



Applying FMEA for Operational Risk Management: Lessons from Minestar Implementation at PT. Borneo Indobara

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ABSTRACT

PT Borneo Indobara (BIB) is planning to implement Minestar, an integrated mining management system, in 2025 to enhance operational efficiency and safety. However, the implementation of this system poses several operational risks that require careful management to ensure success. The aim of this research is to develop a comprehensive risk matrix and propose effective mitigation strategies for the Minestar implementation at BIB, using the SNI ISO 31000:2018 risk management framework. The research employs a mixed-method approach, combining qualitative techniques such as semi-structured interviews and focus group discussions (FGD) with quantitative analysis using Failure Mode and Effect Analysis (FMEA). Data was collected from key stakeholders directly involved in the Minestar project to assess the severity, occurrence, and detection of each identified risk, which were then used to develop a risk matrix. The results of the study identified and prioritized several critical operational risks, with a three-dimensional risk matrix providing a clear visualization of their severity, occurrence, and detection levels. This structured approach allows BIB's management to prioritize risks and allocate resources effectively for risk mitigation. The findings of this research contribute to operational risk management in the mining industry, particularly for the implementation of advanced technologies like Minestar. The practical insights provided can serve as a reference for similar projects in the industry, helping organizations to address operational challenges proactively.

Keywords: Operation Risk management, Mining technology, Failure Mode and Effect Analysis (FMEA).

INTRODUCTION

Coal mining is an industry that fulfills national and international energy (Afin & Kiono, 2021). The mining sector is vital to modern society as it provides invaluable resources that drive our economy and fuel technological advancements (Choi, 2023). In this view, mines are industrial operations that extract mineral deposits wherever and whenever they are economical (Ramani, 2012).

In addition to having a large capital transfer, mining also has a high safety risk (Ullah et al., 2018). In today's technological development, tools are needed to make coal mining effective, efficient, and safe (Kumar, 2016). Using automation techniques and advanced information and

communication technology (ICT), the mining industry can optimize its entire value chain and overcome its difficulties through technological advances (Jang & Topal, 2020). Utilizing the latest sensing, automation, and data analytics developments, smart mining technologies provide promising answers to these problems by streamlining mining operations and improving sustainability, efficiency, and safety (Choi, 2023). The application of technology is also expected to increase efficiency and productivity and monitor safety (Awolusi et al., 2018). The computer system platform serves as the main control center for an intelligent and networked mine safety monitoring system, which creates a graphical user interface for user interaction (Chen & Wang, 2020). The Internet of Things (IoT) collects, stores, and manages all kinds of information in an organized manner, integrating all areas of production, safety, and management information. This has a significant impact on improving coal information levels, operational efficiency, and safety (Fang, 2022).

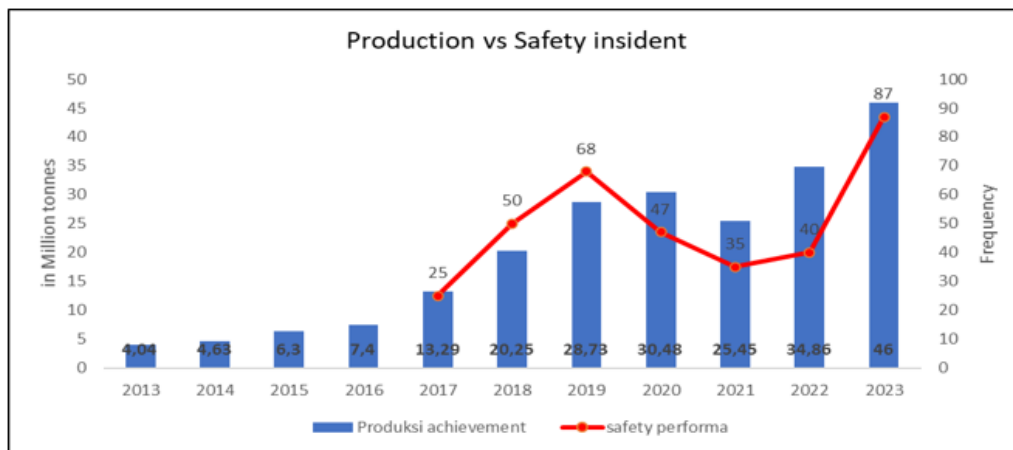


Figure 1. Production Achievement vs Safety Performance of PT Borneo Indobara

Figure 1 shows that from 2017 to 2023, PT. Borneo Indobara (BIB) has experienced a significant increase in coal production yearly. The increase is also accompanied by increased safety risks, shown by the increasing incidence of accidents every year due to the increased population of heavy equipment and humans who operate it. This is of particular concern to management. In 2024, BIB experienced an increase in production of around 11.4% from the previous year. The challenge is using technology to increase productivity and safety with the same unit capacity and workforce. Of course, this challenge is not easy, plus the application of technology in BIB has a complicated complexity that, if not managed and mitigated from the beginning of its application, will not get optimal results in 2025, especially in production capacity, which is planned to be at the peak of BIB production. Minestar is a technology that makes operations effective and safe; this technology will only be implemented in 2025 at BIB to increase production. It is hoped that this technology will be one of the factors that contribute to the success of production and work safety in 2025. On the other hand, applying new technology and systems, such as Minestar, at BIB will likely create new risks that must be mapped

comprehensively. Implementing new technology not only brings benefits and efficiency but also has the potential to create new risks that previously did not exist in conventional mines—for example, dependence on systems and networks and potential operational disruptions in the event of system failure (Ir Julianus Hutabarat, 2021). In addition, changes in work patterns and the need for new skills can risk employee adaptation and productivity.

Therefore, it is crucial to identify, analyze, and map risks comprehensively before and during the implementation of the Minestar. This new risk mapping is a new operational risk that arises from implementing new technology, so this helps BIB prepare appropriate and effective mitigation. Risk management is one of the best preventive measures used in various industries to reduce the impact of a risk or crisis (Ouabira, 2023). This is very important because implementing this Minestar will have an essential role in the coal production process at the mine, which is the supply chain of BIB. Identifying, evaluating, and controlling hazards associated with a company's supply chain is called supply chain risk management (Henni et al., 2024). Risk management takes a crucial initial role in mitigating risks from the start, and the application of Minestar technology can be optimized from the beginning of its application (Tarei et al., 2021). While there have been several studies on mining technology implementation risk management, such as the study by (Jang & Topal, 2020), which discusses the Australian mining industry's transformation and future prospects, including the risks of new technology implementation, then the study by (Choi, 2023), which examines the latest advances in smart mining technology, including risk analysis related to its implementation, then the case study by (Chen & Wang, 2020), on IoT-based coal mine safety monitoring system, which includes operational risk analysis, but there has been no comprehensive study focusing on the operational risks of Minestar implementation.

Research fills the gap by developing a risk matrix for Minestar implementation at BIB. This research offers a more structured and contextualized risk assessment using a multi-method approach combining qualitative and quantitative analyses. The focus on the case of BIB also provides practical insights for other mining companies in Indonesia planning to implement similar technologies. Risks can be identified, assessed, anticipated, and managed using a structured method known as risk management and need to be used at every level of the organization to be successful (Tantarto & Hermawan, 2023). Previous research by (Durst & Zieba, 2019) applied a structural approach to risk management by developing a comprehensive knowledge risk taxonomy for organizations. (Massingham, 2010) proposed a knowledge risk management framework. However, these studies focused on the general organizational context. This study is different as it explicitly examines operational risk management in implementing Minestar technology in the mining industry. In addition, this study identifies and categorizes risks, develops a risk matrix tailored to the needs of BIB, and proposes context-specific mitigation strategies. Thus, this research aims to develop a comprehensive risk matrix and propose effective mitigation

strategies for the Minestar implementation at BIB, using the SNI ISO 31000:2018 risk management framework.

RESEARCH METHOD

The research is conducted using a combination of qualitative and quantitative methods. The qualitative approach will be carried out to explore in depth the various aspects of risks and challenges that will occur during the implementation of Minestar at BIB in 2025, while the quantitative approach will be carried out to measure the weights of each risk which will then be prioritized for the preparation of mitigation for the highest risks.

In collecting data, the author uses several methods, namely semi-structured interviews involving several stakeholders of the Minestar implementation project, including project managers and division heads, namely BIB management who provide full commitment and support. production managers, and mine operations, as end users of the Minestar project who have the ability and experience in their fields, these respondents represent people who have an interest in this Minestar project and later and have more than 10 years of experience in mine operations (table 1).

Table 1. List of stakeholders Minestar implementation of PT. BIB

Member Position Experience		
Expert 1	Contractor Mining Project Manager	More than 15 years
Expert 2	Division Head Mine Operation	More than 15 years
Expert 3	Manager Mine Operation	More than 15 years
Expert 4	Contractor Mining Division Head Operation	More than 15 years
Expert 5	Contractor Mining Operation Manager	More than 15 years
Expert 6	Contractor Mining Optimization	10-15 years
Expert 7	Superintendent Mine Operation	10-15 years

This interview was conducted by determining questions related to the implementation of technology such as the level of commitment of BIB management to the implementation of Minestar, then how adequate the IT infrastructure owned by PT BIB to support the implementation of Minestar, whether BIB has experience in implementing systems such as Minestar

The next step is to conduct focus group discussions and direct observations to the field with benchmarks to PT Cipta kridatama (CK) site PT. Binuang Mitra Bersama (BMB) which has implemented this technology, FGDs are carried out with discussions to find problems that arise at the beginning of the implementation of Minestar there, the members consist of mine optimization managers, production managers, and project managers of PT CK site BMB. Furthermore, direct observation is carried out by looking at the control room, observing the direct process of using the Minestar, analyzing the stages of the Minestar process to observing the dispatcher/controller in carrying out his duties. Semi-structured interviews with stakeholders

at BIB and benchmarking results to CK site BMB are then used as the basis for determining aspects of the operational risk context of Minestar implementation at BIB, while providing quantitative data to support decision making in risk management.

From the results of data collection, operational risk criteria that must be further analyzed are work safety, system and equipment disruption or failure, supply chain risk, internal process failure, risks related to human resources/employees, technology risk, execution, delivery, and process management risk. So, the methodological steps carried out in this study are to determine whether the risk matrix developed from the risk assessment analysis can influence management decisions in risk treatment process at the time of Minestar implementation in 2025.

RESULT AND DISCUSSION

Data Collection

Establishment of contexts

This step is to determine the risk context through a process of semi-structured interviews, FGDs, and benchmarking. As explained in the previous chapter, this interview process is carried out to determine what risks are related to the needs of Minestar at BIB which of course can directly affect these stakeholders, benchmarking is carried out to provide in-depth insight into the operational risks of Minestar implementation.

Next, we must determine the context of risk in the business process, which in this case is generally divided into External, Internal, human, and process failures. Then, from this context, we break it down back into operational risk.

This context identification process helps to ascertain the likelihood of risk occurrence and impact and the management response in the Production division (Dahlan & Fathoni, 2021). The determination of the context that has been approved by stakeholders can be seen in Table 2 below.

Table 2. Context Operational Risk Implementation Minestar

Business Process	Operational Risk
External	Supply chain risks
Internal	Internal process failure
Human factor	Human resources/employee risks
Process	Execution, delivery, and process management risks System and equipment disruption or failure

Confirmation of criteria and risk levels

Risk confirmation is done by determining the value of each level of severity, occurrence and detection, the determination of which is discussed with each interested stakeholder and benchmarking, which is used as the basis for discussion of each stakeholder. The following is a reference for each level of risk that stakeholders have agreed upon. Based on (Dahlan & Fathoni,

2021), the severity and occurrence reference for each confirmed risk level of the Minestar implementation are described in Table 3 and Table 4.

Table 3. Confirm risk level severity

Rating	Criteria
1	Negligible severity. We do not need to think that this consequence will have an impact on product performance
2	Mild severity. The consequences are only mild. End users will not feel the performance
3	
4	
5	Moderate severity. End-users will notice a decrease in performance or appearance, but it is still within the tolerance limit
6	
7	
8	High severity. End users will experience unacceptable adverse consequences that are beyond tolerance. Effects will occur without prior notice or warning
9	
10	Potential safety problem. A very dangerous consequence that can occur without prior notice or warning

Source: (Dahlan & Fathoni, 2021)

Table 4. Confirm Risk level Occurrence

Rating	Criteria	Failure Rate
1	It is unlikely that this cause resulted in the failure mode	1 in 1,000,000
2	Failure will be rare	1 in 20,000
3	Failure will be possible	1 in 4000
4	Failure will be possible	1 in 1000
5	Failure will be possible	1 in 400
6	Failure will be very likely	1 in 80
7	Failure will be very likely	1 in 40
8	Failure will be very likely	1 in 20
9	It is almost certain that failure will occur	1 in 8
10	It is almost certain that failure will occur	1 in 2

Source: (Dahlan & Fathoni, 2021)

Based on (Dahlan & Fathoni, 2021) the detection reference for each confirmed risk level of the Minestar implementation is described in Table 5

Table 5. Confirm Risk level Detection

Rating	Criteria	Incidence Rate
1	Prevention or detection methods are so effective there is no chance that the cause may still arise or occur	1 in 1,000,000
2	The likelihood of that cause occurring is low	1 in 20,000
3	The likelihood of that cause occurring is low	1 in 4000
4	The likelihood of causes occurring is moderate. Prevention or detection methods are still in place	1 in 1000
5	The likelihood of causes occurring is moderate	1 in 400
6	The likelihood that such causes occur is still high	1 in 80

Rating	Criteria	Incidence Rate
7	The likelihood that such causes occur is still high. Prevention or detection methods are less effective, as the cause still recurs	1 in 40
8	The likelihood that the cause occurs is very high. Prevention or detection methods are less effective, as the cause still recurs	1 in 20
9	The likelihood that the cause occurs is very high. Prevention or detection methods are ineffective	1 in 8
10	The likelihood that the cause occurs is very high. Prevention or detection methods are ineffective. The cause will always reoccur	1 in 2

Source: (Dahlan & Fathoni, 2021)

The assessment of each level of severity, occurrence, and detection based on the guidelines above, has been discussed comprehensively with stakeholders who are directly involved and adjusts to the purpose of conducting this research, namely the implementation of Minestar at BIB.

Risk Identification

After confirming each level of risk severity, occurrence, and detection, the next step is to carry out a risk identification process, including the origin of the risk, its impact, the event that occurred, the cause, and the potential resulting from the development of 5W 1H (what, where, who, why, & how) on the Minestar implementation, this step is as described in the research method by conducting semi-structured interviews with direct stakeholders at BIB, as well as conducting brainstorming at the CK site BMB with several respondents as users and owners of Minestar technology. Then at this stage, an in-depth analysis is carried out related to the scope of the business process, failure modes, potential risk impacts, and causes of risk. The scope of the risk identification process in the Minestar implementation can be seen in Table 6.

Business Context	Code	Criterion	Sub-criterion Code	Sub-Criterion (Potential Failure Mode)	Potential failure effect	Potential Cause	Initial treatment
Eskternal	A	Supply chain risks	RA1	Dependence on vendors	unable to provide feedback related to planning so as not to see the potential for optimization	only 1 procurement vendor	hire expert
			RB1	Mismatch of Minestar features with operational needs	Operational needs are not met	wrong initial identification with stakeholders	detailed and intense discussions with vendors
			RB2	Difficulty integrating Minestar with other existing systems or software	Implementation time frame delayed from initial plan	Needs analysis is not comprehensive, limited customization	detailed and intense discussions with vendors
			RB3	Raw data from minestar cannot be retrieved due to ignorance of the flow of data requests to caterpillar	system is not optimized, operational needs are not met	lack of system understanding, inaccurate data	mapping of raw data that will be needed
			RB4	Build quality of minestar devices has not adjusted to mining operational conditions (rain, heat) for 24 hours	system is not optimized, operational needs are not met	non-comprehensive needs analysis, limited customization	detailed and intense discussion with vendors
	B	Techno risk	RB5	Dependence on vendors for system maintenance and upgrades	system maintenance and upgrades are not time flexible	lack of internal expertise, limited access to system	hire experts
			RC1	Inaccuracies in elevation data or mine planning data	high operational risk, potential for large errors	calibration of survey tools not done regularly	develop SOP related to mine update communication flow chart
			RC2	Unsynchronization between actual data in the field and data in the system	high operational risk, potential for major errors	lack of system understanding, inaccurate data	develop SOP related to mine update communication flow chart
			RC3	The absence of a survey team to update the actual elevation due to a large lot of survey work and a lack of teams	production data inaccuracies, reporting difficulties	lack of internal expertise, limited access to system	hire a special survey team to update minestar data
			RC4	Survey crew is not available due to SIA (sickness, permission, alpha)	production data inaccuracies, reporting difficulties	lack of backup system, inadequate training	develop a work plan with a kruw ratio above 2.9
Internal	C	Internal process failure	RC5	Survey supervisors are busy so they cannot manage raw survey data	production data inaccuracies, reporting difficulties	lack of backup system, inadequate training	hire special survey team to update minestar data
			RD1	Failure of the collision sensor to detect when the unit in front of it stops suddenly	incident occurrence, stop operational	system failure, lack of early mitigation	detailed and intense discussions with vendors
			RD2	AI fatigue alarm failed to read face recognice due to closed camera	incident occurrence, stop operational	operator using barrier/face cover, network closed	detailed and intense discussions with vendors
			RD3	Failure of the system to send an alarm to the Controller when the operator is fatigue	incident occurrence, stop operational	network shut down, network delay	detailed and intense discussion with vendors
	D	Work Safety	RE1	Recruitment of experienced man power is difficult	Lack of experienced personnel, making it slow to adapt	Limited labor market, high competition	Create advertisements for experienced controllers in advance
			RE2	Lack of controllers, data analysts, and supervisors who are familiar with the Minestar system	production data inaccuracies, reporting difficulties	Lack of training, ineffective communication	hire expert
			RE3	Difficulty conducting training at BMB due to the absence of instructors or busy work of instructors or dispatchers who will provide insights	Lack of experienced personnel, slow implementation	Lack of training, ineffective communication	provide specialised BMB trainers for BIB transition
			RE4	Difficulty in changing work patterns from manual to Minestar system	employee resistance, temporary decrease in productivity	Lack of training, ineffective communication	socialisation and intense training
			RE5	Rejection or non-compliance of operators / supervisors with system directions	high operational risk, potential for major errors	Lack of training, ineffective communication	socialisation and intense training
human factor	E	Human resources/empl oyeer risks	RE6	Operators have difficulty understanding the training related to the operation of the minestar dashboard (FMS) in the unit cabin	high operational risk, large potential error	Lack of training, ineffective communication	socialisation and intense training
			RE7	Operational supervisors have difficulty understanding the minestar implementation training	high operational risk, potential for large errors	Lack of training, ineffective communication	socialisation and intense training
			RE8	Many new employees in the controller make communication with old employees, especially supervisors, less smooth.	employee resistance, temporary decrease in productivity	Lack of training, ineffective communication	socialisation and intense training
			RE9	The dominance of manual operations is still high, when there are new field supervisors there are also new adjustments that take time.	employee resistance, temporary decrease in productivity	Lack of training, ineffective communication	socialisation and intense training
			RE10	Differences in systems and methods for employees with experience in dispatchers from previous places so that it takes time to adjust.	delay in problem solving, high cost	Lack of training, ineffective communication	socialisation and intense training
	F	System and equipment disruption or failure	RE11	Employees who manage minestar raw data do not yet exist, or are not yet skilled	shortage of experts, implementation hampered	Limited labor market, high competition	hire expert
			RE12	Lack / absence of man power Procont (production Control) which connects the constraints in the field with the controller's work overlay	delay in troubleshooting, high cost	lack of internal expertise, limited access to systems	hire expert
			RE13	Controller ratio that is not in accordance with the number of Overburden Fleets so that digital production control is not maximized (there is no effective ration calculation)	delayed troubleshooting, high cost	Limited labor market, high competition	hire expert, intense training
			RE14	System misoperation by untrained personnel	high operational risk, potential for major errors	lack of internal expertise, limited access to the system	socialisation and intense training
			RF1	Network Delay/Lag that causes inaccurate unit positioning	time frame delayed from the initial plan	Inadequate network infrastructure, signal interference	detailed and intense discussions with vendors
Process	G	Execution, delivery and process management risks	RF2	Inadequate network coverage throughout the mine area	network lag / weak at certain points	Inadequate network infrastructure, signal interference	detailed and intense discussions with vendors
			RF3	Inappropriate placement of mobile tower rajant network resulting in weak networks	network lag / weak at certain points	no initial planning, discussion with engineering mining	detailed and intense discussions with vendors
			RF4	Placement of tower cars in mine locations that change in short-term planning	minestar operational delay due to having to move locations	no initial planning, discussion with engineering mining	intense discussions on long-term mine plans
			RF5	The power supply of the tower car is shorted or not charged due to weather so that the rajant network is down	minestar operational delay due to power supply repair	Inadequate backup power, wrong initial installation	detailed and intense discussions with vendors
			RF6	minestar operational delay during implementation	minestar operational delay during implementation	Inadequate network infrastructure, signal interference	detailed and intense discussion with vendors
	F	System and equipment disruption or failure	RF7	Connection Network rajant failed to send signals to other tower cars or from units to mobile tower rajant	operational minestar delay during implementation	Inadequate network infrastructure, signal interference	detailed and intense discussion with vendors
			RF8	Solar panel for mobile tower power supply is dirty exposed to dust, broken by a stone so that it cannot supply power	delay operational minestar during implementation	non-routine maintenance of solar panels	mobile tower maintenance schedule planning
			RF9	Mobile tower network shut down due to lightning strike	delay operational minestar during implementation	not equipped with lightning rods	detailed and intense discussion with vendor
			RF10	Mobile tower network shut down due to being hit by other OHT, A28 units due to an incident	delay operational minestar during implementation	mobile tower position close to traffic	assessment of mobile tower placement position
			RF11	Central server electricity supply is cut off data from the field is not recorded	delay operational minestar at the time of implementation	lack of backup system, inadequate network stability	detailed and intense discussion with vendors
Process	G	Execution, delivery and process management risks	RF12	Data is not delivered to the central server due to Maintenance tower central / tower central down	delay operational minestar at the time of implementation	Inadequate backup system, network stability	detailed and intense discussion with vendors
			RF13	Damage to control room equipment or unit on-board devices	delay operational minestar at the time of implementation	errors in the initial installation process, overload power supply	backup device provision
			RF14	Problems with sensors or monitoring equipment in the field	delay operational minestar at the time of implementation	Needs analysis not comprehensive, limited customization	detailed and intense discussion with vendors
			RF15	Radio rig in control ROOM is damaged or lost signal	delay operational minestar at the time of implementation	Inadequate backup system, network stability	provision of backup device
			RF16	CPU is not suitable for minestar application	delay operational minestar at the time of implementation	Needs analysis is not comprehensive, customization is limited	detailed and intense discussion with vendors
	G	Execution, delivery and process management risks	RF17	Build quality of minestar device has not adjusted to mining operational conditions (rain, heat) for 24 hours	delay operational minestar during implementation	Needs analysis is not comprehensive, limited customization	detailed and intense discussion with vendors
			RG1	Temporary decrease in productivity during transition and learning period	Operational losses, decreased efficiency	Lack of training, ineffective communication	making a socialisation and training schadule for employees
			RG2	Ritase data lost when network shut down	high operational risk, potential for major errors	Inadequate backup system, network stability	detailed and intense discussion with vendors
			RG3	Latency / delay in data transmission time from unit - car tower-microSD -Controller - server which causes slow downs	production data inaccuracies, reporting difficulties	Inadequate network infrastructure, signal interference	detailed and intense discussion with vendors
			RG4	AI Rajant network incorrectly predicts the speed of data to the server	production data inaccuracies, reporting difficulties	Inadequate network infrastructure, signal interference	detailed and intense discussion with vendors
Process	G	Execution, delivery and process management risks	RG5	Supervision and decision-making methods are still not adjusted to the minestar.	system not optimized, operational needs not met	lack of system understanding, inaccurate data	socialisation and intense training
			RG6	Over-reliance on a new system that is not yet stable	high operational risk, big potential error	lack of backup system, insufficient training	hire expert
			RG7	Supervisory reporting of hauler lane shifts when haulers are diverted from the designated lane	system not optimized, operational needs not met	Lack of training, ineffective communication	intense socialisation and training
			RG8	Delays in information to operational supervisors when the rajant network is down, resulting in late manual reporting	delay in problem solving, high cost	lack of backup system, insufficient training	socialisation and intense training
			RG9	Operator protests regarding the implemented ritase system (disposal-disposal/front-front) which affects operator payments	high operational risk, large potential error	needs analysis is not comprehensive, customization is limited	intense socialisation and training
	G	Execution, delivery and process management risks	RG10	There is no support tool to move mobile tower networking when moving points	Operational losses, decreased efficiency	needs analysis is not comprehensive, customization is limited	provision of specialised heavy equipment for mobile tower mobilisation
			RG11	If there are more productive fleets optimized when there are haulers standing by, it will affect demotivated excavator operators	Operational losses, decreased efficiency	lack of backup system, insufficient training	socialisation and intense training
			RG12	Crowded radio channels, radio signal loss, short duration on digital radio causes less information to be conveyed.	delay in troubleshooting, high cost	Lack of training, ineffective communication	use of digital radio
			RG13	Operators who forget to press the event button on the dash board of the minestar application unit	high operational risk, high potential for error	lack of backup system, insufficient training	socialisation and intense training
			RG14	Wrong decision making due to misinterpretation of Minestar data	high operational risk, potential for large errors	lack of system understanding, inaccurate data	socialisation and intense training
Process	G	Execution, delivery and process management risks	RG15	Over-reliance on automated systems without verification of actual conditions	high operational risk, potential for large errors	Inadequate network infrastructure, signal interference	hire expert

Figure 2. Risk identification Minestar implementation 2025

From the Minestar implementation risk identification table above, there is 1 risk in the supply chain, 5 risks in technology risk, 5 risks in internal process failure, 3 risks in work safety, 14 risks in human resource/employee risk, 17 risks in system and equipment disruption or failure and 15 risks in Execution, delivery, and process management risks with a total of 60 risks identified.

Data Processing

Risk Analysis using the FMEA method

After identifying the risks in the 2025 Minestar implementation, the next step is to analyze the risks and make a list of risks based on the Risk Priority Number (RPN) value, this value is obtained by calculating the multiplication of the severity (S), Occurrence (O) and Detection (D) values with a scale of 1-10 which confirms the risk value in tables 3, 4 and 5. The next step is to calculate the average RPN value of each of the risk criteria, which has been agreed upon with the FGD on stakeholders this way is done to determine the lower limit of the critical risk value whose RPN value is above the critical risk value will be a risk priority for risk treatment.

The RPN value itself will be used as the first step for risk evaluation and risk treatment decision-making. The filling of severity, occurrence, and detection values is obtained using FGDs, semi-structured interviews, and benchmarking to PT CK site BMB, this benchmarking is a factor in providing very important insights and views regarding their experience in using Minestar technology and how they deal with and solve problems faced, as well as insights related to the probability of risk occurrence if this Minestar will be applied at BIB. Risk analysis using FMEA will be shown in Figure 3 below.

Business Context	Code	Criterion	Sub-criterion Code	Sub-Criterion (Potential Failure Mode)	Potential failure effect	S	Potential Cause	O	Initial treatment	D	RPN			
Eksternal	A	Supply chain risks	RA1	Dependence on vendors	unable to provide feedback related to planning so as not to see the potential for optimization	6	only 1 procurement vendor	5	hire expert	1	37.1193416			
			RB1	Mismatch of Minestar features with operational needs	Operational needs are not met	5	wrong initial identification with stakeholders	2	detailed and intense discussions with vendors	2	17			
			RB2	Difficulty integrating Minestar with other existing systems or software	Implementation time frame delayed from initial plan	6	Needs analysis is not comprehensive, limited customization	4	detailed and intense discussions with vendors	5	119			
			RB3	Raw data from minestar cannot be retrieved due to ignorance of the flow of data requests to caterpillar	system is not optimized, operational needs are not met	7	lack of system understanding, inaccurate data	3	mapping of raw data that will be needed	2	33			
			RB4	Build quality of minestar devices has not adjusted to mining operational conditions (rain, heat) for 24 hours	system is not optimized, operational needs are not met	7	non-comprehensive needs analysis, limited customization	4	detailed and intense discussion with vendors	2	59			
	B	Techno risk	RB5	Dependence on vendors for system maintenance and upgrades	system maintenance and upgrades are not time flexible	6	lack of internal expertise, limited access to system	3	hire experts	2	31			
			Average			6.21		3.11		2.43	46.64			
			Internal	C	Internal process failure	RC1	Inaccuracies in elevation data or mine planning data	high operational risk, potential for large errors	7	calibration of survey tools not done regularly	3	develop SOP related to mine update communication flow chart	3	53
						RC2	Unynchronization between actual data in the field and data in the system	high operational risk, potential for major errors	6	lack of system understanding, inaccurate data	4	develop SOP related to mine update communication flow chart	3	70
						RC3	The absence of a survey team to update the actual elevation due to a large lot of survey work and a lack of teams	production data inaccuracies, reporting difficulties	7	lack of internal expertise, limited access to system	3	hire a special survey team to update minestar data	2	44
RC4	Survey crew is not available due to SIA (sickness, permission, alpha)	production data inaccuracies, reporting difficulties				5	lack of backup system, inadequate training	2	develop a work plan with a know ratio above 2.9	1	12			
RC5	Survey supervisors are busy so they cannot manage raw survey data	production data inaccuracies, reporting difficulties				5	lack of backup system, inadequate training	3	hire special survey team to update minestar data	2	20			
Average				5.81		2.85		2.19	36.22					
D	Work Safety	RD1		Failure of the collision sensor to detect when the unit in front of it stops suddenly	incident occurrence, stop operational	6	system failure, lack of early mitigation	3	detailed and intense discussions with vendors	4	54			
		RD2		AI fatigue alarm failed to read face recognition due to closed camera	incident occurrence, stop operational	5	operator using barrier/face cover, camera closed	3	detailed and intense discussions with vendors	3	45			
		RD3		Failure of the system to send an alarm to the Controller when the operator is fatigue	incident occurrence, stop operational	5	network shut down, network delay	2	detailed and intense discussion with vendors	4	43			
Average				5.27		2.69		3.35	47.81					
human factor	E	Human resources/employee risks	RE1	Recruitment of experienced man power is difficult	Lack of experienced personnel, making it slow to adapt	7	Limited labor market, high competition	5	Create advertisements for experienced controllers in advance	4	144			
			RE2	Lack of controllers, data analysts, and supervisors who are familiar with the Minestar system	production data inaccuracies, reporting difficulties	6	Lack of training, ineffective communication	3	hire expert	1	29			
			RE3	Difficulty conducting training at BMB due to the absence of instructors or busy work of instructors or dispatchers who will provide insights	Lack of experienced personnel, slow implementation	6	Lack of training, ineffective communication	4	provide specialised BMB trainers for B1B transition	1	32			
			RE4	Difficulty in changing work patterns from manual to Minestar system	employee resistance, temporary decrease in productivity	6	Lack of training, ineffective communication	5	socialisation and intense training	3	95			
			RE5	Rejection or non-compliance of operators / supervisors with system directions	high operational risk, potential for major errors	7	Lack of training, ineffective communication	4	socialisation and intense training	2	61			
			RE6	Operators have difficulty understanding the training related to the operation of the minestar dashboard (FMS) in the unit cabin	high operational risk, large potential error	5	Lack of training, ineffective communication	4	socialisation and intense training	3	54			
			RE7	Operational supervisors have difficulty understanding the minestar implementation training	high operational risk, potential for large errors	6	Lack of training, ineffective communication	3	socialisation and intense training	2	44			
			RE8	Many new employees in the controller make communication with old employees, especially supervisors, less smooth	employee resistance, temporary decrease in productivity	5	Lack of training, ineffective communication	4	socialisation and intense training	2	43			
			RE9	The dominance of manual operators is still high, when there are new field supervisors there are also new adjustments that take time	employee resistance, temporary decrease in productivity	5	Lack of training, ineffective communication	3	socialisation and intense training	2	35			
			RE10	Differences in systems and methods for employees with experience in dispatchers from previous places so that it takes time to adjust	delay in problem solving, high cost	4	Lack of training, ineffective communication	3	socialisation and intense training	1	18			
			RE11	Employees who manage minestar raw data do not yet exist, or are not yet skilled	shortage of experts, implementation hampered	7	Limited labor market, high competition	4	hire expert	2	62			
			RE12	Lack / absence of man power Procont (production Control) which connects the constraints in the field with the controller's work overlay	delay in troubleshooting, high cost	4	lack of internal expertise, limited access to systems	2	hire expert	1	13			
			RE13	Controller ratio that is not in accordance with the number of Overburden Fleets so that digital production control is not maximized (there is no effective ration calculator)	delayed troubleshooting, high cost	7	Limited labor market, high competition	4	hire expert, intense training	2	54			
			RE14	System misoperation by untrained personnel	high operational risk, potential for major errors	5	lack of internal expertise, limited access to the system	4	socialisation and intense training	3	63			
Average			5.73		3.70		2.33	49.31						
Process	F	System and equipment disruption or failure	RF1	Network Delay/Lag that causes inaccurate unit positioning	time frame delayed from the initial plan	4	Inadequate network infrastructure, signal interference	3	detailed and intense discussions with vendors	3	37			
			RF2	Inadequate network coverage throughout the mine area	network lag / weak at certain points	8	Inadequate network infrastructure, signal interference	3	detailed and intense discussions with vendors	2	32			
			RF3	Inappropriate placement of mobile tower rajant network resulting in weak networks	network lag / weak at certain points	7	no initial planning, discussion with engineering mining	2	detailed and intense discussions with vendors	1	17			
			RF4	Placement of tower cars in mine locations that change in short-term planning	minestar operational delay due to having to move locations	5	no initial planning, discussion with engineering mining	3	intense discussions on long-term mine plans	2	36			
			RF5	The power supply of the tower car is shorted or not charged due to weather so that the rajant network is down	minestar operational delay due to power supply repair	5	Inadequate backup power, wrong initial installation	2	detailed and intense discussions with vendors	3	37			
			RF6	Network rajant down so that the system does not run	minestar operational delay during implementation	8	Inadequate network infrastructure, signal interference	2	detailed and intense discussion with vendors	2	30			
			RF7	Connection Network rajant failed to send signals to other tower cars or from units to mobile tower rajant	operational minestar delay during implementation	5	Inadequate network infrastructure, signal interference	3	detailed and intense discussion with vendors	2	31			
			RF9	Mobile tower network shut down due to lightning strike	delay operational minestar during implementation	7	not equipped with lightning rods	2	detailed and intense discussion with vendor	2	26			
			RF10	Mobile tower network shut down due to being hit by other OHT, A2B units due to an incident	delay operational minestar during implementation	8	mobile tower position close to traffic	1	assessment of mobile tower placement position	2	24			
			RF11	Central server electricity supply is cut off data from the field is not recorded	delay operational minestar at the time of implementation	8	lack of backup system, inadequate training	2	detailed and intense discussion with vendors	3	48			
			RF12	Data is not delivered to the central server due to Maintenance tower central / tower central down	delay operational minestar at the time of implementation	5	Inadequate backup system, network stability	2	detailed and intense discussion with vendors	2	24			
			RF13	Damage to control room equipment or unit on-board devices	delay operational minestar at the time of implementation	5	errors in the initial installation process, overload power supply	3	backup device provision	3	41			
			RF14	Problems with sensors or monitoring equipment in the field	delay operational minestar at the time of implementation	5	Needs analysis is not comprehensive, limited customization	3	detailed and intense discussion with vendors	3	32			
			RF15	Radio rig in control ROOM is damaged or lost signal	delay operational minestar at the time of implementation	7	Inadequate backup system, network stability	3	provision of backup device	2	30			
			RF16	CPU is not suitable for minestar application	delay operational minestar at the time of implementation	6	Needs analysis is not comprehensive, customization is limited	2	detailed and intense discussion with vendors	1	13			
			Average			6.19		2.43		2.10	31.64			
Execution, delivery and process management risks	G		RG1	Temporary decrease in productivity during transition and learning period	Operational losses, decreased efficiency	5	Lack of training, ineffective communication	4	making a socialisation and training schude for employees	3	54			
			RG2	Rtase data lost when network shut down	high operational risk, potential for major errors	8	inadequate backup system, network stability	3	detailed and intense discussion with vendors	3	63			
			RG3	Latency delay in data transmission time from unit-car tower-microSD - Controller - server which causes slow downs	production data inaccuracies, reporting difficulties	5	Inadequate network infrastructure, signal interference	2	detailed and intense discussion with vendors	2	18			
			RG4	AI Rajant network incorrectly predicts the speed of data to the server	production data inaccuracies, reporting difficulties	5	Inadequate network infrastructure, signal interference	2	detailed and intense discussion with vendors	2	21			
			RG5	Supervision and decision-making methods are still not adjusted to the minestar.	system not optimized, operational needs not met	5	lack of system understanding, inaccurate data	4	socialisation and intense training	2	34			
			RG6	Over-reliance on a new system that is not yet stable	high operational risk, big potential error	6	lack of backup system, insufficient training	3	hire expert	2	34			
			RG7	Supervisory reporting of hauler lane shifts when haulers are diverted from the designated lane	system not optimized, operational needs not met	5	Lack of training, ineffective communication	3	intense socialisation and training with vendors	3	45			
			RG8	Delays in information to operational supervisors when the rajant network is down, resulting in late manual reporting	delay in problem solving, high cost	6	lack of backup system, insufficient training	2	socialisation and intense training	2	27			
			RG9	Operator protests regarding the implemented rtase system (disposal-disposal/front-front) which affects operator payments	high operational risk, large potential error	6	needs analysis is not comprehensive, customization is limited	5	intense socialisation and training with vendors	2	69			
			RG10	There is no support tool to move mobile tower networking when moving points	Operational losses, decreased efficiency	6	needs analysis is not comprehensive, customization is limited	2	provision of specialised heavy equipment for mobile tower mobilisation	2	21			
			RG11	If there are more productive fleets optimized when there are haulers standing by, it will affect demotivated excavator operators	Operational losses, decreased efficiency	3	lack of backup system, insufficient training	2	socialisation and intense training	2	12			
			RG12	Crowded radio channels, radio signal loss, short duration on digital radio causes less information to be conveyed.	delay in troubleshooting, high cost	6	Lack of training, ineffective communication	4	use of digital radio	2	36			
			RG13	Operators who forget to press the event button on the dash board of the minestar application unit	high operational risk, high potential for error	5	lack of backup system, insufficient training	5	socialisation and intense training	3	80			
			RG14	Wrong decision making due to misinterpretation of Minestar data	high operational risk, potential for large errors	5	lack of system understanding, inaccurate data	3	socialisation and intense training	3	50			
			RG15	Over-reliance on automated systems without verification of actual conditions	high operational risk, potential for large errors	4	Inadequate network infrastructure, signal interference	4	hire expert	3	60			
Average			5.43		3.19		2.30	39.88						

Figure 3. Risk Analysis Minestar Implementation

From figure 3, the RPN value is obtained from the highest to the lowest from the calculation of the multiplication of severity, occurrence, and detection, from the risk analysis table, the highest average RPN value is obtained in human resources/employee risk criteria with an average RPN value of 49,31, next is for the risk criteria for work safety which has an average RPN value of 47,51, in the third rank is techno risks with an average RPN value of 46,84, for the fourth rank execution, delivery and process risks with an average RPN value of 39,88 while for Supply chain and internal process failure risk respectively in the 5th and 6th rank with an average RPN value of 37,12 and 36,22 and in the 7th rank is system & equipment disruption risk with an average value of 31,64.

By obtaining the average value of each risk criterion, the next step is to determine the critical value of the risk of each criterion; this critical value will be the lower / lower limit of the risk value, which will be critical if it is above the threshold. The calculation to get the critical value of risk is with the following formula and calculation:

$$\begin{aligned} \text{Limit value/critical value} &= (\sum \text{RPN Average Risk Criterion}) / (\text{Total Risk Criterion}) \\ &= 288,5/7 \\ &= 41,21 \end{aligned}$$

Table 8. Critical Value

Code	Criterion	S	O	D	RPN
E	Human resources/employee risks	6.7	3.7	2.3	49.31
D	Work safety	5.3	2.7	3.4	47.51
B	Techno risk	6.2	3.1	2.4	46.84
G	Execution, delivery and process management	6.4	3.2	2.3	39.88
A	Supply chain risks	6.1	4.6	1.7	37.12
C	Internal process failure	5.8	2.9	2.2	36.22
F	System and equipment disruption or failure	8.2	2.4	2.1	31.64
Total					288.52

From Table 8, the critical risk value is obtained which is the lower limit of a risk that can be considered critical. From the table, it can be seen that the risk criteria that are colored red 3 risks criteria have an average RPN value above the critical value, namely Human resources/employee, work safety, and techno risk. These three critical risks will later become the basis for management decision-making for risk-handling priorities.

Risk matrix mapping and 3D visualization of risk matrix

After the weight of the risk sub-criteria is obtained from the risk analysis with FMEA, the next step is to map the risk matrix on each risk sub-criteria by looking at the Severity, Occurrence, and detection values. the categorization of each risk sub-criteria value has been explained in Tables 3, 4, and 5 in the previous discussion. The coloring of each level of risk value will make it easier for safeguards to see the risk value, in this study the authors have discussed through FGDs with stakeholders adding color information, namely at ratings 1-3 will be given additional green,

4-6 will be given yellow, 7-8 will be given orange and 9-10 will be given red. for red, RPN values will be given to values above the critical risk value of 41,21. if the risk analysis value is more than 41,21 it will be red (very high risk), the RPN value between 30 – 41 will be orange (High risk), the RPN value between 20 – 29 will be yellow (medium risk) and if the RPN value is below 19, it will be green (low risk).

Each risk in the sub-criteria will be written in the form of a code consisting of the risk criteria code and then the risk sub-criteria code. The following is the risk mapping:

Sub-criterion Code	Sub-Criterion (Potensial Faillure Mode)	S	O	D	RPN
RE1	Recruitment of experienced man power is difficult	7	5	4	144
RB2	Difficulty integrating Minestar with other existing systems or software	6	4	5	119
RE4	Difficulty in changing work patterns from manual to Minestar system	6	5	3	95
RG13	Operators who forget to press the event button on the dash board of the minestar application unit	5	5	3	80
RC2	Unsynchronization between actual data in the field and data in the system	6	4	3	70
RG9	Operator protests regarding the implemented ritase system (disposal-disposal/front-front) which affects operator payments	6	5	2	69
RG2	Ritase data lost when network shut down	8	3	3	63
RE14	System misoperation by untrained personnel	5	4	3	63
RE11	Employees who manage minestar raw data do not yet exist, or are not yet skilled	7	4	2	62
RE5	Rejection or non-compliance of operators / supervisors with system directions	7	4	2	61
RG15	Over-reliance on automated systems without verification of actual conditions	6	4	3	60
RB4	Build quality of minestar devices has not adjusted to mining operational conditions (rain, heat) for 24 hours	7	4	2	59
RG1	Temporary decrease in productivity during transition and learning period	5	4	3	54
RE13	Controller ratio that is not in accordance with the number of Overburden Fleets so that digital production control is not maximized	7	4	2	54
RE6	Operators have difficulty understanding the training related to the operation of the minestar dashboard (FMS) in the unit cabin	5	4	3	54
RD1	Failure of the collision sensor to detect when the unit in front of it stops suddenly	6	3	4	54
RC1	Inaccuracies in elevation data or mine planning data	7	3	3	53
RG14	Wrong decision making due to misinterpretation of Minestar data	5	3	3	50
RF11	Central server electricity supply is cut off data from the field is not recorded	8	2	3	48
RG7	Supervisory reporting of hauler lane shifts when haulers are diverted from the designated lane	5	3	3	45
RD2	AI fatigue alarm failed to read face recomice due to closed camera	5	3	3	45
RC3	The absence of a survey team to update the actual elevation due to a large lot of survey work and a lack of teams	7	3	2	44
RE8	Many new employees in the controller make communication with old employees, especially supervisors, less smooth.	5	4	2	44
RE7	Operational supervisors have difficulty understanding the minestar implementation training	6	3	2	43
RD3	Failure of the system to send an alarm to the Controller when the operator is fatigue	5	2	4	43
RF13	Damage to control room equipment or unit on-board devices	5	3	3	41
RA1	Dependence on vendors	6	5	1	37
RF5	The power supply of the tower car is shorted or not charged due to weather so that the rajant network is down	5	2	3	37
RF1	Network Delay/Lag that causes inaccurate unit positioning	4	3	3	37
RG12	Crowded radio channels, radio signal loss, short duration on digital radio causes less information to be conveyed.	6	4	2	36
RF4	Placement of tower cars in mine locations that change in short-term planning	5	3	2	36
RE9	The dominance of manual operations is still high, when there are new field supervisors there are also new adjustments that take time.	5	3	2	35
RG5	Supervision and decision-making methods are still not adjusted to the minestar.	5	4	2	34
RG6	Over-reliance on a new system that is not yet stable	6	3	2	34
RB3	Raw data from minestar cannot be retrieved due to ignorance of the flow of data requests to caterpillar	7	3	2	33
RF2	Inadequate network coverage throughout the mine area	8	3	2	32
RF14	Problems with sensors or monitoring equipment in the field	5	3	3	32
RE3	Difficulty conducting training at BMB due to the absence of instructors or busy work of instructors or dispatchers who will provide insight	6	4	1	32
RF7	Connection Network rajant failed to send signals to other tower cars or from units to mobile tower rajant	5	3	2	31
RB5	Dependence on vendors for system maintenance and upgrades	6	3	2	31
RF6	Network rajant down so that the system does not run	8	2	2	30
RF15	Radio rig in control ROOM is damaged or lost signal	7	3	2	30
RE2	Lack of controllers, data analysts, and supervisors who are familiar with the Minestar system	6	3	1	29
RG8	Delays in information to operational supervisors when the rajant network is down, resulting in late manual reporting	6	2	2	27
RF9	Mobile tower network shut down due to lightning strike	7	2	2	26
RF12	Data is not delivered to the central server due to Maintenance tower central / tower central down	5	2	2	24
RF10	Mobile tower network shut down due to being hit by other OHT, A2B units due to an incident	8	1	2	24
RG10	There is no support tool to move mobile tower networking when moving points	6	2	2	21
RG4	AI Rajant network incorrectly predicts the speed of data to the server	5	2	2	21
RC5	Survey supervisors are busy so they cannot manage raw survey data	5	3	2	20
RG3	Latency /delay in data transmission time from unit - car tower-microSD -Controller - server which causes slow downs	5	2	2	18
RE10	Differences in systems and methods for employees with experience in dispatchers from previous places so that it takes time to adjust.	4	3	1	18
RB1	Mismatch of Minestar features with operational needs	5	2	2	17
RF3	Inappropriate placement of mobile tower rajant network resulting in weak networks	7	2	1	17
RE12	Lack / absence of man power Procont (production Control) which connects the constraints in the field with the controller's work overlay	4	2	1	13
RF16	CPU is not suitable for minestar application	6	2	1	13
RG11	If there are more productive fleets optimized when there are haulers standing by, it will affect demotivated excavator operators	3	2	2	12
RC4	Survey crew is not available due to SIA (sickness, permission, alpha)	5	2	1	12

Figure 4. Mapping Risk matrix's Minestar implementation

From the risk mapping, a 3D visualization of the risk matrix on the implementation of Minestar at BIB is obtained, then from the mapping, a 3-dimensional visualization of the risk

matrix is obtained, with the determination of the x and z axes being occurrence and Severity because the two levels are inversely proportional, where when the probability of occurrence is higher, it will be easier to detect, then the y axis is Detection.

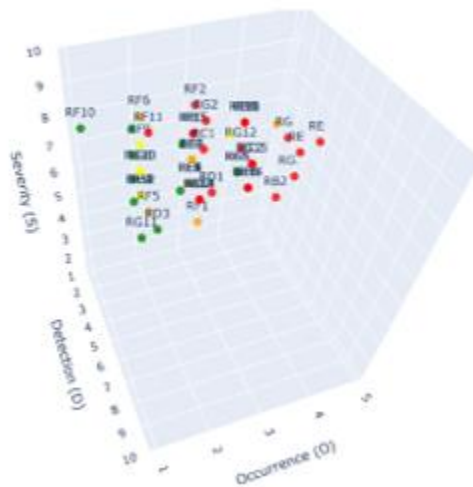


Figure 5. 3D Risk matrix Minestar implementation PT. BIB

Risk Treatment (Risk Mitigation)

From the results of the FMEA analysis in Table 9, the risk priority number of each risk in the implementation Minestar is obtained, from this value it can be determined which risks are a priority for mitigation. For the risks in the Minestar implementation above in this discussion, mitigation will be carried out on risks that have the top 5 rankings for the RPN value, from Table 9 The risks with the top 5 rankings are System miss operation by untrained personnel, Operators who forget to press the event button on the dashboard of the Minestar application unit, Failure of the collision sensor to detect when the unit in front of it stops suddenly, Ritase data lost when the network is shut down and Difficulty in changing work patterns from manual to Minestar system. The following are the mitigation steps for each of these risks:

a. Recruitment of experienced manpower is difficult (Code RE1)

This risk has the highest RPN value with a value of 144, where the Severity value is 7, the Occurrence value is 5, and the detection value is 4. Recruitment of experienced manpower is identified as likely to occur during the initial transition period of Minestar implementation; this risk has a very high-risk category and must be mitigated immediately at the beginning to minimize the possibility of occurrence during the implementation period. The initial handling in the FMEA method is to make an advertisement to find an experienced controller. After conducting FGDs with stakeholders who are directly involved and insights from benchmarking to CK-BMB, the mitigation efforts made are by mapping manpower needs based on experience in previous dispatchers, looking for manpower experienced in the use of similar technologies such as hexagon, data mine, existing manpower conducting training at CK-BMB.

b. Difficulty integrating Minestar with other existing systems or software

This risk has an RPN value of 119, where the Severity value is 6, the Occurrence value is 4, and the detection value is 5. The risk of difficulty integrating the system in Minestar with the existing system, the risk was identified as likely to occur during the initial implementation of Minestar, this risk has a very high-risk category and must be mitigated immediately at the beginning to minimise the possibility of occurrence during implementation. The initial treatment in the FMEA method is a detailed and intense discussion with the vendor. After conducting FGDs with stakeholders directly involved and insights from benchmarking to CK-BMB, the mitigation efforts made are identification of existing systems, then bringing in the caterpillar team to synchronize the current system, making a list of device or system changes that potentially cannot be synchronized and must be fulfilled before the end of 2024.

c. Difficulty in changing work patterns from manual to Minestar system

This risk has an RPN value of 95, where the Severity value is 6, the Occurrence value is 5, and the detection value is 3. Difficulties in adaptation from the manual system to the Minestar system will be prone to occur at the beginning of the transition to implementing the Minestar system, but it does not rule out the possibility that it will still occur during the journey of using the Minestar with a smaller possibility (occurs in new employees). this risk has a very high-risk category and must be mitigated immediately at the beginning to minimize the possibility of occurrence during implementation, the initial treatment in the FMEA method is socialization and intense training. After conducting FGDs with stakeholders directly involved and insights from benchmarking to CK-BMB, the mitigation effort is to conduct training on the use of Minestar from the beginning of November 2024 by making a training schedule for each operator with a maximum of 30 operators, operators who have been trained will be refreshed training periodically and scheduled and a survey is conducted to see employee acceptance of the Minestar system quantitatively, make banners, banners or posters online or physically sent via WA group, in physical form installed to the location where operators gather at the beginning of the shift or the end of the shift (Change shift Area) related to the positive impact of using the Minestar system on production and safety.

d. Operators who forget to press the event button on the dashboard of the Minestar application unit

This risk has an RPN value of 300, where the Severity value is 10, the Occurrence value is 6, and the detection value is 5. For operators who forget to press the dashboard button at the beginning of the shift or even change events during the shift, the risk is identified as likely to occur during the trip using this Minestar. The possibility will be high at the beginning of the implementation transition. this risk has a very high-risk category and must be mitigated immediately at the beginning to minimize the possibility of occurrence during implementation, the initial treatment in the FMEA method is socialization and intense training. After conducting FGDs with stakeholders who are directly involved and insights from

benchmarking to CK-BMB, the mitigation efforts made are to conduct training on the use of Minestar from the beginning of November 2024 by making a training schedule for each operator with a maximum number of 30 operators, operators who have been trained will be refreshed training regularly and scheduled by looking at the value of understanding quantitatively, making banners, banners or posters online or physically sent via WA group, in physical form installed to the location where operators gather at the beginning of the shift or the end of the shift (Change shift Area).

e. Asynchronization between actual data in the field and data in the system

This risk has an RPN value of 70, where the Severity value is 6, the Occurrence value is 4 and the detection value is 3. Inconsistency between data in the field and data in the system, this risk is identified as likely to occur during the trip using Minestar; this risk has a high-risk category and must be mitigated immediately at the beginning to minimize the possibility of occurrence during implementation. The initial treatment in the FMEA method is to develop SOPs related to the mine renewal communication flow chart. After conducting FGDs with stakeholders directly involved and insights from benchmarking to CK-BMB, the mitigation efforts made are to update field data such as survey data, face position units periodically (outlined in the SOP), specializing manpower who update field data, specific communication lines between operational supervisors and controllers when changes occur in the field.

CONCLUSION

The transition from manual to automatic real-time systems, such as Minestar at BIB in 2025, presents a complex challenge that requires thorough risk mitigation. Early mitigation is essential to identify and manage potential risks before the system's implementation. However, the lack of documentation on risk identification at BIB led researchers to analyze and review risk management related to Minestar using the SNI ISO 31000 risk management framework. Through a combination of FMEA analysis, FGDs, semi-structured interviews, and benchmarking, risk criteria were assessed and categorized by their Risk Priority Number (RPN). The analysis revealed three critical risk areas: human resources, work safety, and technology, all classified as very high risk. Risk mapping in a 3D matrix helped prioritize these risks, and mitigation strategies were developed for the top five risks, including recruitment challenges and system integration difficulties.

While the study provides valuable insights for management to prioritize risks and allocate resources effectively, it has limitations. The research focused primarily on operational risks, excluding financial and strategic aspects, and relied on subjective assessments from stakeholders. Additionally, the static model requires continuous updates to reflect changing project conditions and insights from similar technologies. Future research should integrate financial and strategic aspects into the risk assessment model for a more comprehensive approach. Moreover, developing a dynamic model capable of adjusting real-time risk

assessments and evaluating the effectiveness of the proposed mitigation strategies after the Minestar implementation will be critical for long-term success.

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