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Selecting Outdoor Wireless Solution for Bara Prima Borneo Using Analytic Hierarchy Process

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ABSTRACT: The advancement of wireless communication technology is critical for improving the efficiency, safety, and productivity of mining operations. This study focuses on evaluating and recommending an optimal outdoor wireless network solution for Bara Prime Borneo (BPB) mining operations in East Kalimantan, Indonesia, using the Analytic Hierarchy Process (AHP) for decision-making. The current Wi-Fi infrastructure faces significant challenges, including limited coverage, interference, and scalability issues, which hinder its effectiveness in the demanding mining environment.

To address these challenges, the study employs a comprehensive approach to identify stakeholder expectations and value perceptions, explore alternative wireless network designs such as Private LTE and Kinetic Mesh, and systematically select the most suitable solution using AHP. Through discussions with subject matter experts and secondary data collection, the study outlines the strengths, weaknesses, opportunities, and threats (SWOT) associated with the existing Wi-Fi network and potential alternatives.

Using AHP, the study prioritizes various criteria such as coverage, reliability, cost, scalability, and security. The recommended design aims to bridge the gap between current capabilities and future needs, ensuring robust and extensive network coverage that supports various digital applications essential for modern mining.

By selecting the proposed solution using AHP, BPB can achieve a more reliable and scalable wireless network, enhancing overall operational efficiency and safety while meeting the evolving demands of its mining operations.

KEYWORDS: Analytic hierarchy process, Decision making, Mining, value-focused thinking.

1. INTRODUCTION

PT Bara Prime Borneo is a prominent coal mining company located in East Kalimantan, Indonesia. It operates one of the largest open-pit mining operations in the world. As an Indonesian-incorporated entity, PT Bara Prime Borneo engages in coal mining and sales, catering to both domestic and international customers across various industrial sectors.

The company manages its extensive operations from its head office in East Kalimantan Province and has representative offices in Jakarta, Samarinda, and Balikpapan. PT Bara Prime Borneo was operated a mining area spanning 84,938 hectares. Supported by a workforce of over 4,499 employees and 21,000 personnel from contractors and associated companies, the company's production capacity reaches 70 million tonnes per year.

PT. Bumres Tbk acquired PT Bara Prime Borneo in 2003. Following the acquisition, the company continued to expand, achieving a production capacity of 16.4 million tonnes of coal in the same year, and further increasing to 56.97 million tonnes in 2017. In 2017, PT Bara Prime Borneo also commenced operations of a 3×18 MW steam power plant (PLTU), with 1x18 MW dedicated to supporting the electrification of communities in East Kutai.

The Coal Contract of Work (PKP2B) for PT Bara Prime Borneo concluded in December 2021. Subsequently, the company initiated the process to extend its operations by applying for a Special Mining Business Permit (IUPK) from the Government of the Republic of Indonesia. The PKP2B area covers approximately 614.53 km², encompassing the Sangatta and Bengalon mines. The IUPK extends to cover the North Sangatta and Bengalon areas to the north, and from the South Sangatta Subdistrict to Rantau Pulung in the south.

PT Bara Prime Borneo's management and employees are dedicated to achieving excellence and continuous improvement in human rights, sustainable development, and business performance. This commitment aligns with the company's vision, mission, and core values, driving their efforts to maintain high standards and deliver outstanding results.

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2. BUSINESS ISSUE

The utilization of technology in BPB's mining operations has become increasingly prevalent and is considered essential to support production. Initially, the implementation of outdoor wireless technology was limited to certain fleet management heavy units and a few stationary sensors. This outdoor wireless system was Wi-Fi-based, with a coverage radius ranging from 50 meters to 400 meters.

As business needs evolved, driven by automation and digitalization, the outdoor wireless system at BPB became more complex and expansive to accommodate emerging business cases. Beyond dispatching heavy units, new digital needs began to surface, such as tire sensors, heavy unit health sensors, fuel management systems, supervisory gadgets, TV dashboards, and more.

The users of these systems are no longer limited to the Mining Operations division but are increasingly needed by other divisions and departments that previously did not have digitalization products. The outdoor wireless coverage become larger and complex.

SWOT	Wi-Fi	Wi-Fi Mesh
Strength	WLAN mobility, I.e., a student attending class, accesses the Internet, and learning	Decreased need for Internet gateways
	WLAN technology allows the network to go where regular wire cannot go	The ability to configure routes dynamically
	The WLAN was clearly better then wired in setup/teardown time and effort	MetroMesh Networks Promote Economic Development
Weakness	The WLAN is significantly worse than wired in the risk of jamming and potential for inference	Bandwidth is limited to the point-to-point link
	The WLAN is not capable to download and upload large data files	Possible point of failure
	The problem has been the lack of interoperability among WLAN products from different manufacturers	More channels are required for each link
Opportunity	The Future is very Bright for Hospitality WiFi LLC. With High-End Resorts, Cities etc.	Eliminating Wired Backhaul to Every Mesh Router
	The components required to process 802.11 frames and forward traffic over Ethernet connections into the LAN	Throughput in Maximizing Large Networks
	Two related technologies will transform WLANs in the next evolutionary: MIMO and spread of distributed switching	Redundant, self-configuring and self-healing network architecture
Threat	One of the most common security mistakes made by WLAN administrators is to not change the default SSID	Network access control through authentication
	One technique believes can be very effective is disabling regular broadcast of SSIDs, is very different	Secure end-to-end transmission of sensitive data
	The WLAN service cannot be perfectly secured	Protection of wireless clients from other malicious wireless clients

Figure 1. SWOT analysis for Wi-Fi Technology (Ravichandiran, 2009)

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The existing Wi-Fi infrastructure is distributed across three major pit departments: Bintang (orange), Hatari (yellow), and Jupiter (green). The outdoor wireless system for the Fleet Management System is generally divided into two components: Root Access Point (RAP) and Mesh Access Point (MAP).

1. Root Access Point (RAP).
   These are the primary access points that connect directly to the central network infrastructure. They serve as the main nodes that distribute the network signal across the mining site. The RAPs are strategically placed to ensure coverage and connectivity, forming the backbone of the wireless network.
2. Mesh Access Point (MAP).
   These access points extend the network coverage by connecting to RAPs and other MAPs. They create a mesh network, enabling seamless communication across vast and challenging terrains. This infrastructure is crucial for the efficient operation of the Fleet Management System and other digital applications essential for modern mining operations. In addition, various Wi-Fi access points are deployed to support digitalization products that are not covered by the Fleet Management System network. These wireless connections are installed in several critical locations, including Shift Change areas, Loading Points, Dumping areas, and Lookout points.

Figure 2. Wi-Fi Access Point as outdoor wireless in BPB

Despite significant efforts to maximize the wireless network, coverage currently extends to only about 30% of the mining area. This limitation is due to the constraints of the existing Wi-Fi technology. To ensure all systems operate optimally, BPB need outdoor wireless solution that can cover a large area and more reliable.

Through discussions with subject matter experts (SMEs) and secondary data collection from long-term company planning documents, it has been identified that there are numerous stakeholders involved in the implementation of an outdoor wireless network for mining operations. These stakeholders are engaged at various stages, including the pre-implementation, implementation phase, and post-implementation phase.

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Table 1. Stakeholder, Engagement status, and Roles (Source: Author)

No	Stakeholder Group	Stakeholder	Engagement Phase	Role/Function
1	Regulatory Bodies	Ministry of Communication and Informatics	Pre-implementation, implementation	Regulation, license
2	Custodian of use cases (BPB)	MOD, MSD, CMD, HSES, SIC, CPHD, BPID, IT	Pre-implementation, Post-implementation	Responsible for optimizationa and digitalization services that run on outdoor wireless system
3	Custodian of infrastructure (BPB)	BPB Management	Pre-implementation, Post-implementation	Corporate strategy and technology roadmap
		Project Taskforce	Pre-implementation, Implementation, Post-implementation	Responsible for planning, identifying, and defining requirement of the project
		IT	Pre-implementation, Implementation, Post-implementation	Technical planning, equipment maintenance, supporting expert skills, assets management
4	Solution Provider	Vendor A, Vendor B, Vendor C, Vendor D	Pre-implementation, Implementation, Post-implementation	Planning, study, design, installation, maintenance, troubleshoot.
		Local Contractor/Partner	Implementation, Post-Implementation	Installation, maintenance, troubleshoot

There are four design proposals from different providers, which can be broadly categorized into two technologies: Private LTE and Wireless Wi-Fi Mesh. The providers using Private LTE are Vendor A, Vendor B, and Vendor C. In contrast, Vendor D employs their proprietary version of Wireless Wi-Fi Mesh solution.

From the assessment and provider survey, there are several designs that has been submitted to BPB. These design area:

1. Vendor A design a combination of Private LTE with public infrastructure in Kutai Timur area. Vendor A propose additional 8 new communication tower, 4 new fixed communication tower in existing location, and utilize 1 BPB existing tower.
2. Vendor B design a Private LTE infrastructure. Vendor B propose additional 7 new MBTS and utilizing 6 existing BPB tower.
3. Vendor C design a Private LTE infrastructure. Vendor C propose additional 7 new communication tower, 1 vendor C mobile communication tower, and utilizing 6 existing BPB communication tower.
4. Vendor D design a Wireless Mesh infrastructure. This wireless mesh design requires 17 mobile tower and 14 solar trailers.

Determining outdoor wireless solution for BPB is important because it will address company pain point in operating current wireless network. This study will address question related to design proposal, such as:

a. What is the root cause of outdoor wireless issue in BPB?
b. What criteria should be used to evaluate these alternative solutions?
c. What are the alternative solutions that can effectively address existing outdoor wireless system in BPB?
d. Which solution is the best to implement in BPB mining?

This study objectives to find best recommendation for future outdoor wireless solution.

1. To identify root cause of outdoor wireless issue in BPB.
2. Finding alternative solutions that can help addressing issues in BPB.

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3. To identify criteria that can help evaluate the alternative solutions.
4. Determining the best outdoor wireless solution for BPB.

3. DATA COLLECTION

The data collection phase is critical for gathering the necessary information to support the evaluation and decision-making process. This chapter outlines the various methods used to collect data from stakeholders, experts, and existing literature. The goal is to ensure that the data collected is both comprehensive and relevant to the research objectives, thereby enabling a thorough analysis using Value-Focused Thinking (VFT) and the Analytic Hierarchy Process (AHP).

The author will utilize various data collecting techniques, such as:

1. Literature study
   The author will use literature studies to collect information from various sources such as books, scientific journals, articles, and other sources related to the study. Some internal documents regarding the implementation of outdoor wireless in BPB also will be explored.
2. Interview
   Interaction through interview will be conducted depending on the level of flexibility. There will be direct interaction between author and interview participants to explore topics, understand the proposal, and gather insights. Interview participants will be conducted by part of the project team that is directly involved during the selection process of outdoor wireless solutions.
3. Questionnaire
   In this study, questionnaires will be distributed to the relevant parties especially for the solution providers. The questionnaire will be a data collection tool that uses structured questions to obtain information and data from each respondent.

The data through various research methodologies will be categorized into two: primary data and secondary data source.

1. Primary Data Source
   The author is gathering data through company owned data that related to outdoor wireless in BPB. Focused group discussion, interview, and questionnaire also conducted by author to gather comprehensive information.
2. Secondary Data Source
   Secondary data collection involves gathering and reviewing existing literature, reports, and technical documents that related to BPB outdoor wireless solution. The data should provide background information and contextual understanding relevant to the research problem.

4. ANALYSIS

Mining operations rely heavily on reliable communication and data transmission, especially with the increasing complexity and expansion of these operations. However, the current wireless infrastructure, predominantly based on traditional Wi-Fi, presents several limitations that affect efficiency and safety. These challenges were identified through focused group discussions with stakeholders and can be categorized as follows:

1. Coverage Issues
   Wi-Fi signal strength diminishes over distance and is obstructed by physical barriers, leading to dead zones that require many access points and mobile repeaters. Coverage is limited to critical areas, with varying range depending on the device.
2. Interference Problems
   Operating in unlicensed frequency bands, Wi-Fi is prone to interference from external sources, including contractors, causing signal degradation and connectivity issues, which disrupt mining operations.
3. Security Risks
   The outdated authentication methods and widely known password keys in use for over 15 years pose security vulnerabilities. The network's encryption and device firmware have not been updated, further increasing risk.
4. Labour-Intensive Maintenance

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Maintaining over 200 access points in the mining area requires significant labor, including repositioning repeaters and relocating access points during blasting activities.

5. Scalability Challenges
   As mining operations increasingly adopt digital tools and IoT sensors, the network struggles to scale, with large, flat network structures creating inefficiencies in accommodating growing demand.

These issues highlight the need for exploring more robust alternatives to traditional Wi-Fi for BPB's outdoor wireless solutions. Problem tree analysis uses to illustrate the problem.

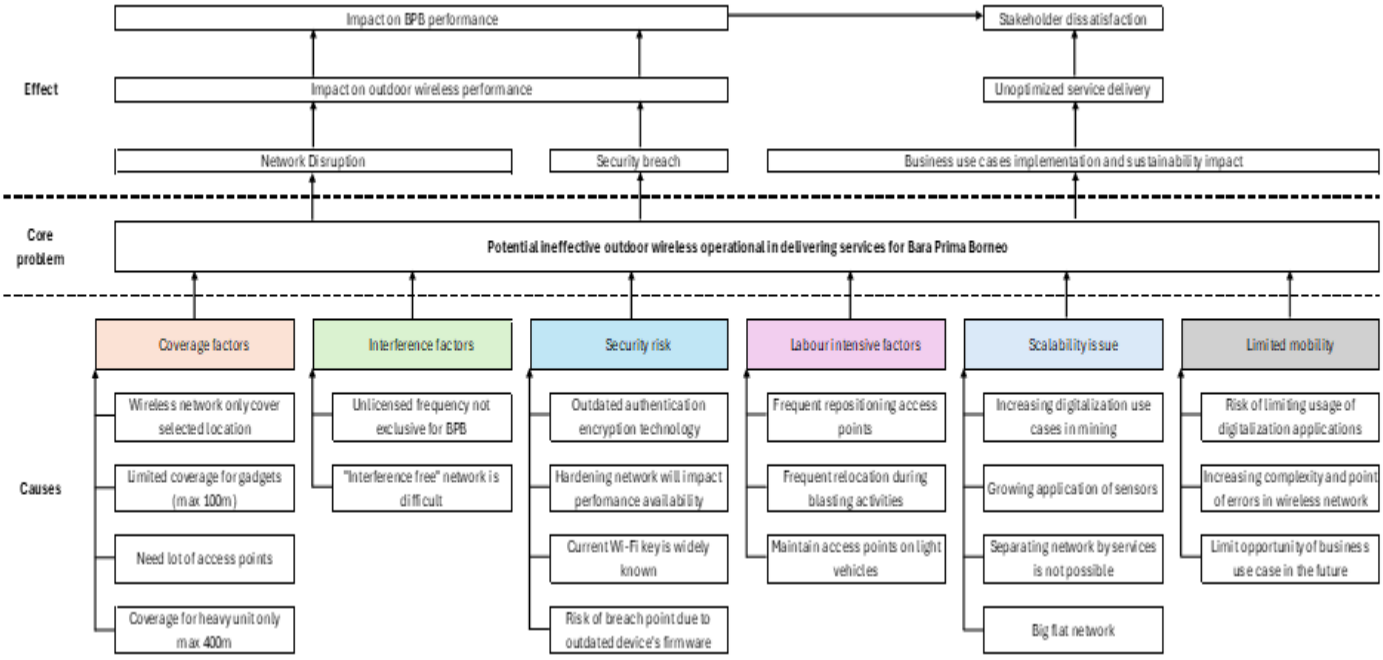

Figure 3. Problem Tree Analysis for current BPB outdoor wireless situation

Value-Focused Thinking (VFT) is used for this study for evaluation and reflect the objectives of the decision-makers. VFT is a strategic approach that prioritizes the identification and integration of core values in the decision-making process (Keepney, 1996). Instead of beginning with possible alternatives and working backward to determine how they align with objectives, VFT used by defining what is most important and then uses those to guide decision criteria and the evaluation of alternatives.

Subject Matter Expert (SME) in BPB gathered and discussed about wish lists of ideal outdoor wireless solution. Expert from IT collaborate with each correspondent from each division that have critical use cases.

The author conducted interviews with both the Management team and SME who play crucial roles as decision-makers in the organization. These interviews were important in gathering understanding of the key factors that influence the success and sustainability of the outdoor wireless solution in BPB.

These attributes, which reflect the priorities and concerns of the organization, were then systematically categorized into specific criteria. These criteria will serve as the foundation for evaluating and selecting the best wireless solution that aligns with the current operational needs and the long-term strategic goals of the company. The connection related to attributes, mean-objectives, and fundamental objectives can be found below.

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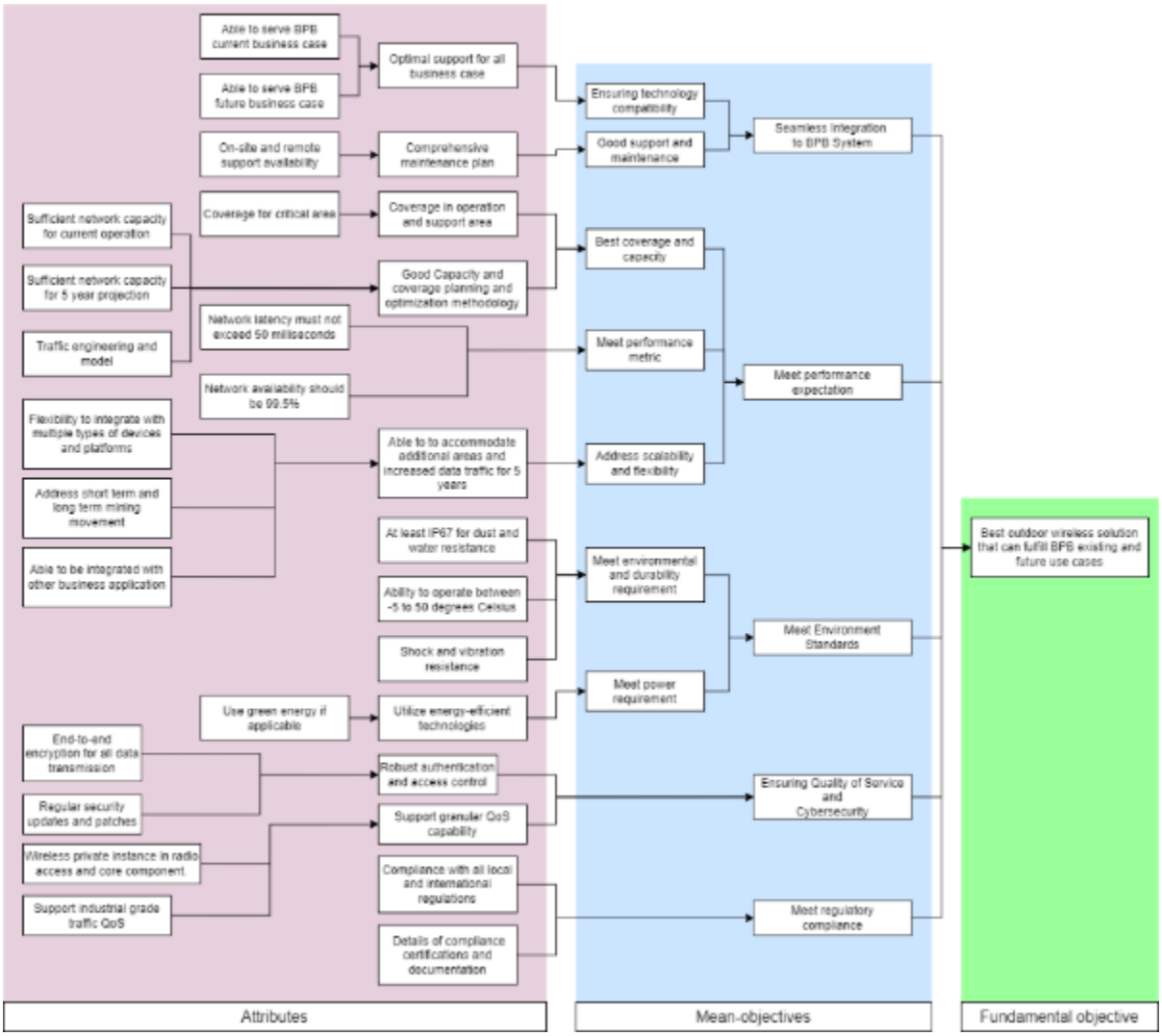

Figure 4. Hierarchy of Fundamental Objectives

These mean objectives are derived from stakeholders' values and are essential in guiding the overall strategy. When transitioning to AHP, these mean objectives are transformed into criteria that can be systematically evaluated. This structured approach ensures that the decision-making process is both comprehensive and aligned with the organization's priorities. The conversion table can be shown below.

Table 2. Mean Objectives to Criteria (AHP) conversion with description

No.	Mean Objectives (VFT)	Criteria (AHP)	Description
1	Seamless integration to BPB System	Integration to BPB System	Refer to ability to ensuring technology compatibility and good support. This means the solutions have to serve current and future business case and has comprehensive maintenance plan.
2	Meet performance expectation	Wireless performance	Refer to ability to deliver best coverage, meet performance metric and address scalability issue. These criteria highlight technology aspect that meet on BPB requirement on capacity, traffic engineering, availability, and cover mining movement.

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3	Meet environment standards	Enviromental impact	Refer to ability of system that meet environmental standards. Because of the nature of environment in mining area, the system equipment must be able to operate in harsh condition.
4	Ensuring Quality of Service and Cybersecurity	QoS and Cybersecurity	Refer to issue about implementation of quality of service and cybersecurity. The ability to have end-to-end encryption, security patches, updates.
5	Meet Regulatory Compliance	Regulatory compliance	Refer to compliance to government and industry standards. These criteria ensuring the technology will have legality of operation in Indonesia.

Once the criteria were derived from the Value-Focused Thinking (VFT) process and converted into specific, measurable criteria within the Analytic Hierarchy Process (AHP) framework, the next crucial step is to generate viable alternatives that could be evaluated against these criteria. To achieve this, the criteria were shared with four vendors in the outdoor wireless technology space. Each vendor was invited to submit design proposals that addressed the specific needs and challenges outlined in the criteria.

Table 3. Vendor profile

No.	Company	Year Founded	Core Industry	Technology
1	Vendor A	1995	Telecommunication	Mobile Broadband (4G)
2	Vendor B	1984	Telecommunication	Mobile Broadband (4G)
3	Vendor C	1989	Telecommunication	Mobile Broadband (4G)
4	Vendor D	2001	Wireless Communications and Networking	Kinetic Mesh

The vendors were tasked with developing four design proposals, each showcasing their understanding of the mining environment's unique demands and their technical expertise in outdoor wireless solutions. The goal was to not only assess their technical capabilities but also to evaluate their creativity and problem-solving skills in addressing the complex requirements of the project. This approach ensured a comprehensive evaluation of different technological approaches and design philosophies, providing a robust set of alternatives for consideration in the final decision-making process.

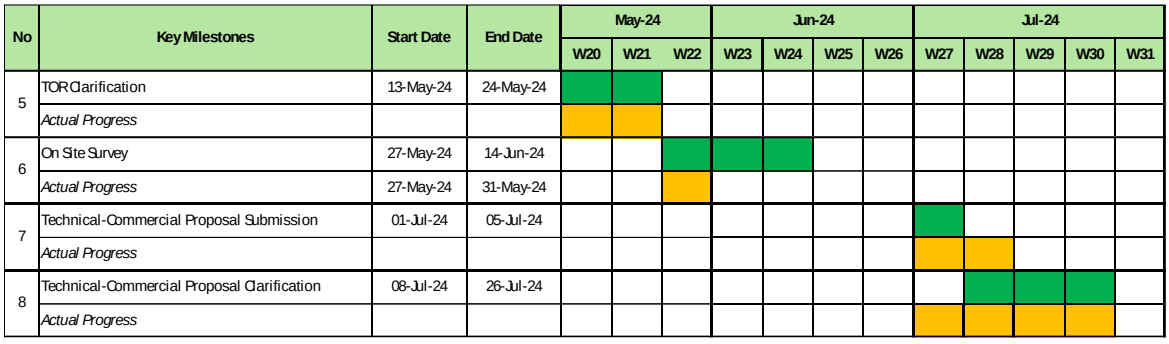

Figure 5. Planned and actual progress of clarification

There are some steps that needed to be taken to allow vendors to know exactly BPB requirements and verify their technology proposal. After sending TOR document for their data, each vendors given time to communicate through group discussion with BPB SME. Figure 4.4 shows actual communication progress for all vendors before finalizing the proposal.

1. Term of Reference (TOR) Clarification
   The Term of Reference (TOR) Clarification process was scheduled to take place between May 13th and May 24th, 2024. The activities of confirming the TOR document conducted in Week 20 to Week 22. Each vendor given meeting appointment to interview and gather information about the document and BPB environment.

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2. On-Site Survey
   The On-Site Survey was scheduled between May 27th and June 14th, 2024. However, because all vendor agreed to conduct survey at the same time, the survey was conducted and completed earlier than anticipated, specifically from May 27th to May 31st, 2024. This ahead-of-schedule completion allowing the vendors submit the initial proposal earlier.
3. Technical-Commercial Proposal Submission
   The Technical-Commercial Proposal Submission was scheduled between July 1st, and July 5th, 2024. Each vendor has submitted the initial proposal on:
   - Vendor A: July 11th, 2024.
   - Vendor B: July 12th, 2024.
   - Vendor C: July 16th, 2024.
   - Vendor D: July 5th, 2024.
4. Technical-Commercial Proposal Clarification
   On this stage, BPB conducted intense communication through multiple focused group discussions with each vendor. The design is examined together by BPB and vendor's expert. The discussion took place on:
   - Vendor A: July 9th and July 30th, 2024
   - Vendor B: July 12th and July 27th, 2024
   - Vendor C: July 16th and July 24th, 2024
   - Vendor D: July 2nd and July 25th, 2024

Following the submission of the proposals, a thorough proposal clarification process was conducted on month of July 2024. During this period, each of the four vendors was engaged in detailed discussions to address any ambiguities, refine their proposals, and ensure full compliance with the criteria outlined in the Term of Reference (TOR) document.

The proposal clarification process resulted in the submission of refined and optimized design proposals from all four vendors. These final designs provide a solid foundation for the implementation phase, ensuring that the selected solution will be fully compliant with the objectives and capable of delivering the service. The outdoor wireless proposal from each vendor:

1. Vendor A design a combination of Private LTE with public infrastructure in Kutai Timur area. Provider A propose additional 8 new mobile communication tower, 4 new fixed communication tower in existing location, and utilize 1 BPB existing tower.

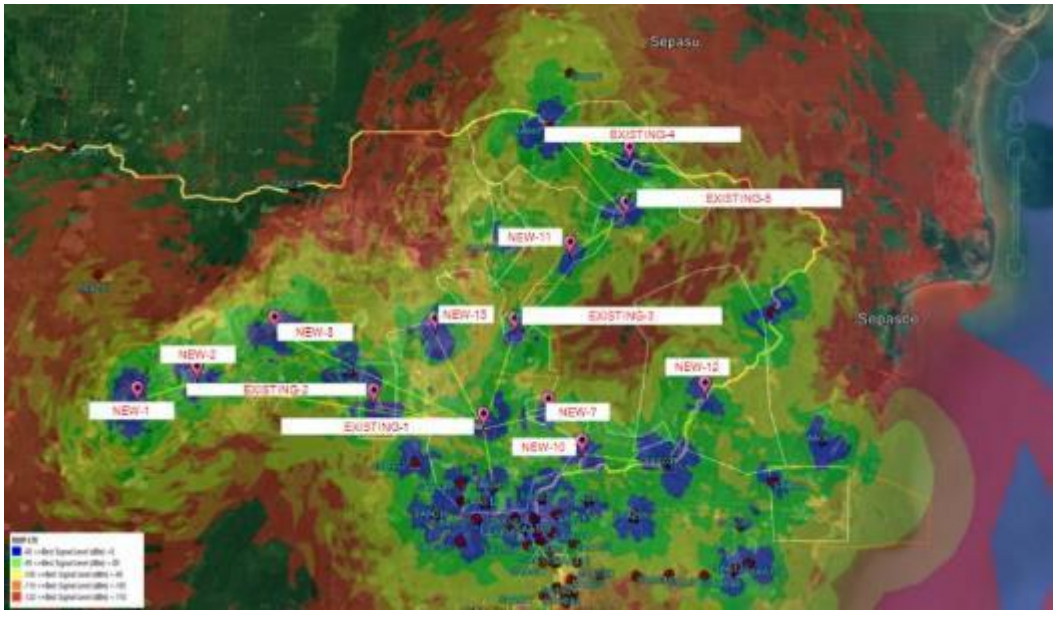

Figure 6. Coverage and infrastructure planning from Vendor A

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2. Vendor B design a Private LTE infrastructure. Vendor B propose additional 7 new mobile communication tower and utilize 6 BPB existing tower.

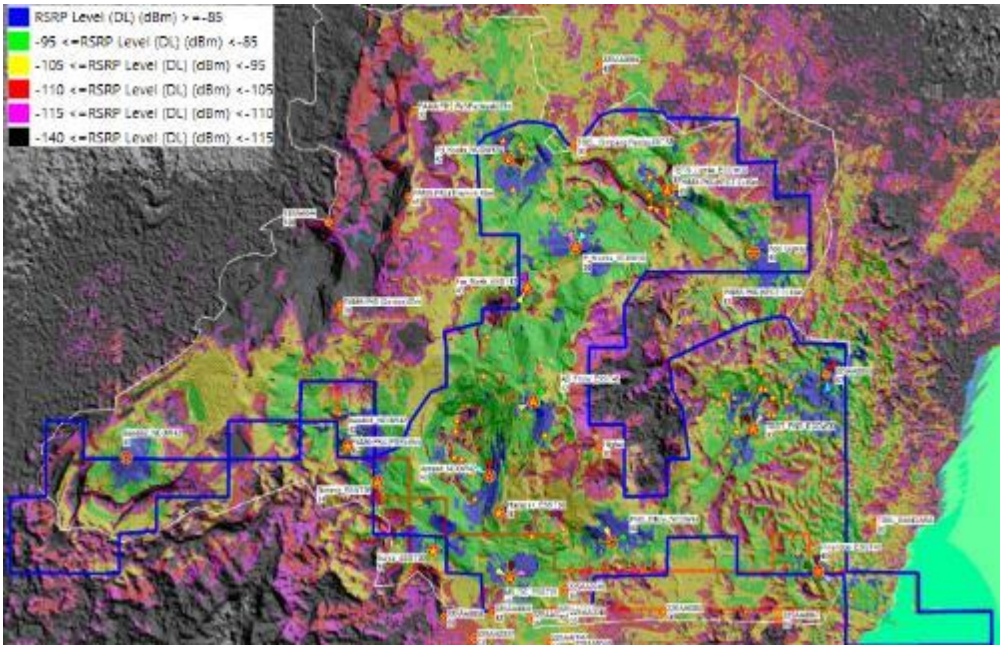

Figure 7. Coverage and infrastructure planning from Vendor B

3. Vendor C design a Private LTE infrastructure and utilizing additional 7 new mobile communication tower, utilizing one vendor C mobile communication tower, and utilizing 6 BPB existing tower.

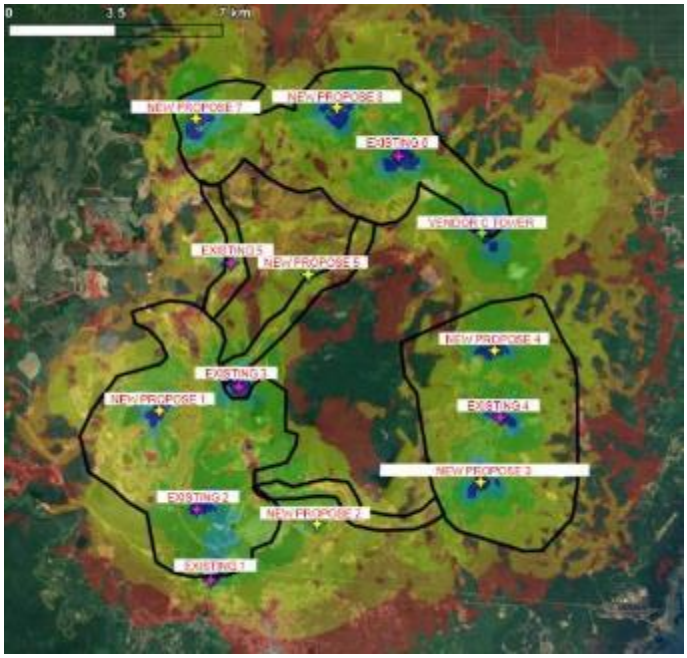

Figure 8. Coverage and infrastructure planning from Vendor C

4. Vendor D design a Wireless Mesh infrastructure. The wireless mesh design requires 17 existing infrastructure mobile repeaters and 14 new mobile trailers.

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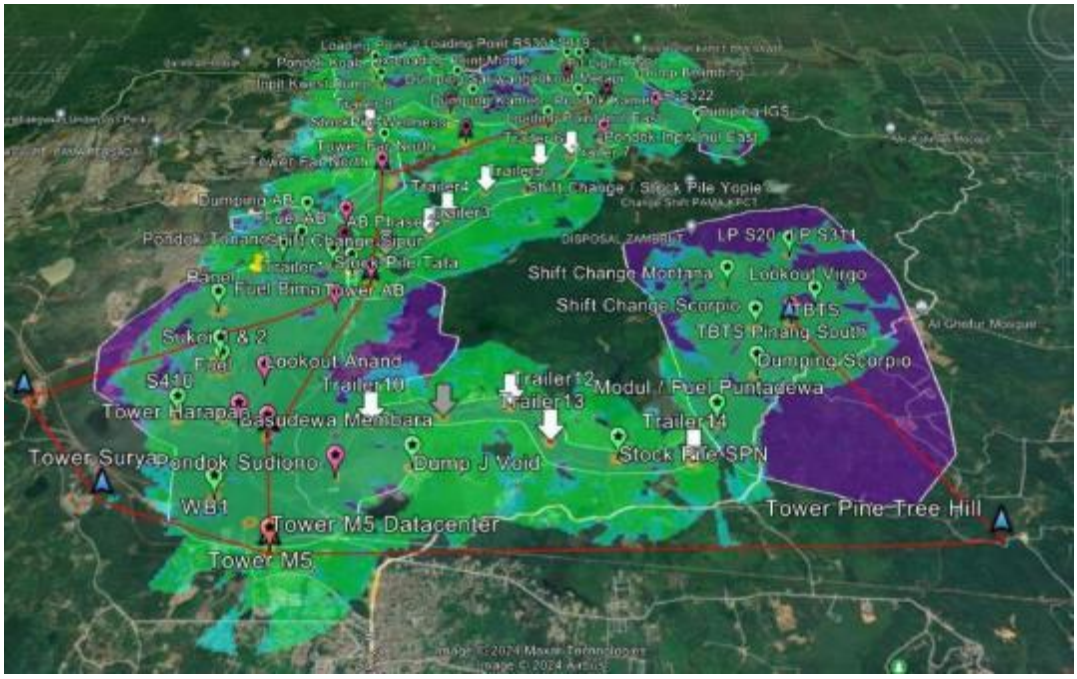

Figure 9. Coverage and infrastructure planning from Vendor D

After conducting several in-depth group discussions with each vendor, author evaluated each proposed solutions to ensure alignment with the project's specific requirements. These discussions were instrumental in refining and clarifying the details of each proposal, allowing us to assess how well they addressed the criteria outlined in the Term of Reference (TOR) document, particularly those based on the Analytic Hierarchy Process (AHP).

To conduct pairwise comparisons, the respondents are selected from each division that classified as subject matter experts for business cases. There are two personnel from four division that closely associated with operational aspects. Their input is crucial for conducting analysis

Table 4. List of respondents of SME for AHP process

No	Personnel	Division	SME Group
1	Manager IT Site Sangatta	IT	SME 1 (IT)
2	Superintendent IT Infrastructure		
3	Manager BPID	BPID	SME 2 (BPID)
4	Superintendent BPID		
5	Manager Mining Optimization	MOD	SME 3 (MOD)
6	Superintendent Mining Optimization		
7	Manager Mining Service	MSD	SME 4 (MSD)
8	Superintendent Mining Service		

In accordance with the result of interviews and focused group discussions with SME from BPB and vendors, there are four alternatives and five criteria.

1. Construct structure hierarchy

   The objective of this analysis is to select the most suitable design proposal for the outdoor wireless solution at BPB. The selection criteria are crucial as they ensure that the chosen design not only meets BPB's current requirements but also addresses

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future needs. The four design proposals submitted by the vendors will be evaluated using the Analytic Hierarchy Process (AHP. The structure of AHP model hierarchy is shown in below.

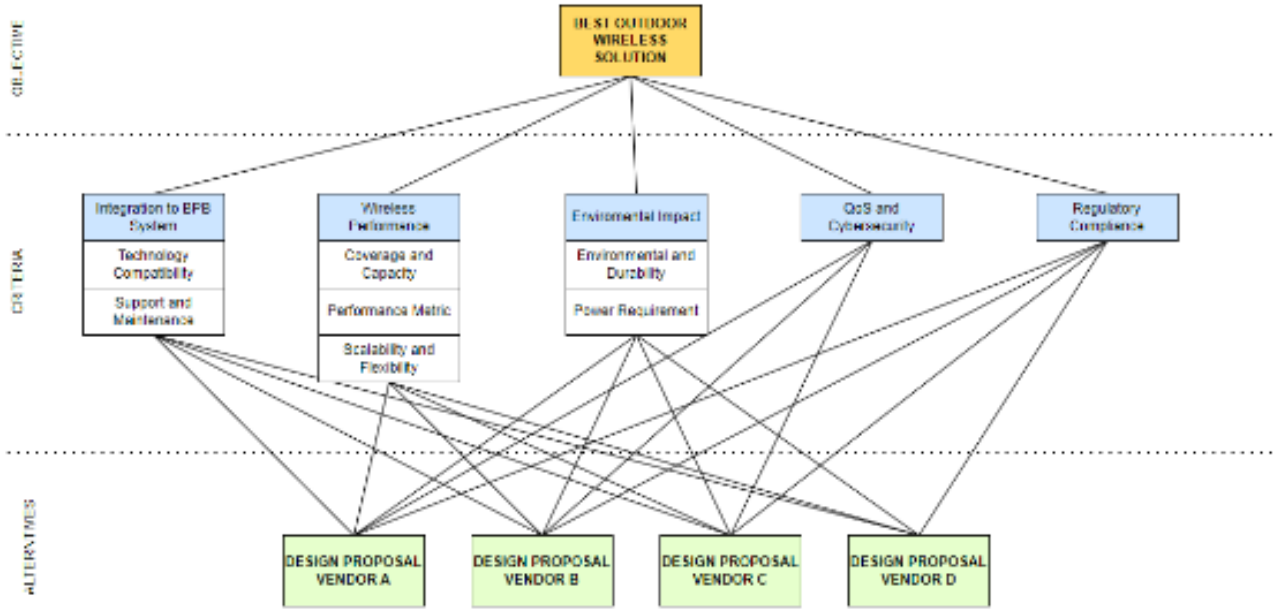

Figure 10. AHP to determine solution for four vendor proposals

2. Hierarchy Result

The pairwise comparisons of the criteria and sub-criteria were converted into a questionnaire by Business Performance Management Singapore (BPMSG) software, which the selected respondents were asked to complete by providing their importance for each comparison table. Respondents in Table 4 will conduct focused group discussions using BPMSG to obtain pairwise comparisons of the criteria and alternative solutions.

Decision Hierarchy

Level 0	Level 1		Level 2		Glb Prio.
Best Outdoor Wireless Solution			QoS and Cybersecurity	0.150	15.0%
			Regulatory Compliance	0.080	8.0%
	Integration to BPB System	0.300	Technology Compability	0.600	18.0%
			Support and Maintenance	0.400	12.0%
	Wireless Performance	0.400	Coverage and Capacity	0.500	20.0%
			Performance Metric	0.200	8.0%
			Scalability and Flexibility	0.300	12.0%
	Environment Impact	0.070	Environmental and Durability	0.700	4.9%
			Power Requirement	0.300	2.1%
OK. Submit for group eval or alternative eval. Alternatives					1.0

Figure 11. Decision hierarchy in BPMSG

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Based on interviews with SMEs, the criteria and sub-criteria were weighted to determine the best outdoor wireless solution. The approach addresses current challenges and future opportunities for improving outdoor wireless operations.

1. QoS and Cybersecurity (15% priority) ensure the solution maintains service levels and robust security, focusing on network traffic prioritization and protection against threats.
2. Regulatory Compliance (8% priority) examines whether the solution meets relevant regulations and industry standards to avoid legal risks.
3. Integration to BPB Systems (30% priority) emphasizes seamless integration, with technology compatibility (18%) to support current and future use cases, and support/maintenance (12%) to ensure system reliability.
4. Wireless Performance is the most critical factor (40% priority), with coverage capacity (20%), performance metrics (20%), and scalability/flexibility (12%) crucial for operational effectiveness.
5. Environmental Impact (7% priority) ensures the solution is sustainable, with a focus on device durability (5%) and efficient power requirements (2%).

Each SME group interviewed separately by its division. This separated focused group discussion is to identify each division preferred alternatives. Other reason is to simplify discussion when adjusting the consistency ratio. Figure 12 shows the result after quantifying the alternatives.

Decision Hierarchy

Level 0	Level 1	Level 2	Glb Prio.	Vendor A	Vendor B	Vendor C	Vendor D
Best Outdoor Wireless Solution	QoS and Cybersecurity 0.150		15.0%	0.118	0.337	0.381	0.164
	Regulatory Compliance 0.080		8.0%	0.204	0.274	0.315	0.208
	Integration to BPB System 0.300	Technology Compability 0.600	18.0%	0.144	0.241	0.321	0.293
		Support and Maintenance 0.400	12.0%	0.092	0.114	0.391	0.404
	Wireless Performance 0.400	Coverage and Capacity 0.500	20.0%	0.153	0.203	0.331	0.313
		Performance Metric 0.200	8.0%	0.196	0.224	0.267	0.313
		Scalability and Flexibility 0.300	12.0%	0.139	0.345	0.314	0.201
	Environment Impact 0.070	Environmental and Durability 0.700	4.9%	0.175	0.255	0.255	0.314
		Power Requirement 0.300	2.1%	0.110	0.245	0.245	0.400
			1.0	14.5%	24.7%	33.0%	27.8%

Figure 12. AHP result regarding the decision criteria

Based on the analysis using BPMSG, the consolidated result show in Figure 4.12. Vendor C rank first in 33%, followed by Vendor D in 27.8%. The Vendor B rank third in 24.7% and Vendor A rank last in 14.5%.

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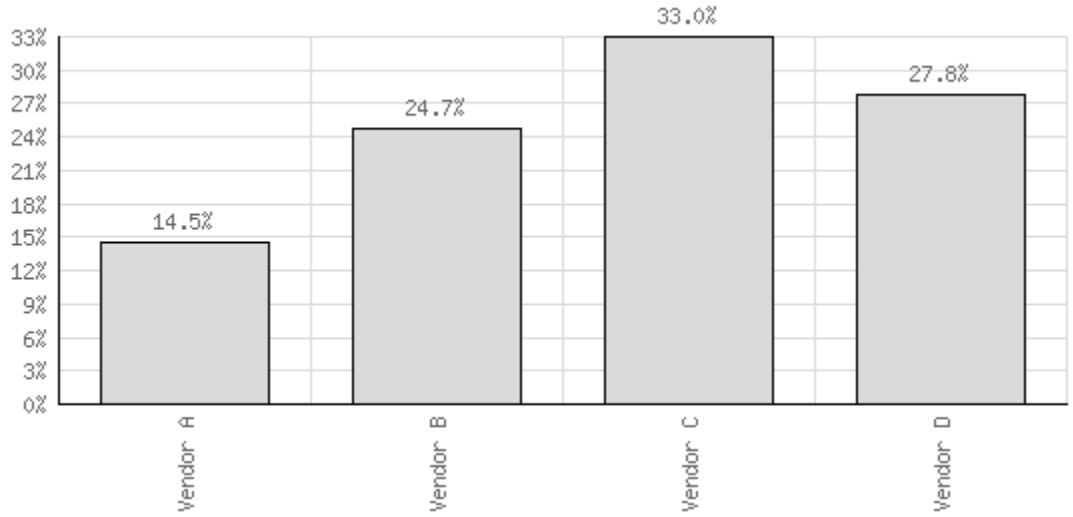

Figure 13. Consolidated results

6. CONCLUSION

After conducting a series of in-depth studies, it can be concluded that this research offers significant insights into the process of selecting the best outdoor solution for BPB. The study identifies and thoroughly analyses key findings to address the research question.

1. What is the root cause of outdoor wireless issue in BPB?
   Through the application of Stakeholder Analysis and Value-Focused Thinking (VFT), the synthesis of the analysis has revealed six key challenges for existing outdoor wireless solution, such as:
   - Coverage factors
   - Interference factors
   - Security risk
   - Labour intensive factors
   - Scalability issues
   - Limited mobility

2. What criteria should be used to evaluate the alternative solutions?
   Focused group discussion conducted with framework of VFT are used to determine criteria for the best outdoor wireless solution. The results of the synthesis of analysis are known to have five design criteria, such as:
   - Integration to BPB System
   - Wireless performance
   - Environmental impact
   - QoS and Cybersecurity
   - Regulatory compliance

3. What are the alternative solutions that can effectively address existing outdoor wireless system in BPB?
   Alternative designs for outdoor wireless solutions were obtained after conducting interviews and focused group discussions with experts from each vendor. The alternative solutions are:
   - A combination of Private LTE with public infrastructure that utilize additional 8 new mobile communication tower, 4 new fixed communication tower in existing location, and utilize 1 BPB existing tower.
   - Private LTE infrastructure within BPB mining area that utilize additional 7 new mobile communication tower and utilize 6 BPB existing towers.

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- Private LTE infrastructure within BPB mining area that utilize 7 new mobile communication towers, utilizing one vendor C mobile communication tower, and utilizing 6 BPB existing towers.
- Wireless Kinetic Mesh infrastructure that utilizes 17 existing infrastructure mobile repeaters and 14 new mobile trailers.

4. Which solution is the best to implement in BPB mining?
   Utilizing the Analytic Hierarchy Process (AHP) method with the assistance of BPMSG software, the analysis results indicate that the optimal design proposal for the outdoor wireless solution is design proposal from Vendor C. The vendor proposes Private LTE infrastructure within BPB mining area that utilize 7 new mobile communication towers, utilizing one vendor C mobile communication tower, and utilizing 6 BPB existing towers.

Regarding the selection of the design proposal from Vendor C, here are some things that can be improve for future recommendation by the author:

1. Continuously perform risk assessments to regularly review and update the identified risks. This approach enables ongoing monitoring and the ability to adapt to emerging risks, ensuring that risk management strategies remain relevant and effective over time.
2. To explore alternative options, consider collaborating with industry experts or conducting benchmarking against other companies. This will provide valuable insights that extend beyond the findings of this research.
3. Regarding deployment scenario, conduct comprehensive strategy planning that correlates with constraint of budget for efficient and effective implementation strategy.

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