technology developments, it is suggested that they should explore more in using diagnostic tools. It will meet the challenges of competitiveness (El kihel et al. 2022). It also enables the company to manage critical resources and energy efficiently (El kihel et al. 2022).

Table 4. Geomean score of preventive maintenance characteristics

No	Criteria	Criteria Code	Geomean Criteria	Sub Criteria Code	Geomean Sub Criteria
1	Management	A	4.81	A1	4.90
2				A2	4.69
3	Planning	B	4.83	B1	4.80
4				B2	4.83
5	Spare Parts and Tools	C	4.78	C1	4.90
6				C2	4.61
7				C3	4.73
8	Monitoring and Inspection	D	4.56	D1	4.61
9				D2	4.22
10	Human Resource	E	4.61	E1	4.52
11				E2	4.80
12				E3	4.41
13	Performance	F	4.89	F1	4.97
14				F2	4.80
15	Information Management	G	4.67	G1	4.69
16				G2	4.43
17				G3	4.73

Statement about measurement items of preventive maintenance is very appropriate to describe preventive maintenance activities at mines (F1). The highest score means that maintenance personnel have same understanding of what they should deliver to customers (Operation and Engineering Department). Maintenance personnel is aware that their preventive maintenance works will give positive result to the project. If it is not achieved, they will evaluate periodically (F2) by using digitally recorded data (G3). Unfortunately, although it is digitally recorded, it has not been integrated with other data (G2). Integration should be made to get more efficient production systems (Shaheen and Nemeth 2022).

In human resource criteria, managerial and technical workers are separated during preventive maintenance activities (E1). The planning and monitoring activities are carried out by staff (managerial level) and the execution is carried out by mechanics. Both have the specific importance roles. Unfortunately, staff (managerial level) did not get regular training related to preventive maintenance (E3). Regular trainings are only given to mechanics (E2). Management should consider in training their staff because it will significantly affect maintenance performance (Fatoni and Nurcahyo 2018).

6. Conclusion

Maintenance management is an important thing to do in the company as well as in the coal mining industry. This paper discusses the effectiveness of preventive maintenance characteristics in the coal mining industry.Preventive maintenance characteristics are needed when planning and implementing maintenance activities. From some literature, we have identified seven characteristics of preventive maintenance that influence the maintenance performance of heavy mining equipment.Suggested research found that most respondents agreed with the defined characteristics. Besides that, the internal consistency and reliability of the seventeen questions from the seven characteristics is good. Consistency of score is measured by using Cronbach's alpha. We used the geometric mean to analyze the data from survey.

According to the study's findings, the preventive maintenance performance question received the highest score, and the monitoring and inspection question received the lowest score.Therefore, it can be concluded that maintenance staff members agree on the quality of service that they should provide to consumers (Operation and Engineering Department). The maintenance team is aware that their proactive maintenance efforts will benefit the project.It was discovered through this study that only mechanics received regular training in preventative maintenance, not the staff (managerial level). Management should take these recommendations to give training to their personnel because

it will have a big impact on how good maintenance is performed.Besides that, the inspection can be evaluated because the result of the study showed that it has the lowest score.The existing maintenance system may cause visual inspection to lose some of its significance.As a recommendation, management can modify or evaluate the procedures for maintenance activities, especially for the inspection process. As a result, compliant inspections on maintenance operations for industry 4.0 can be anticipated. For future research, it can be learned at other heavy equipment objects that have different characteristics and also for preventive maintenance in the coal mining industry that has implemented digital-based maintenance.

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