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Decision Making to Choose Communication Network System for Teleremote Dozer Operation Using Analytic Hierarchy Process

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ABSTRACT: One type of heavy equipment is a mining material pushing tool called a dozer. Dozers generally work in areas near cliffs that are prone to landslides, where these areas can be classified as dangerous areas. New technology is needed to increase the safety of dozer operators from the threat of danger when operating a dozer. Teleremote dozers are one method that can reduce the risk of accidents that can happen to dozer operators. Instead of operating the dozer from inside the cabin, the operator operates the dozer via a remote control device.

There is an important aspect in operating a teleremote dozer, namely the need for a signal that will transmit data and commands from the remote control to the dozer unit operating in the field. Good and uninterrupted signal quality is the main key to good teleremote dozer operations with minimal risk.

The wireless signal network system currently used by companies will enter its obsolete period. However, the old system was tough and not easily damaged. There are strategic options for supporting the signal network for teleremote dozer operations: maintaining the old network system, replacing it with a new one, or using the old and new systems in a hybrid manner. Because there will only be one strategy chosen, a decision must be made. The SWOT AHP method is used for decision making regarding the strategy to be taken. The results of the AHP SWOT will produce a strategy, which will become a benchmark for making subsequent alternatives. Determining alternative types of network systems to support teleremote dozer operations will use the AHP method.

KEYWORDS: AHP, decision-making, mining, network, SWOT.

1. INTRODUCTION

Coal mining is one of the industrial activities in Indonesia that contributes significantly to the country's income. One type of coal mining is open-pit mining. Open-pit mining is a surface mining technique used to extract rocks or minerals from the earth through a large open hole. Typically, this mining method is more effectively applied in relatively flat areas. MCD is the largest coal mining company in Indonesia, located in East Kalimantan, with a concession area covering 84,938 hectares in the Sangatta, Rantau Pulung, and Bengalon areas. Operational aspects of mining include the operation of digging and hauling equipment, along with the management of operators who operate these equipments.

In addition to digging and hauling equipment, mining operations also require auxiliary equipment. The mentioned auxiliary equipment is a dozer. The dozer plays a role in smoothing the excavation area and clearing overburden material that falls when the hauling equipment is loaded by the excavator[1]. To ensure the optimal operation of the dozer and the safety of the operator, the dozer is modified to be remotely controlled from a control station. The devices that need to be installed on the dozer are a remote-control module and a wireless camera. Both devices operate using radio signals sent from the module to the control station. The radio signal must not be interrupted, or the commands from the control station to the dozer will also be interrupted. Wireless communication networks typically use high-frequency radio methods[2]. The communication system used by MCD employs an access point method, where several access points are placed in various locations covering the operational area of excavation and transport equipment.

The currently used wireless network system at MCD is of the traditional mesh type, where several nodes are placed in positions considered to provide signal coverage for moving mining equipment. If the mining location changes, the nodes must also be relocated according to the movement of the excavation equipment. This also applies to dumping areas where remote-controlled dozer units operate. If the dumping area shifts, the nodes must be moved to follow the working area of the remote-controlled dozer. The current wireless network system is considered suboptimal due to the occurrence of signal disruptions and interrupted video streaming feed. This may be because the signal transmission from the nodes to the remote-controlled dozer is obstructed by trucks or heavy equipment

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passing through the signal line between the node and the remote-controlled dozer. Signal interruptions result in the fail-safe system of the dozer automatically stopping its operation, reducing the effectiveness and productivity of the remote-controlled dozer's work and leading to a failure to achieve production targets. The consequence of this is a lack of income for the company.

The transmission system of the teleremote dozer can be considered to be working well when the wireless network connection between the control station and the dozer experiences minimal signal interruptions. If the signal remains uninterrupted, remote dozer operation will be as smooth as when the dozer is operated directly by an operator inside the cabin. Based on aspects such as reducing the effort of moving nodes, the requirement for uninterrupted signals, ease of installation and maintenance of network systems, low cost, and considering the current wireless systems that will become obsolete, a latest wireless network system is needed to accommodate the operation of a teleremote dozer in the dumping area at MCD.

2. BUSINESS ISSUE

Teleremote dozer is one of future programs that will be implemented in MCD. Currently, the teleremote dozer is still performing trial to ensure the sustainability of the systems. Ensuring the entire system to work properly is a must, since the mining operation should adhere to the safety aspect. Figure 1 shows the overall teleremote dozer trial project scheme, where it shows aerial picture, the dozer, the truck that will pose as challenge, dumping point, and access points.

Figure 1. Teleremote dozer trial scheme

The wireless data transmission network plays a crucial role in MCD's open-pit mining operations. This network is essential for sending data from the fleet management systems' modules of excavation and transport equipment to servers and dispatchers, as well as receiving data in the opposite direction. The network also facilitates the operation of the teleremote dozer. Data sent from the remote control module to the control station and vice versa, as well as video streaming data from cameras to the control station, is transmitted using the wireless network. Both data clusters have a considerable size, necessitating a network capable of accommodating this volume of data. The signals from the network transceiver must meet the performance requirements of the teleremote dozer manufacturer to ensure uninterrupted data transmission. The details of the requirements are shown in Table 1, and Table 2 shows the current network system that was implemented during the first teleremote dozer trial.

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Table 1. Network Requirements

Client Radio Min. Connection Speed (Mbps)	Minimum Throughput Capability (per machine)	Avg. Steady State Bandwidth Utilization (per machine)	Average Latency	Maximum Latency	Jitter	Consecutive Packet Loss OR Out of Order Packets	Average Packet Loss	Maximum Packet Loss	Max Handover Time (cell to cell, AP to AP)	Max Loss of connectivity	Network IP Protocols
24 Mbps (Machine Side)	6Mbps per RC Machine 2Mbps per Semi-Autonomous Machine	4.5Mbps per RC Machine 1Mbps per Semi-Autonomous Machine	< 50 msec	< 100 msec	<25 msec	<= 2 packets for all protocols	< 1%	< 2%	250msec	1.5 seconds	UDP, TCP, ICMP, ARP, PIM, IGMP

Table 2. Current Network System in MCD for Teleremote Dozer

Component	HW Model	SW Version	Frequency	Comment
Infrastructure Access Point	1572EAC	N/A	Unlicensed 2.4GHz & 5GHz	
On-board Radio	IW3702-2E	ap3g2-k9w7-tar.153-3.JK	Unlicensed 2.4GHz & 5GHz	
On-board Antenna(s)	Mobile Mark OD3-2400MOD2	N/A	2.4GHz	For information on the 5GHz antenna solution please contact Caterpillar Site Communication Team
WLC	3504 5520	8.5.160	N/A	
On-board Power Conditioner	Axiomatic AX083110	N/A	N/A	Only required on 12v CAT machines

Currently, the network used by MCD has some weaknesses and does not fully meet the requirements set by the manufacturer. The issue is described as follows:

1. AP-Controller reassociation process takes too long
2. AP CAPWAP process occurrence when lost/unstable connection on backhaul
3. AP reposition activities to follow Pit Progress or blasting radius
4. Short range connection (AP to AP / AP to Client) takes only 300-500 meters

Additionally, the wireless network system currently in use is expected to reach the end of its service life in 2024, where the manufacturer has published the end-of-life and end-of-service bulletin worldwide. This situation requires MCD to explore alternative solutions, specifically a wireless network system that will meet the requirements for operating the teleremote dozer. The main part of the wireless network system that will obsolete is Cisco 1570 series as seen in Figure 2.

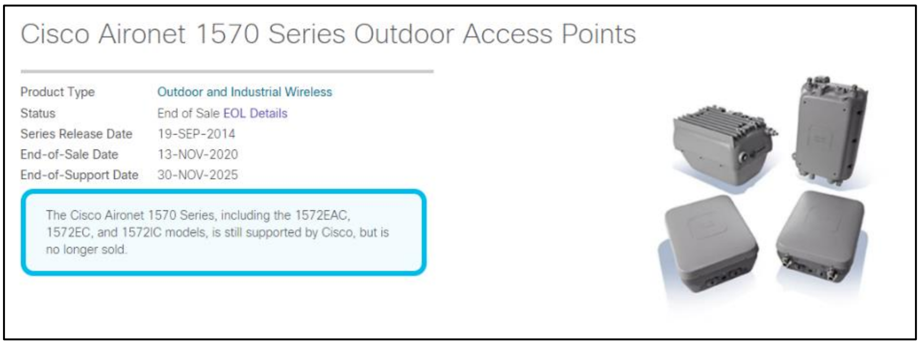

Figure 2. Access Point Hardware that Will be Obsolete in 2024 (Cisco, 2022)

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3. DATA COLLECTION

Both qualitative and quantitative data gathering were conducted for this research. There are various methods to collect the data, and the methods are based on the research objective, needed data type, and available data.

3.1. Qualitative Data

Qualitative data refers to non-numerical information that typically describes qualities or characteristics. Qualitative data provides insights into the underlying reasons, motivations, and patterns behind phenomena to capture subjective experiences, opinions, or behaviors. The methods used to gather the qualitative data are:

- **Interview** with the respondent and main user of the teleremote dozer
- **Questionnaire** with the respondent in regards with the decision-making method and tool
- **Focus Group Discussion** with other party involved in the

3.2. Quantitative Data

Quantitative data consists of numerical information that can be measured and expressed using numbers. It deals with quantities, amounts, or sizes, making it suitable for mathematical analysis and statistical interpretation. The methods used to gather the quantitative data are:

- **Product Information** from vendors
- **Trial-and-test result** after completing the trials

4. ANALYSIS

There are two goals to achieve in this thesis: best strategy, and best alternative for teleremote dozer network communication. Both of them are using AHP-OS tool by BPMSG. Before getting into the alternative, the steps to get there are as follows:

4.1. Gap Analysis

Gap analysis is an analytical tool designed to measure the difference between the current state or performance of an organization at a specific time and the desired or potential state in the future It is a strategic analysis process to evaluate the gap between the current ongoing processes and the expected outcomes[3].

A gap analysis measures actual against expected results to identify suboptimal signal coverage and performances, among other things including the systems's obsolence. The lag and intermittent connection that disrupted the signal transmission led to the teleremote dozer disconnecting, making the dozer unable to work properly. The factors causing disruptions include interference, long distances between nodes requiring continuous repositioning, and disruptions due to excessive battery usage as a power source. The expected condition or goal is that the company can utilize wireless communication systems with minimal signal transmission disruptions, interference, and relatively low energy consumption to eliminate network performance issues. Reducing the frequency of node repositioning can decrease the cost of node relocation carried out by contractors. Network systems with low power usage can also reduce the cost of acquiring new batteries. Last but not least, the new network system should be easy to repair, have low procurement costs, and guarantee safety aspects during operation and maintenance.

4.2. Brainstorming

Brainstorming is a creative technique in which team members spontaneously generate ideas or solutions freely without evaluating or criticizing them during the session. The primary goal of brainstorming is to produce as many ideas as possible in a short amount of time.Brainstorming strategy is one of the most important strategies in provoking creativity and solving problems in the educational, commercial, industrial and political fields[4].

It is known that the wireless communication network for mining equipment at MCD will enter obsolete period. The communications network vendor currently in use has published that their devices will no longer be produced. Their devices will also not receive maintenance or repair services if they experience damage or failure. However, their devices are known to be reliable and rarely experience damage. This makes mining engineers and IT specialists from MCD confident in the sustainability of the wireless network devices currently in use. However, engineers and specialists are still brainstorming to

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look for other alternatives, namely a more advanced wireless network system as a precaution if the current network system is damaged or fails completely.

As time goes by, wireless network technology in mines continues to develop. There are several technologies that can cover the weaknesses of traditional mesh, as well as provide more benefits for mining operations. There are several coal mining sites in Indonesia, where the majority have been using wireless network systems for the implementation of fleet management systems. Generally, mining companies share knowledge in mining forums, professional social networks, or personal sharing sessions as requested. From these activities, information regarding the types of wireless communication systems used by these mining sites is obtained.

One of alternatives that raised of these technologies is Long Term Evolution (LTE). LTE is currently commonly used for communication networks on smartphones, has quite wide network coverage, and data transmission from LTE is considered quite fast. This is in accordance with MCD's mining area which tends to expand. This alternative was obtained after receiving information that one mining site adjacent to MCD is using LTE as a wireless network to support fleet management systems. This alternative was then chosen because, according to initial information, the performance of LTE was considered satisfactory for sites with contours similar to those at MCD's pit. It is also known that LTE is used in more than 3 open pit mining companies in Indonesia, so it is assumed that LTE shows satisfactory performance in mining industry.

Kinetic Mesh is a type of dynamic and adaptive wireless network that can automatically build and maintain connections with devices within the network, even when network conditions change drastically. This network operates by automatically rerouting communication paths between devices according to changes in network topology or environmental conditions. The advantage of Kinetic Mesh over traditional mesh networks is its ability to quickly adapt to changes in network topology, including device mobility or signal interference. This makes it an excellent choice in dynamic or mobile environments such as field operations, where traditional connections may not be reliable enough.

In the context mentioned in Central Sulawesi, the implementation of Kinetic Mesh becomes an interesting alternative because it allows for addressing challenges in environments that may not be suitable for conventional wireless network infrastructure like LTE. With the similarity in functionality between Kinetic Mesh and more well-known traditional mesh networks, such as those used by MCD, the familiarization and training processes can be facilitated due to the operational and maintenance similarities between the two. With the adoption of Kinetic Mesh, the expectation is that the time and cost allocation required for network training, familiarization, and maintenance can be reduced due to the similarity in operation between Kinetic Mesh and more well-known traditional mesh networks. This can help expedite the implementation process and reduce barriers associated with introducing new technology.

4.3. Interview

The interview is an important data gathering technique involving verbal communication between the researcher and the subject. Interviews are commonly used in survey designs and in exploratory and descriptive studies[5]. After considering the available alternative possibilities, it is necessary to have a further understanding of the advantages and disadvantages of the alternative strategies that have been identified. To obtain this understanding, a method of interview is required. After obtaining alternatives, an interview is conducted to obtain deeper information related to the strategy alternatives as well as the product alternatives. Interview was conducted to three participants who are understand about the network system in mining. One of the most commonly used methods in qualitative inquiry is the semi-structured interview. As the name implies, these interviews have a degree of structure but also offer researchers significant latitude to adjust course as needed; researchers make such adjustments as a result of their in-interview analysis[6]. The reason for their selection is their comprehensive understanding of the performance of the wireless communication network system. Table 3 shows the respondents/interviewees

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Table 3. List of Interviewees

No	Position	Division	Years of Experience	Amount
1	Assistant Manager - Mine Control and Dispatch	Mining Operation	16	1
2	Senior Engineer - Dispatch	Mining Operation	11	1
3	Senior Engineer - Dispatch	Mining Operation	5	1

The interview was conducted in a semi-structured way. Aside from gathering data and personal insights, the interviewees are the co-workers of the author in MCD section. Previously, all interviewees were informed that they were chosen to become part of the thesis data gathering by interview, and they agreed. The interviewees were informed with the preliminary and general description of the question and goal of the interview. It took time in the working hours and placed in the working station of each interviewee.

From the interview result, it was discovered that the more advanced wireless communication network system could be integrated with the current system. There are several considerations that are at the root of this idea. Among them is familiarity, because the old system is still used so that engineers and specialists can easily carry out troubleshooting if the communication network system experiences problems. Integration with old systems also has an impact on cost efficiency, where old devices can still be used. This means that companies do not need to spend money on replacing the entire wireless communications network system, so expenses can be further reduced. Should the company agrees, it is recommended to replace the whole network with the brand new system. Aside from the big advantages from bringing a more sophisticated system, the newer system also guarantees the 24/7 maintenance service.

However, it is obvious that they do not recommend to maintain the old system for a longer time even though it is robust and does not experience any substantial breakdown, unless integrated. Network in mining, especially if used for teleremote dozer plays significat role. They prefer not to put any risk by still utilizing the old system.

4.4. SWOT Analysis

Based on the interview results, it was found that there were 3 alternative strategies related to the use of wireless communication networks for teleremote dozer operations, which is replacing the old system or performing hybrid method with the older one. It was also found that these success parameters were determined based on the strengths and weaknesses of the proposed strategies. The interviewee only explained that a more in-depth analysis was needed regarding the advantages and disadvantages of the strategy. SWOT (Strength, Weakness, Opportunity, Threat) Analysis is a tool used for strategic planning and strategic management in organizations. It can be used effectively to build organizational strategy and competitive strategy. In accordance with the System Approach, organizations are wholes that are in interaction with their environments and consist of various sub-systems [7]. SWOT analysis is used to see what points are the internal strengths and weaknesses of the strategy, as well as opportunities and threats as external components of the proposed strategy.

In general, the results of the SWOT analysis include all two alternatives. There are 9 aspects identified for each criteria, that later can be referred to as sub-criteria. It is expected that the results of the SWOT analysis can be a reference in determining the best alternative strategy. SWOT analysis to determine strategy is as shown in Table 4, and later is inserted to the AHP OS online software to be calculated and set as part of questionnaire.

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Table 4. SWOT Analysis for Best Strategy

Criteria	Sub-criteria	Symbol
Strength	Enhanced Functionality	S1
	Scalability	S2
	Competitive Advantage	S3
	Balance between innovation and familiarity	S4
	Risk mitigation	S5
Weakness	Disruption from previous old system	W1
	Implementation Cost	W2
	Integration challenges	W3
	Complexity in hybrid	W4
	Potential of inconsistency	W5
Oppotunity	Process Optimization	O1
	Innovation	O2
	Phased implementation	O3
	Flexibiity	O4
	Cost-effectiveness	O5
Threat	Implementation failure	T1
	Compatibility issue	T2
	Training Requirement	T3
	Maintenance Challenge	T4
	Resistance to change	T5

4.5. Case Study and Product Information for Best Strategy

The results of the SWOT criteria and sub-criteria analysis in the Table 4 above will be pairwised so that they are able to be processed using the AHP method. To get pairwise results, input is needed from stakeholders who understand how important one aspect or sub-criterion is when compared to other sub-criteria. The step taken is to create a questionnaire, where stakeholders can compare each criterion equally. To facilitate the calculation and analysis of AHP, the BPMSG online-based software is used. AHP-OS is a web-based tool to support rational decision making based on the Analytic Hierarchy Process (AHP). It allows user to define a hierarchy of criteria for a decision problem, to calculate priorities and evaluate a set of decision alternatives against those criteria [8].

The steps for operating AHP-OS are as follows (Goepel, 2018):

1. Define the objective and relevant criteria of the decision problem and structure them in a hierarchy. Each branch in the hierarchy is defined by its node (the category) and the node's leafs (the sub-categories). The node is followed by a colon, leafs are separated by comma, and a branch is closed by a semicolon
2. Compare criteria in categories and sub-categories with respect to the objective to find their weights based on pairwise comparisons. Compare each pair of criteria with respect to the project and category: which criterion in each pair is more important, and how much more on a 1 - 9 scale?
3. View the results. The decision hierarchy will be shown with local and global priorities, and a breakdown by the nodes with their corresponding priority vector and their (consolidated) decision matrix. Data can be downloaded in csv format for further use in a spreadsheet program.
4. Name a set of alternatives. From the Group Result Menu it is possible to use the calculated priorities of the decision hierarchy for further alternative evaluation. The decision hierarchy will be show with a button Alternatives. From there user can define the number and names of alternatives.
5. Compare, how good they match your decision criteria. Again pairwise comparisons based on the AHP are used.

After these five steps have been carried out, respondents can fill in the data individually. The input results from respondents will be processed by the AHP-OS system, and can be seen at that time, both individually and as aggregate calculation results. This can make it easier to carry out calculations, analysis, and can even provide recommendations for AHP results[8].

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The results from Table 4 will be inputted into the AHP OS. The AHP OS will automatically generate a questionnaire using radio buttons as seen in Figure 3. This questionnaire is also capable of providing feedback in the form of a consistency ratio. If the consistency ratio value exceeds 0.1 or 10%, then the AHP system will recommend respondents to adjust the input.

Table 4. SWOT Analysis for Best Strategy

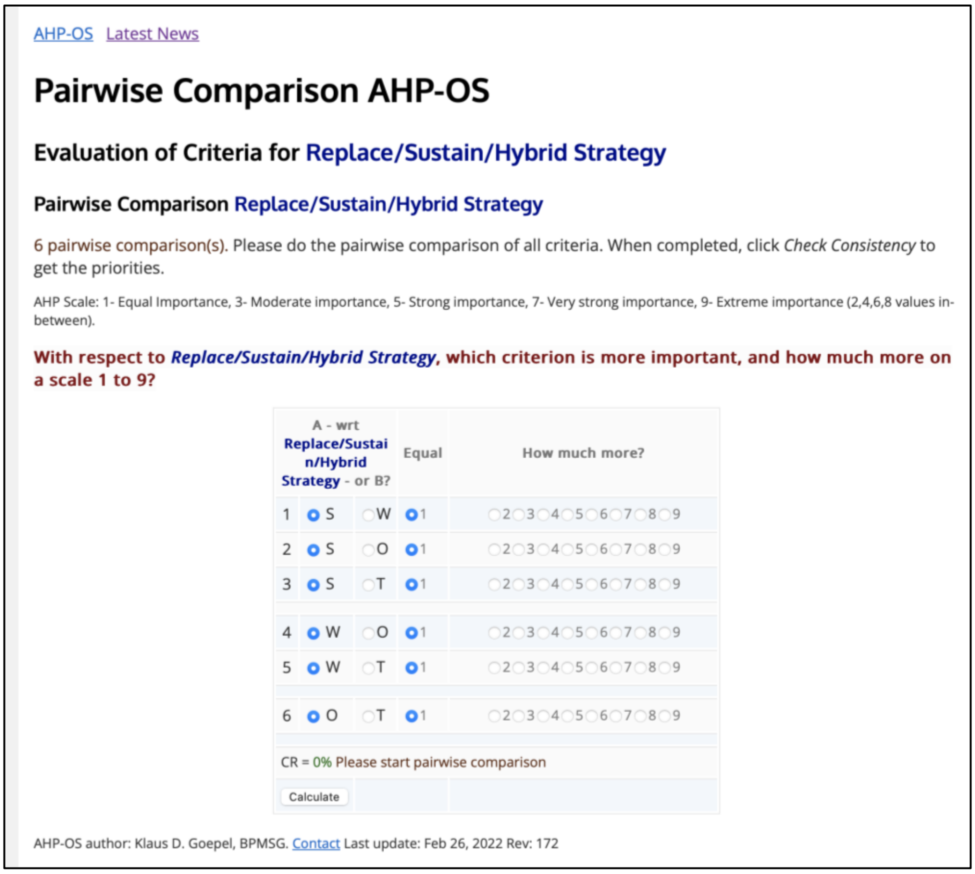

Figure 3. Pairwise Comparison Questionnaire Page for SWOT

The questionnaire was created after the SWOT criteria emerged and given to the same interviewees as the respondents. The respondents are assumed to know the priority level of the sub-criteria that will be pairwised to determine the best alternative strategy in determining the implementation strategy for a wireless communication system for teleremote dozer operations. Questionnaire given to the interviewees are online-based on the AHP-OS by BPMSG, which is automatically made by the system. Since the interviewees are not familiar with the AHP OS software, they are guided during filling the form. The decision hierarcy made up from criteria and sub-criteria are then filled up by the respondents. The three respondents gave different scores from each other, so the final scores from the respondents' assessments will be averaged. This has been accommodated by the AHP OS system by BPMSG. The results of filling out the pairwise for AHP questionnaire in Decision Hierearcy are shown in Table 5, where Enhanced Functionality becomes the first priority with local weigh 46%, and global weigh of 28%.

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Table 5. Pairwise Result of SWOT Analysis for Best Strategy

Decision Hierarchy			
Level 0	Level 1	Level 2	Glb Prio.
Replace/Sustain/Hybrid Strategy	S 0.604	Enhanced Functionality 0.464	28.0%
		Scalability 0.352	21.3%
		Competitive Advantage 0.103	6.2%
		Balance between innovation and familiarity 0.081	4.9%
	W 0.133	Disruption from previous old system 0.169	2.2%
		Implementation Cost 0.132	1.8%
		Integration challenges 0.361	4.8%
		Complexity in hybrid 0.218	2.9%
		Potential of inconsistency 0.120	1.6%
	O 0.163	Process Optimization 0.161	2.6%
		Innovation 0.170	2.8%
		Phased implementation 0.045	0.7%
		Flexibility 0.538	8.8%
		Cost-effectiveness 0.085	1.4%
	T 0.101	Implementation failure 0.515	5.2%
		Compatibility issue 0.271	2.7%

After the criteria weighting was conducted, respondents were asked to fill out a questionnaire to select the best alternative strategy in the communication network system to support teleremote dozers. The same method was employed, which is to determine choices based on the previously weighted criteria. The final results from the respondents' submissions are as follows: Replace Old System with a value of 57.6%, Hybrid with a value of 23.3%, and Maintain Old System with a value of 19.1% as shown in Table 6.

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Table 6. Decision Result of SWOT Analysis for Best Strategy

Decision Hierarchy						
Level 0	Level 1	Level 2	Glb Prio.	Replace Old System	Maintain Old System	Hybrid
Replace/Sustain/Hybrid Strategy	S 0.604	Enhanced Functionality 0.464	28.00%	0.782	0.083	0.135
		Scalability 0.352	21.30%	0.716	0.081	0.203
		Competitive Advantage 0.103	6.20%	0.741	0.067	0.192
		Balance between innovation and familiarity 0.081	4.90%	0.324	0.162	0.514
	W 0.133	Disruption from previous old system 0.169	2.20%	0.214	0.581	0.206
		Implementation Cost 0.132	1.80%	0.084	0.646	0.271
		Integration challenges 0.361	4.80%	0.204	0.562	0.235
		Complexity in hybrid 0.218	2.90%	0.514	0.292	0.194
		Potential of inconsistency 0.120	1.60%	0.122	0.651	0.227
	O 0.163	Process Optimization 0.161	2.60%	0.749	0.081	0.17
		Innovation 0.170	2.80%	0.772	0.069	0.159
		Phased implementation 0.045	0.70%	0.456	0.11	0.434
		Flexibility 0.538	8.80%	0.394	0.267	0.34
		Cost-effectiveness 0.085	1.40%	0.146	0.277	0.577
	T 0.101	Implementation failure 0.515	5.20%	0.346	0.282	0.371
		Compatibility issue 0.271	2.70%	0.137	0.497	0.365
		Training Requirement 0.151	1.50%	0.19	0.462	0.348
		Maintenance Challenge 0.063	0.60%	0.705	0.129	0.166
			1	57.60%	19.10%	23.30%

4.6. Case Study and Product Information for Best Alternative

Interviews were used as the method for collecting primary and secondary data in this thesis. Secondary data were obtained from case study interviews with a representative from another site to understand the type of communication network system used, its strengths, weaknesses, performance, and the vendor of the system. Primary data were obtained from interviews with the vendor of the communication system identified in the previous interview. From the vendor, specifications, operation procedures, vendor credibility, and the overall system price were obtained. The interview method used is also semi-structured, because this method creates engagement between the interviewee and interviewer that is more relaxed. Semi-structured interviews can also provide more information due to the flexibility of the atmosphere created, moreover due to the case studies interview are conducted via online meeting. This is done since the interviewees' locations are not based in Sangatta.

To learn more about both types of systems, it is necessary to obtain more detailed information. The team at MCD prefers to gather data by conducting interview sessions with mining site representatives who have already used the wireless communication system that is being considered as an alternative. The representatives chosen from the mining company are a representation of the site used for brainstorming. The team wants to further understand the performance of both LTE and Kinetic Mesh used by the site. In addition to performance, strengths and weaknesses, the team also wants to know the vendors and types of services provided to clients or users. This information is useful to provide an initial overview if ultimately choosing one of these systems.

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The results of the interview with representatives from the site using Private LTE indicate good performance in transmitting data for fleet management systems. Data from approximately 200 units of trucks and diggers are transmitted without experiencing slow transmission. Furthermore, LTE networks theoretically can also be used to transmit live streaming video from CCTV cameras. Kinetic Mesh is considered as new wireless network systems, especially in Indonesia. There is only one mining site operating Kinetic Mesh located in Sulawesi, and they only operate the Kinetic Mesh just several months prior. Nevertheless, the case study interview continued to gather the performance and vendor information. The result of the mining site's Kinetic Mesh application is found satisfactory, as its redundancy helps to ensure the data transfer is uninterrupted. The Private LTE vendor used is a mobile telecommunications company located in Indonesia. LTE is evidently not only used in the public sector for cellular communication but also for communication purposes in mining operations. They are also the vendor for the site using LTE systems as a wireless network system in their pit. According to the overview they provided, their LTE system is capable of serving the data transmission needs of fleet management systems. Their LTE system is also capable of being used as a means of data transmission for teleremote dozers. Technical specifications and frequency usage have been explained by the vendor and ensured to comply with the radio frequency usage regulations of the country.

4.7. Trial and Test

Trial-and-test is carried out as a form of validation of the SWOT analysis results for each wireless communication system, and to ensure that the system selected is suitable for the MCD mining environment and can be used to support teleremote dozer operations. The trial of each system are conducted in separate location and separate time, due to changing of pit topology, mining priority, and availability of the dozer unit itself. Availability is a measurement of the readiness of unit, and it does not experience breakdown, service, or overhaul.

There are 2 systems that are proposed to replace traditional mesh communication network systems, namely Kinetic Mesh and LTE. However, there are 2 types of LTE proposed and tested at MCD, namely Private and Small LTE. Both use the same working principle, but have slight differences in features, signal coverage, and frequency range usage. The parameters that are the criteria for this trial-and-test have been explained in the FGD session, and are divided into 2 main criteria, namely Technical and Commercial. The Technical Criteria has 10 sub-criteria, while the Commercial Criteria only has 2 sub-criteria. The results of the trial and test is shown in Table 7.

Table 7. Trial and test result of wireless network for teleremote dozer

No	Criteria	Measurement	XL's Private LTE	Rajant Kinetic Mesh	Smartfren's Small LTE
	Trial Location		Trial in Pama's Gerdas area	Trial in MCD Inul East-Inpit	Trial in MCD Dumping RL 10
A	TECHNICAL:				
1	Duration during trial	Minutes	381	705	1241
2	Distance during trial	Meter	650 - 800	700 - 800	1200 - 1240
3	Blinking event on Camera	Event	30	67	3
4	Lost Signal on tele-remote dozer control	Event	10	3	36
5	Throughput & data traffic performance of packets sending/received	Mbps	8-Mbps upload & 8-Mbps download limited by XL setting in order not to disturb Pama network. Actually UL or DL should be more 40	UL : 35.2 DL : 35.0	UL : up to 35 DL: up to 35 depending the distance between BTS and end node

			Mbps in totally from 1 BTS		
6	Infrastructure (HW & SW) assessment and their ease of installation	units	When trial, it uses Core machine, 1 unit of complete macro BTS set, 2 units of Robustel modems, and 1 unit of Omni antenna on Dozer E444	When trial, it uses 4 kits of Peregrine Breadcrumbs (1 mobile node, 2 fixed nodes, 1 backup node), 1 Slipstream (miniCPU), and 2 pairs of PTP 5.8 GHz links	When trial, it uses 1 unit LTE small Cell, 1 unit RF Antenna, 2 units of Robustel modems, and 1 unit Omni antenna on Dozer E444.
7	Mobility when moving between Towers/Poles or Different areas	Yes/No	Yes, using roaming mechanism, moving from one BTS cell to other BTS/ repeater cells	Yes	No, it is not flexible when the dozer moves very far from the previous location. The minimum time to move BTS and its link is 1 shift day.
8	Channel of radio frequency used	MHz	900 and 1800 MHz (Telco Operator license)	2400 and 5800 MHz (free license)	2300 MHz (Telco Operator license)
9	Ease of use for monitoring & reporting tools	Yes/No	Yes, use its NMS and combine with existing/ third party tools	Yes	Yes, combine with existing third party apps/tool (PRTG)
10	Redundancy link	Yes/No	Yes, every BTS or repeater cell can have multiple paths to core machines.	Yes, it has multiple paths to multiple Access Points using Instamesh protocol.	No, it only has single dedicated path to MCD tower/ network
11	Ease of maintenance		No, It's quite complex due to the use of core machines connecting to our firewall & router, BTS system and LTE modem	Relative. It's not complex but not simple too.	Yes, it's simplest connection due to only consists 1 BTS with embedded core and one LTE modem

B COMMERCIAL:

1	Cost	USD	Very expensive (over-spec), Minimum IDR 194 Millions per month or USD 12,500 per month for 5 Years	USD 91,093 (Buy)	USD 3,000 per month (Rent) for 3 Year including maintenance by Smartfren & MKN
2	services and parts support from Vendor	Yes/No	Yes, from XL-Axiata and Huawei.	Yes, from Gratelindo & Rajant	Yes, from Smartfren and Baicells

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4.8. Determining the Alternatives

After conducting pairwise comparisons and determining the weights of the criteria, respondents then assigned values to the offered alternatives. Three alternatives were compared with the Global Priority weights of the seven criteria. The results from the questionnaires filled out by the three respondents indicate that Kinetic Mesh is the first choice with a score of 66.8%, followed by Small LTE with a score of 18.1%, and Private LTE in the last position with a score of 15.1%.

Respondents' assessments in choosing Kinetic Mesh as the best alternative for the wireless communication system to support the teleremote dozer are influenced by the results of tests and trials, where Kinetic Mesh demonstrated satisfactory results and is considered capable of meeting the operational needs of the teleremote dozer. The results of the Consolidated Alternative Selection can be seen in Table 8.

Table 8. Pairwise Result of SWOT Analysis for Best Alternative

Level 0	Level 1	Level 2	Glb Prio.	Private LTE	Small LTE	Kinetic Mesh
Select New Wireless Systems	Technical 0.743	Lost Signal Event 0.176	13.10%	0.111	0.134	0.754
		Throughput and Traffic 0.049	3.70%	0.076	0.277	0.646
		Infrastructure 0.119	8.80%	0.088	0.164	0.748
		Mobility 0.176	13.00%	0.083	0.169	0.748
		Frequency Used 0.029	2.20%	0.139	0.153	0.708
		Redundancy 0.322	23.90%	0.192	0.084	0.724
		Maintenance 0.128	9.50%	0.086	0.251	0.663
	Commercial 0.257	Cost 0.442	11.40%	0.086	0.193	0.722
		Vendor Support 0.558	14.40%	0.333	0.333	0.333
Result			1	15.10%	18.10%	66.80%

5. CONCLUSION

A wireless communication network system is necessary to support the operation of teleremote dozers. There is a constraint that the wireless communication system currently owned by PT. KPC is approaching obsolescence, and its performance is not capable of optimally supporting the operation of teleremote dozers. Despite nearing obsolescence, the current communication system has high robustness and does not deteriorate quickly, thus it can still be used for a longer period.

Given this issue, alternative strategies are needed to accommodate the requirements of the wireless communication system for teleremote dozer operations. Three types of alternative strategies emerged: maintaining the existing system, replacing it with a new system, or implementing a hybrid approach. The selection of alternative strategies uses the SWOT AHP method, and ultimately, the input calculations from respondents for the AHP method indicate that the best strategy chosen is to replace it with a new communication system.

Several new system alternatives were generated, namely Small LTE, Private LTE, and Kinetic Mesh. After a series of tests conducted on each system, it was found that each system has its own strengths and weaknesses. The AHP method is used to determine the alternative system to be selected based on predetermined criteria. The result of the AHP indicates that Kinetic Mesh is chosen as the best alternative as a wireless communication system to support the teleremote dozer system.

The Analytic Hierarchy Process (AHP) can be used to accommodate the determination of an alternative based on multiple criteria, including quantifying qualitative criteria. In determining alternative strategies, SWOT AHP can provide assessments based on observed SWOT aspects, and then determine which SWOT aspects are the focal points using AHP. This study states that Kinetic Mesh was selected based on input from respondents and processed using the AHP method. This is also supported by trial-and-test results. Both methods are expected to be applied in companies when facing issues in decision-making, especially in terms of procuring mining equipment, computer devices, or business strategy-related issues.

A larger number of respondents will provide a more comprehensive view and yield more objective results due to the involvement of a larger number of people. The more respondents there are, the more alternative options can be provided. Further research, data collection, and a longer available time could help overcome this limitation and provide a deeper understanding related to selecting the best alternatives using AHP.

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