Diagnosis of Maintenance Maturity in an Indonesia's Coal Mining Contracting Company

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Abstract

The trend of coal production in Indonesia has been increasing since 2020. This increase in coal production also has an impact on sales of heavy equipment. Heavy equipment sales have increased from 2020 to the first semester of 2022. Mining haul trucks are currently equipped with industrial 4.0 technology, namely IoT, which can be used to monitor equipment health. Through predictive maintenance or maintenance 4.0, companies can manage resources and energy efficiently. The complexity of technology and this digital revolution if not managed properly will have a negative impact, one of them is reducing the competitiveness of a company. This study aims to identify maturity levels of maintenance in coal mining actors in Indonesia, especially about data driven asset management. There are four maintenance maturity levels that will be assessed: visual inspections, instrument inspections, real time monitoring, and predictive maintenance in industry 4.0. It will be combined with three data maturity levels: initial, established, and advanced. Questionnaire is used to collect opinions of maintenance managers as the owner of maintenance process about their experience in conducting maintenance. It is then summarized to state maturity level of maintenance practices in an Indonesian coal mining contracting company. It is concluded that maintenance characteristics in this company mostly fit with predictive maintenance in industry 4.0 characteristics.

Keywords
Coal Mining, Heavy Equipment, Maintenance 4.0, Predictive Maintenance and Maintenance Diagnosis.

1. Introduction
Baskoro et al. (2021) stated that energy is one of the factors related to economic growth and living standards, including in Indonesia. This energy is divided into primary and secondary energy (Kartiasih et al. 2012). The Ministry of Energy and Mineral Resources Republic of Indonesia (2022) defines primary energy as energy which in its original form is extracted by mining, damming, or utilizing renewable energy. Petroleum, natural gas, coal, and renewable energy are primary energy in Indonesia (Secretariat General National Energy Council 2019). Among these energy sources, one of the most important is coal. In 2025 it is estimated that 30% of Indonesia's energy sources will come from coal (Baskoro et al. 2021).

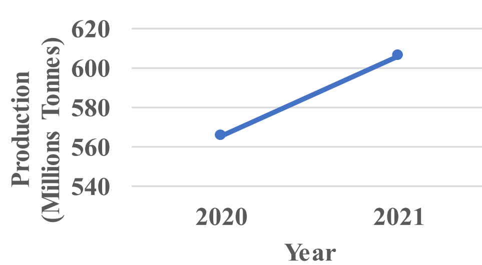


Figure 1. Coal production trend in Indonesia
(source: Katadata 2022)

The trend of coal production in Indonesia has been increasing since 2020 (Figure 1). In fact, according to CNBC Indonesia (2022) in the first semester of 2022 its production reached 360 million tons, while in the first half of 2021 its production was 286 million tons. It is caused by the rising coal price since 2021. In addition, CNBC Indonesia (2022) stated that this was also driven by the energy crisis in Europe. The Russia-Ukraine war since February 2022 has forced European countries to impose economic sanctions by stopping coal supplies from Russia. Indonesian coal eventually became the replacement. Indonesia's coal exports to Europe are usually less than 1 million tons per year to almost 4 million tons until October 2022.

This increase in coal production also has an impact on sales of heavy equipment. Most of heavy equipment sales occurred in the mining sector, which was 39% (Bisnis 2022). Heavy equipment sales have increased from 2020 to the first semester of 2022 as shown in Figure 2. The Indonesian Heavy Equipment Sole Agent Association (PAABI) estimates that sales in 2022 will reach 18,000 units (Bisnis 2022). Heavy equipment products that are widely sold are Komatsu, Caterpillar, and Hitachi. In Figure 3, it can be concluded that the total sales of these three products are more than 50%.

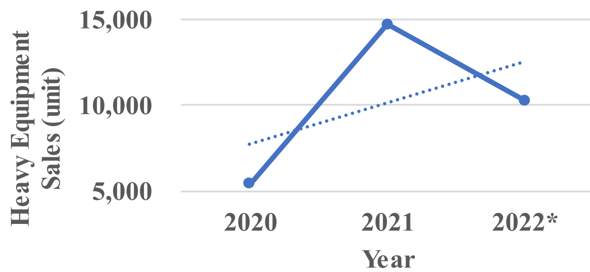


Figure 2. Heavy equipment sales in Indonesia
(source: Data Industri 2022)

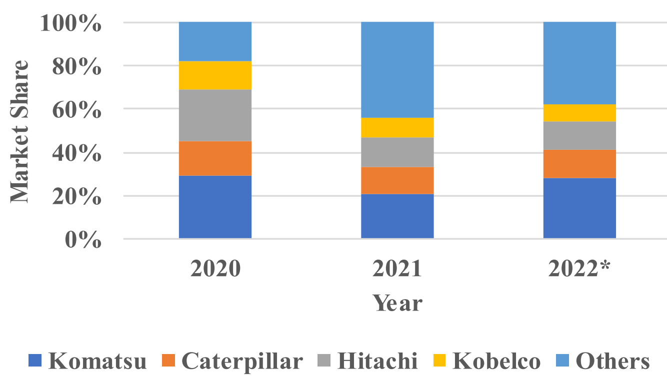
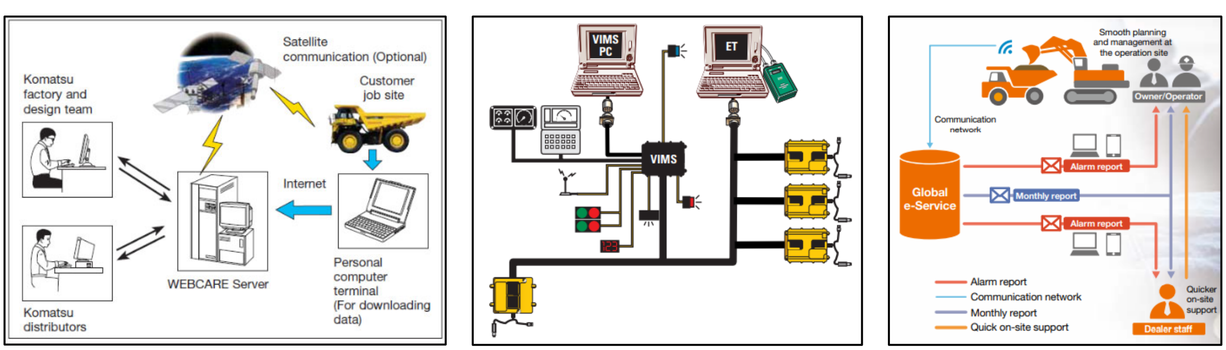


Figure 3. Market share of heavy equipment brands in Indonesia
(source: Data Industri 2022)



(a) (b) (c)
Figure 4. IoT system in Komatsu (a), Caterpillar (b), and Hitachi (c) trucks

In open pit mining, trucks and excavators are a major part of the material transport operation (Alla et al. 2019). Komatsu (Komatsu Ltd 2016), Caterpillar (Caterpillar Inc 2009), and Hitachi (Hitachi Construction Machinery Co. Ltd 2020) haul trucks are currently equipped with industrial 4.0 technology, namely IoT, which can be used to monitor equipment health. This technology is described in Figure 4. Its application also has an impact on sustainability (Osburg and Lohrmann 2017). Dastbaz and Cochrane (2019) adds that the growth in the application of this technology is driven by the benefits it provides related to corporate growth and sustainability, one of which is through predictive maintenance. Through predictive maintenance or maintenance 4.0, companies can manage resources and energy efficiently (El kihel et al. 2022).

1.1. Objectives

In the mining, equipment maintenance has a significant part of total operating costs, ranging from 20% to 35% (Alla et al. 2020). Hauling trucks play important roles in open pit mines around the world. Hauling trucks account for about 40% of the total maintenance costs (Alla et al. 2020). Maintenance 4.0 can be used to prevent premature components and equipment failures. This study aims to identify maturity levels of maintenance in 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). PAMA has a domestic market share of 21% in Indonesia (PT United Tractors Tbk 2022). According to the 2021 Annual Report, UT has coal mining contractor subsidiaries that spread across 15 sites throughout Indonesia.

2. Literature Review

Hien et al. (2022) divided maintenance maturity into four, namely visual inspection, instrument inspection, real time monitoring, and predictive maintenance in Industry 4.0. They are defined in Table 1. In predictive, proactive, or prescriptive maintenance, Bona et al. (2021) stated that Industry 4.0 technology is an important prerequisite. Industry 4.0 technology encourages innovative and effective solutions, such as remote maintenance or self-maintenance, which offer solutions towards more advanced maintenance policies (Silvestri et al. 2020) thereby contributing to the development of efficient and safe maintenance (Bona et al. 2021). Predictive maintenance according to Roda and Macchi (2021) is an advanced maintenance concept, namely a holistic approach that uses knowledge from past developments, ranging from the e-maintenance concept and intelligent maintenance concept to more recent developments including smart maintenance and maintenance 4.0.

Table 1. Maintenance maturity level (Hien et al. 2022)

Capability	Level 1 Visual Inspections	Level 2 Instrument Inspections	Level 3 Real Time Monitoring	Level 4 Predictive Maintenance in Industry 4.0
Process	• Periodic inspection (physical) • Checklist • Paper recording	• Periodic inspection (physical) • Instruments • Digital recording	• Continuous inspection (remote) • Sensors • Digital recording	• Continuous inspection (remote) • Sensors and other data • Digital recording
Content	• Paper based condition data • Multiple inspection points	• Digital condition data • Single inspection point	• Digital condition data • Multiple inspection points	• Digital condition data • Multiple inspection points • Digital environment data • Digital maintenance history
Performance measure	• Visual norm verification • Paper based trend analysis • Prediction by expert opinion	• Automatic norm verification • Digital trend analysis • Prediction by expert opinion	• Automatic norm verification • Digital trend analysis • Monitoring by CM software	• Automatic norm verification • Digital trend analysis • Prediction by statistical software • Advanced decision support
IT	• MS Excel/MS Access	• Embedded instrument software	• Condition monitoring software • Condition database	• Condition monitoring software • Big data platform and network • Statistical software
Organization	• Experienced craftsmen	• Trained inspectors	• Reliability engineers	• Reliability engineers • Data scientist

In the context of Industry 4.0 (I4.0), predictive maintenance is changing the way of thinking of maintenance from a cost to a business opportunity in the industry. However, Kaczmarek et al. (2022) also said that there were several obstacles in the process of implementing I4.0 technology in maintenance. The most significant is the lack of IT infrastructure and the lack of information security and privacy protection. One of these IT infrastructures is related to data maturity. Brasen et al. (2021) defines data maturity as the company's ability to plan, collect, process, enrich, decide, and operate IoT sensor networks. This definition is described in Table 2. The collected data will be further processed by data scientists whose roles include data retrieval, data preparation, data exploration, data modeling, presentation, and automation (Sajid et al. 2021).

Table 2. Data maturity level (Brasen et al. 2021)

Identification	Low/Initial	Medium/Established	High/Advanced
Data usage	No or only an initial	Regularly used	Used to predict specific components life cycle or root causes of failures
Asset condition	Generally older	There are mechanisms built in or retrofitted to extract data	Highly advanced and digitally connected
Asset performance check	Supervised manually Visual inspection	Progression in the process of utilizing data	There is high quality information about its condition
Organization	• Little or no connected skills • No or only initial governance and strategy	• Some analytic/technical capabilities connected to the company • Some governance and strategy have been established	• There are highly specialized data analytic capabilities • Advanced data driven asset management is a key element

Predictive maintenance taxonomy in the context of I4.0 was developed by Zonta et al. (2020). The taxonomy presented relates to methods, interactions, models, monitoring focus, and goal constraints. Furthermore, Wen et al. (2022) provides an overview of the predictive maintenance workflow and how a prognostic approach is applied. The application of statistical and machine learning-based remaining useful life (RUL) predictions is reviewed in various fields, namely in rotating engines, aircraft, power systems, and electrical and electronic components. In the predictive maintenance management problem, the current health status of the equipment and the breakdown characteristics are combined to increase the accuracy of predicting equipment downtime (Geng and Wang 2022). By considering maintenance resource constraints and equipment downtime, a predictive maintenance scheduling model is built on multiple equipment to minimize total maintenance costs. Tao et al. (2022) add that economic risk is significantly reduced by increasing the accuracy of the RUL estimation, maximizing the loss of availability to the permissible limit due to maintenance activities, or maximizing the number of available workshops. This benefit can also be obtained through the implementation of the Realtime Condition Monitoring (RTCM) strategy defined by Alla et al. (2020) as the ability to monitor conditions in real-time and to alert the maintenance and operation team if there are abnormal conditions. Alla et al. (2020) specifically stated that there were statistically significant differences in the duration and amount of downtime through the implementation of the RTCM strategy at the mine site.

3. Methods

The research was conducted in the coal mining sector. A case study was conducted on one of the coal mining contractor companies in Indonesia. According to the 2021 Annual Report, PAMA as a subsidiary of UT is a coal mining contractor that spread across 15 sites throughout Indonesia. 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). An empirical quantitative study was conducted and data were collected by questionnaire. Classification of maintenance maturity in each level in Table 1 and Table 2 are then combined to create the statements for audit current state of maintenance in this company. To be more specific, questionnaires are applied to the largest population of mining equipment, namely haul trucks. List of statements are shown in Table 3. Questionnaire is using a multiple-choice type. Respondents can only choose one statement for one subitem. The variable is a nominal one. Because it has nominal type of data, the most dominant answers (mode) for each subitem will be mapped as stated in Table 1 and Table 2 to determine which maturity level maintenance is.

Table 3. List of questionnaire statements to determine maintenance maturity level

Item (I1)	Subitem (I2)	Statement (I3)
A. Process	A1. Inspection	A11. Physical inspection is carried out periodically
		A12. Remote inspection is carried out continuously
	A2. Recording	A21. Recording using checklist paper
		A22. Recording using digital instruments such as acoustic monitoring or thermal imaging
		A23. Recording using digital sensors
B. Content	B1. Asset	B11. The machines are old and can only be visually inspected manually
		B12. The machine has a mechanism that is built in or retrofitted to be able to retrieve data
		B13. Advanced, digitally connected machines
	B2. Data	B21. Existing data describes the condition at one point on the machine
		B22. Existing data describe conditions at several points on the machine
		B23. The existing data depicts maintenance history digitally
	B3. Data usage	B31. No data or only preliminary data
		B32. Routine data is used
		B33. The data is used with advanced algorithms to predict the component life cycle or root cause of failure
C. Performance measure	C1. Verification	C11. Data verification is done visually
		C12. Data verification is done automatically
	C2. Trend analysis	C21. Paper-based data trend analysis
		C22. Digital data trend analysis
	C3. Predicting	C31. Predictions are made based on expert opinion
		C32. Monitoring is carried out using condition monitoring software
		C33. Predictions are made with statistical software
		C34. There is advanced decision support for predictions
D. IT	D1. Software	D11. Using MS Excel
		D12. Using the software embedded in the instrument
		D13. Using special condition monitoring software
		D14. Using statistical software
	D2. Database	D21. Data is stored locally
		D22. Data is stored in a simple database
		D23. Data is stored on big data platforms and networks
E. Organization	E1. Subject	E11. Data is analyzed by experienced mechanics or technicians
		E12. Data is analyzed by trained supervisors
		E13. Data is analyzed by reliability engineer
		E14. Data is analyzed by data scientist
	E2. Skills	E21. Little or no expertise with data related to the organization both internal and external
		E22. There are several levels of organizational awareness and data-related process development
		E23. Organizations have highly skilled data analysis capabilities
	E3. Governance and strategy	E31. None or only initial governance and strategy is still under development
		E32. There are data-driven asset management governance and strategies
		E33. Data-driven asset management is a key element in corporate strategy and governance

4. Data Collection

Questionnaire is spread to maintenance managers or selected positions as the owner of maintenance process at PAMA. Their profile is given in Table 4. The chosen manager level is the one that in the top position of maintenance operational or other specified aspect at PAMA. They handle all operational activities at eighteen PAMA's sites. Specifically for managers, each of them handles six sites. All respondents have been working at PAMA for 16 – 27 years. Their last educations are level 3 diploma and bachelor's degree. All respondents are working at Head Office of PAMA.

Table 4. Respondents' profile

No.	Position	Level	Ownership	Work Experience	Last Education
1	Chief Region 1 Maintenance Expert	Senior Manager	Operational of 6 sites (ARIA, ASMI, CCOS, KIDE, SMMS, TOPB)	21 years	Bachelor's Degree
2	Chief Region 2 Maintenance Expert	Manager	Operational of 6 sites (BEKB, INDO, KPCB, KPCS, KPCT, TCMM)	18 years	Bachelor's Degree
3	Chief Region 3 Maintenance Expert	Manager	Operational of 6 sites (ABKL, BAYA, BRCB, BRCG, BTSJ, MTBU)	27 years	Level 3 Diploma
4	Mining Equipment Technical Expert Coordinator	Assistant Manager	Technical aspect in maintenance of all mining equipment	16 years	Bachelor's Degree
5	System Development Expert Coordinator	Assistant Manager	System development in maintenance of all mining equipment	17 years	Bachelor's Degree
6	System Development Expert	Assistant Manager	Big data project in maintenance of all mining equipment	16 years	Bachelor's Degree

5. Results and Discussion

Questionnaire that has been filled by respondents is summarized into Table 5. The most dominant answers of each subitem are marked by green color. In the process, the most appropriate characteristics are physical inspection is carried out periodically (A11) and recording using checklist paper (A21). In the content, the most appropriate ones are the machine has a mechanism that is built in or retrofitted to be able to retrieve data (B12), existing data describe conditions at several points on the machine (B22), and the data is used with advanced algorithms to predict the component life cycle or root cause of failure (B33). In the performance measure, the most appropriate ones are data verification is done visually (C11), data verification is done automatically (C12), digital data trend analysis (C22), predictions are made with statistical software (C33), and there is advanced decision support for predictions (C34). In the IT, the most appropriate ones are using statistical software (D14) and data is stored on big data platforms and networks (D23). In the organization, the most appropriate ones are data is analyzed by reliability engineer (E13), there are several levels of organizational awareness and data-related process development (E22), and data-driven asset management is a key element in corporate strategy and governance (E33). All respondents completely agree with statement regarding subitem E13 (data is analyzed by reliability engineer).

Table 5. Summary of questionnaire's answers

I1	I2	I3	Count	I1	I2	I3	Count	I1	I2	I3	Count
A	A1	A11	5	**C**	C1	C11	3	**E**	E1	E11	0
		A12	1			C12	3			E12	0
	A2	A21	3		C2	C21	1			E13	6
		A22	2			C22	5			E14	0
		A23	1		C3	C31	1		E2	E21	1
B	B1	B11	1			C32	1			E22	4
		B12	4			C33	2			E23	1
		B13	1			C34	2		E3	E31	1
	B2	B21	0	**D**	D1	D11	1			E32	0
		B22	4			D12	0			E33	5
		B23	2			D13	2				
	B3	B31	1			D14	3				
		B32	1		D2	D21	1				
		B33	4			D22	0				
						D23	5				

The most chosen statements above are then mapped into Table 6. They are marked by the green color. The black ones are statements that are not or less appropriate to maintenance activities at PAMA. Respondents' answers are spread in all maturity level of maintenance, but mostly in level 4 (predictive maintenance in I4.0). They agree with 11 of 17 statements regarding to level 4 of maturity level. It means that PAMA has partially (65%) carried out predictive maintenance in I4.0. The black items must be improved so that all statements comply with all characteristics in the definition of predictive maintenance in I4.0. They are remote inspection is carried out continuously, recording using digital sensors, advanced and digitally connected machines, using special condition monitoring software, data is analyzed by data scientist, and organizations have highly skilled data analysis capabilities. The improvement must consider the four dimensions of maintenance strategy planning: service delivery strategy, organization and work structure, treatment methodology, and support system (Rahayu et al. 2019). This implementation can lead a company to be more competitive, especially in the resource costs (Wibowo and Nurcahyo 2020), by controlling or reducing failure before significant physical deteriorations occurs (Dachyar et al. 2018).

Table 6. Result of questionnaire (indicated by the green color)

Capability	Level 1 Visual Inspections	Level 2 Instrument Inspections	Level 3 Real Time Monitoring	Level 4 Predictive Maintenance in Industry 4.0
Process	• Physical inspection is carried out periodically • Recording using checklist paper	• Physical inspection is carried out periodically • Recording using digital instruments	• Remote inspection is carried out continuously • Recording using digital sensors	• Remote inspection is carried out continuously • Recording using digital sensors
Content	• The machines are old and can only be visually inspected manually • Existing data describe conditions at several points on the machine • Routine data is used	• The machine has a mechanism that is built in or retrofitted to be able to retrieve data • Existing data describes the condition at one point on the machine • Routine data is used	• The machine has a mechanism that is built in or retrofitted to be able to retrieve data • Existing data describe conditions at several points on the machine • Routine data is used	• Advanced, digitally connected machines • Existing data describe conditions at several points on the machine • The existing data depicts maintenance history digitally • The data is used with advanced algorithms to predict the component life cycle or root cause of failure
Performance measure	• Data verification is done visually • Paper-based data trend analysis • Predictions are made based on expert opinion	• Data verification is done automatically • Digital data trend analysis • Predictions are made based on expert opinion	• Data verification is done automatically • Digital data trend analysis • Monitoring is carried out using condition monitoring software	• Data verification is done automatically • Digital data trend analysis • Predictions are made with statistical software • There is advanced decision support for predictions
IT	• Using MS Excel • Data is stored locally	• Using the software embedded in the instrument • Data is stored in a simple database	• Using special condition monitoring software • Data is stored in a simple database	• Using special condition monitoring software • Using statistical software • Data is stored on big data platforms and networks
Organization	• Data is analyzed by experienced mechanics or technicians • Little or no expertise with data related to the organization both internal and external • None or only initial governance and strategy is still under development	• Data is analyzed by trained supervisors • There are several levels of organizational awareness and data-related process development • There are data-driven asset management governance and strategies	• Data is analyzed by reliability engineers • There are several levels of organizational awareness and data-related process development • There are data-driven asset management governance and strategies	• Data is analyzed by reliability engineer • Data is analyzed by data scientist • Organizations have highly skilled data analysis capabilities • Data-driven asset management is a key element in corporate strategy and governance

6. Conclusion

Diagnosis of maintenance maturity level is an important step to develop maintenance strategy. This activity should be taken if an organization want to shift their maintenance level to the higher maturity level. This study is carried out to determine which maintenance maturity level is an Indonesia's coal mining contractor. Some literatures are taken as a baseline to create the questionnaire. The questionnaire is a multiple-choice type and spread to owners of related maintenance processes. Their answers are mostly mapped in level 4 of maintenance maturity (predictive maintenance in I4.0). The compliance of their current state is 65% of the defined characteristics. As a recommendation, management should improve their process so that it will be fit with the characteristics. For future research, this diagnosis can be used to develop a framework for the company to be fully mature in maintenance. The framework should cover all maintenance aspects so that it can be fully deployed effectively. Due to limitation of diagnosis that is only conducted in a company, future research should be taken for other companies so we can compare which one is better. Based on this comparison, management can take counter measure to be more competitive.

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Prof. Dr. Ir. Rahmat Nurcahyo, M.Eng.Sc. is currently active as an academic staff in Industrial Engineering Department, University of Indonesia. He started his higher education in Mechanical Engineering, University of Indonesia and graduated in 1993. He continued his study in University of New South Wales and obtain his master degree (M.Eng.Sc.) in 1995. He got his doctoral degree in Faculty of Economics, University of Indonesia in 2012. He is an International Register of Certificated Auditors and a member of Ikatan Sarjana Teknik Industri dan Manajemen Industri Indonesia (ISTMI).

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