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Risk Mitigation in MRO Spare Parts Procurement Using House of Risk and FMEA
(Case Study: PT. Pupuk Iskandar Muda)

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Abstract

The procurement of *Maintenance, Repair, and Overhaul* (*MRO*) spare parts is critical for ensuring factory reliability, yet it is fraught with supply chain risks that can disrupt operations. PT. Pupuk Iskandar Muda faces challenges such as delays in spare parts delivery and inefficiencies in procurement processes, which negatively impact production. This study aims to identify operational risks in *MRO* spare parts procurement and develop mitigation strategies using the *House of Risk* (*HOR*) method and *Failure Mode Effect Analysis* (*FMEA*). Data were collected through interviews and questionnaires from key departments and analyzed using qualitative and quantitative approaches, including severity, probability, and correlation assessments. The study identified 26 risk events and 25 risk agents, with 14 priority risk agents contributing to 81.32% of the total risk exposure. Nine key mitigation actions were formulated, such as enhancing planning performance, improving demand forecasting, and standardizing communication protocols with partners. The integration of *HOR* and *FMEA* provided a robust framework for proactive risk management. Findings highlight the importance of targeted mitigation strategies to enhance supply chain resilience and minimize operational disruptions. This research offers practical implications for PT. Pupuk Iskandar Muda and similar industries by providing actionable insights to optimize spare parts procurement and maintain operational continuity.

Keywords: Supply Chain, HOR, Risk Agent, ARP, Mitigation Action

INTRODUCTION

The development of the chemical industry in Indonesia is progressing rapidly (Lubis et al., 2022). Chemical industry development activities in Indonesia are directed to improve national capabilities in meeting the needs for chemicals in daily life, particularly in the fields of agriculture and other food sectors (Aswicahyono et al., 2011; Hadiyanto & Irianto, 2021). In the face of increasing business competition, especially in the fertilizer and petrochemical industries, companies are not only focusing on investing in new factory construction, factory reactivation, and factory revitalization to improve efficiency (Darmastuti et al., 2020; Firdaus et al., 2022), but are also implementing numerous internal improvements to make the supply chain process more effective and efficient (Hosseini et al., 2018; Chopra & Meindl, 2019), especially in the procurement of factory parts for Maintenance, Repair & Overhaul (MRO) needs as a means to maintain factory efficiency (Waeyenbergh & Pintelon, 2002; Bouslah et al., 2018).

Spare parts inventory management is crucial for companies that rely on continuous machinery or equipment operation. The reliability of industrial equipment decreases over time with usage, so at certain points, equipment must be maintained or even replaced (Jackson & Pascual, 2008). One form of equipment maintenance is the immediate replacement of damaged equipment to prevent prolonged operational downtime. Equipment shutdowns can result in unnecessary costs, making the supply of spare parts critical and necessitating careful planning and control to avoid shortages or unavailability.

In line with the company's vision and mission to become a competitive fertilizer and petrochemical company, it is necessary for companies to consistently pay attention to supply chain management both at the macro level and within each work unit in more detail. Effective supply chain design ensures not only operational efficiency but also strategic responsiveness to dynamic market conditions (Christopher & Peck, 2004; Seuring & Müller, 2008). This approach enhances the company's resilience to disruptions or risks of uncertainty, both internally and externally (Sheffi & Rice, 2005; Ivanov et al., 2014). Integrating risk management within supply chains can significantly reduce vulnerabilities, especially in industries dependent on raw materials and global logistics (Tang, 2006; Pettit et al., 2010).

The benefits of supply chain management in a company are significant, including improving service, increasing customer satisfaction, boosting revenue, reducing operational costs, and strengthening the company's capabilities. These benefits illustrate the various advantages that can be achieved if the supply chain is managed effectively. Therefore, robust supply chain management is indispensable for any company.

The supply chain process for spare parts procurement begins with the Factory Maintenance Planning work unit, proceeds to the Receipt & Warehousing Planning work unit, which manages inventory, and then continues to the Procurement work unit as the implementing unit for the procurement of goods/services. Afterward, it returns to the Receipt & Warehousing Planning work unit, and finally, once the goods are received, the process is completed by the Finance work unit handling payment.

In the Procurement Planning work unit, it is essential to effectively manage the supply chain process for parts procurement, beginning with the planning of spare parts purchases and followed by the procurement process, with a maximum service time of 54 calendar days from the receipt of the purchase request document to the issuance of the purchase order to partners/vendors. Ensuring the establishment of reliable supply chain management in the procurement process, including identifying and managing all potential risks, is necessary to prevent them from becoming obstacles.

One of the risk events in the procurement supply chain experienced by the Procurement work unit is the delay in issuing purchase orders, which prolongs the delivery time of spare parts to the warehouse. As a result, the spare parts received by the Planning, Acceptance & Warehousing work unit do not match the required dates for replacement or repair work planned by the Maintenance Planning work unit, affecting equipment reliability and potentially disrupting production and resulting in lost revenue opportunities for the company.

The Procurement work unit is responsible for the procurement process of goods/services, with initial demand sourced from the Receipt & Warehousing Planning work unit and the Maintenance Planning work unit. Generally, the supply chain workflow involves identifying the quantity of needs, specifying demand, determining the budget or estimated purchase price, selecting partners or suppliers, negotiating and managing contracts or purchase orders, expediting and controlling the delivery of goods, and evaluating partner or supplier performance.

To date, the Receipt & Warehousing Planning and Procurement work units have received numerous complaints from the Maintenance Planning work unit regarding the excessive duration of the spare parts procurement process, which often exceeds the maximum service time set by management—54 calendar days from the receipt of the purchase request to the issuance of the purchase order to partners/vendors. This delay causes spare parts delivery by the Materials & Warehousing work unit to be late and not in accordance with the dates required for replacement or repair work planned by the Maintenance Planning work unit. Currently, the company has implemented general risk management, but for the Procurement work unit, risk management has not been felt to be sufficiently appropriate, as it only addresses issues perceived to occur at certain times and has not been identified using the *Supply Chain Risk Management* (*SCRM*) approach.

Research on supply chain risk management using the *House of Risk* (*HOR*) method has been conducted in several studies, including by Ratna Purwaningsih, Christine Nauli Ibrahim, and Novie Susanto (2021), who applied the *House of Risk* method to the supply chain of pulp industry production material procurement, and by I. N. Pujawan and L. H. Geraldin, "House of Risk: A Model For Proactive Supply Chain Risk Management," *Journal of Business Process Management*, vol. 15, no. 6, pp. 953-967, 2009.

Based on the above, this study will analyze risk events, risk agents, and priority risk agents that trigger risks in the supply chain process of factory parts procurement using the *House of Risk* (*HOR*) tools approach. The aim is to prevent or reduce the likelihood of risk agent occurrence and to formulate actions for system improvement in the supply chain process of factory parts procurement within the company.

RESEARCH METHODS

The research utilizes data officially obtained from PT Pupuk Iskandar Muda's Department of Receipt Planning & Warehousing and Department of Procurement of Goods and Services, focusing on the supply chain process for *Maintenance, Repair & Overhaul* (*MRO*) materials procurement of critical factory spare parts. The study examines key work units involved in procurement processes, including Goods & Services Procurement, Receipt and Warehousing Planning, Maintenance Planning, and the Reliability Section, with data collection scheduled for May 2024. The company currently employs the SAP *Enterprise Resource Planning* (*ERP*) system to manage integrated operational activities, which enhances data management efficiency and overall business performance, while the procurement flow follows the structured process illustrated in Figure 3.1.

Data collection combines literature studies with primary and secondary data gathering, employing the *Criticality Rank Assessment* method based on *Failure Mode Effect Analysis* (*FMEA*) to evaluate equipment risks and the *House of Risk* (*HOR*) method for mitigation analysis. Qualitative data is analyzed through discussions and interviews with relevant work units to examine historical events and risk causes, while quantitative analysis applies FMEA to assess the severity and occurrence frequency of equipment failures. Additionally, HOR Phase 1 identifies risk agent-event relationships and prioritizes them using *Aggregate Risk Potential* (*ARP*) values, followed by HOR Phase 2 to determine mitigation strategies through preventive actions.

The integrated approach of qualitative and quantitative methods ensures comprehensive risk assessment and mitigation planning. By combining FMEA's technical evaluation with HOR's structured risk management framework, the study provides actionable insights into spare parts procurement risks. This dual methodology not only identifies critical failure points but also establishes prioritized preventive measures, enhancing the reliability and efficiency of PT Pupuk Iskandar Muda's supply chain operations for critical spare parts.

RESULTS AND DISCUSSION

Criticality Ranking based on Failure Mode Effect Analysis on Spare Parts Policy Stock

C02 Resiprocating Compressor, GTG and Syn Gas Turnine equipment in the factory are some of the equipment that is included in the vital (critical) criteria based on their function to factory operations. As in the CO2 Compressor functions to transfer CO2 from the Ammonia-1 Plant to the Urea-1 Plant synthesis system, if this equipment is not available, it will result in the operation of Urea 1 stop (shutdown). Identification of MRO spare parts (stock) needs to be carried out to prevent errors in procurement planning that are directly related to factory operations so that a criticality analysis of MRO spare parts is carried out based on the Failure mode of the spare part. This assessment includes several analysis criteria (Multi Criteria Analysis).

Table 1. Recommendations from Parts Classification

Maintenance	Logistics	Spare Parts Category	Criticality Level	Strategy
A	A	AA	H	Availability of goods in the warehouse is required
A	B	AB	H	Availability of goods in the warehouse is required
A	C	AC	H	Availability of goods in the warehouse is required
B	A	BA	H	Availability of goods in the warehouse is required

Maintenance	Logistics	Spare Parts Category	Criticality Level	Strategy
B	B	BB	M	Availability of goods in the warehouse adjusted to the financial condition and storage warehouse capacity of a company
B	C	BC	M	Availability of goods in the warehouse adjusted to the financial condition and storage warehouse capacity of a company
C	B	CB	M	Availability of goods in the warehouse adjusted to the financial condition and storage warehouse capacity of a company
C	A	CA	L	Availability of goods in the warehouse is not required (Purchase by order)

Source : Katarzyna Antosza, R. M. Chandima Ratnayake (2019)

In determining the classification of parts, the method used is a multi-criteria analysis method that involves important factors in terms of maintenance by using Failure mode effect analysis on equipment equeipment so that equipment criticality ranking of an equipment and spare parts derivatives of the equipment is obtained. From table 4.1 above, the results of the critical category of MRO spare parts needed for factory operations at PT Pupuk Iskandar Muda are obtained. The recapitulation of MRO spare parts with the category of spare parts insurance which is a critical spare part for factory operations that is a priority in the procurement process can be seen in the following table 2:

Table 2. Recapitulation of List of Insurance Spare Parts Mechanical PIM-2 Plant items

No.	Material	Description	Equipment No.	Min (Re-Order Point)	Max (Stock Lvl)	UoM	Consequence & Criticality Parts	Estimated Loss	Last PO Price (Unit Price)	Leadtime	Effect When Spare Part Is Not Available
1	6145788	BEARING PAD SET HITACHI 2MC6520 COMPR	61-105 JHP	1	2	SET	Direct Effect - Critical	Shut down total ammonia-2	326,528,100	12 months	Compressor cannot be operated. Bearing vibration and temperature increase and abnormal sound. Stop.
2	6135286	BEARING PAD SET,JOURNAL,89.39X160X80MM	61-105JT	1	2	SET	Direct Effect - Critical	Shut down total ammonia-2	335,000,000	12 months	Turbine cannot be operated. High vibration and abnormal sound. Unsafe condition. Stop.
3	6135287	BEARING PAD SET,JOURNAL,89.39X160X80MM	61-105JT	1	2	SET	Direct Effect - Critical	Shut down total ammonia-2	335,000,000	12 months	Turbine cannot be operated. High vibration and abnormal sound. Unsafe condition. Stop.
4	6202304	BLADES:FAN,8 BLADE,24F(AXIAL FLOW	63-OB2101A-D	1	2	SET	Direct Effect - Critical	Urea production cut rate	359,000,000	12 months	Water Cooling Tower temperature rises and abnormal heat dissipation process is disturbed. Stop.
5	6144735	BEARING PAD THRUST, 350-3272527, HITACHI	61-105JLP	1	2	SET	Direct Effect - Critical	Shut down total ammonia-2	372,645,350	12 months	Compressor cannot be operated. Bearing vibration and temperature increase and abnormal sound. Stop.

No.	Material	Description	Equipment No.	Min (Re-Order Point)	Max (Stock Lvl)	UoM	Consequence & Criticality Parts	Estimated Loss	Last PO Price (Unit Price)	Leadtime	Effect When Spare Part Is Not Available
6	6145784	BEARING PAD SET,THRUST,HITACHI BCH304	61-102J	1	2	SET	Direct Effect - Critical	Plant-2 production cut rate	388,050,500	12 months	Compressor cannot be operated. High vibration and abnormal sound. Unsafe condition. Stop.
7	6202305	BLADES:FAN,8 BLADE,28H(AXIAL FLOW	63-OB2001A-F	1	2	SET	Direct Effect - Critical	Ammonia production cut rate	391,000,000	12 months	Water Cooling Tower temperature rises and abnormal heat dissipation process is disturbed. Stop.
8	6142948	BEARING PAD SET,JOURNAL,HITACHI 3MC6525	61-105JLP	1	2	SET	Direct Effect - Critical	Shut down total ammonia-2	400,000,000	12 months	Compressor cannot be operated. Bearing vibration and temperature increase and abnormal sound. Stop.
9	6142952	BEARING PAD SET,JOURNAL,HITACHI 2BCH509	61-101JLP	1	2	SET	Direct Effect - Critical	Plant-2 production cut rate	405,257,000	18 months	Compressor cannot start up due to high vibration. Plant 2 has no supply because it cannot operate. Process.
10	6141279	BEARING PAD SET,JOURNAL,HITACHI 2MC6508	62-OB101	1	2	SET	Direct Effect - Critical	Shut down total Urea-2	404,972,167	12 months	Compressor cannot be operated. High vibration. Bearing temp rises and abnormal sound. Stop.
11	6137298	BLADE,IMPELLER,FAN,8BLADE,8 530MM,FRP	63-OB2001A-F	1	2	SET	Direct Effect - Critical	Ammonia production cut rate	421,531,965	12 months	Fan CT cannot be operated. CW temperature rises, process disturbed. Unsafe condition.

Mapping of business process activities of MRO material procurement planning based on SCOR model

A plan is a process to balance demand with supply to determine the best course of action to meet the needs of procurement, production and delivery. *Source* is a process of procuring goods and services to meet demand. *Make* is the process of transforming raw materials into the desired final product. Here make is not in this scor table because the company does not carry out the process of producing goods. *Deliver* is the process of fulfilling demand for goods and services which usually includes transportation and distribution. *Return* is the process of returning a product for a variety of reasons.

Table 3. Mapping of business process activities based on the SCOR model

No	Business Process	Sub-Process
1	Plan	Maintenance Planning
		Material Planning
2	Source	Supplier Selection
		Procurement Method Selection
3	Deliver	Goods Delivery
		Goods Quality Check
4	Return	Goods Rejection

Source : Data collection

Identify Risks

Risk identification is a stage with the aim of finding out the risk events that disrupt *the company's supply chain* activities and to find out the *risk agents* that cause the *risk events*. Identification was carried out through interviews at the Warehousing Receipt Planning Department, Maintenance Planning Department, Reliability Section and Goods and Services Procurement Department at PT. Pupuk Iskandar Muda.

Risk Event

Risk Event is an event/event that can disrupt MRO material supply chain activities in the company. This risk event was obtained from the results of the interview which was then encoded using the letter E which aims to make it easier to read later.

Risk Agent

Risk agents are things that can cause a risk event to occur so that it can disrupt the MRO material supply chain activities in the company. Risk agents are obtained from the results of interviews which are then coded using the letter A which aims to make it easier to read further. The company's *risk agents* can be seen in Table 4 as follows:

Table 4. Risk Agents at PT. Pupuk Iskandar Muda

No	**Risk Agent**	**Code (Aj)**
1	Increased demand	A1
2	Inaccurate goods requirement planning	A2
3	Information and communication errors	A3
4	Sudden spare parts request	A4
5	Predictive Maintenance not yet optimal	A5
6	Lack of coordination between related work units	A6
7	Incomplete equipment repair history data	A7
8	Equipment master not updated	A8
9	Material master data not updated	A9
10	Material is obsolete	A10
11	Planner's negligence in reordering	A11
12	Planner's inaccuracy in planning requests	A12
13	Inaccurate price sources	A13
14	Errors in goods price estimation calculation	A14

Risk Assessment

The risk assessment was carried out using the assessment form filled out during the interview with PT. Pupuk Iskandar Muda. There are 3 forms in this risk assessment, namely the risk *event assessment questionnaire, the risk* agent assessment questionnaire and *the* questionnaire on the level of relationship between *risk event* and *risk agent*. This risk assessment was obtained by giving a questionnaire to the *Vice President* of Procurement of Goods & Services, *Vice President* of Maintenance Planning and continued by conducting an interview to discuss the results of the assessment from filling out the questionnaire that had been carried out. The amount of risk value is greatly influenced by the subjectivity of the three *stakeholders* who fill out the questionnaire, and affects the severity of the risk event, the probability level of the risk cause, and the correlation value between the risk event and the risk cause.

The following are the results of risk assessment of the stages in risk assessment, namely determining the *severity* of the risk event, determining the probability level of the risk cause and determining the correlation or relationship between the risk event and the risk cause.

Determining the Severty Value of Risk Events

Every risk event that occurs will be assessed on the severity level. The severity level states how much disruption caused by risk events can disrupt business processes (Iiryaning, 2012). The severity score was assessed through interviews with respondents, namely the Vice President of Maintenance Planning, the Vice President of Receipt & Warehousing Planning, and the Reliability Manager.

The scale used in determining the impact of risk events is based on scale criteria 1-10 with explanations as in the previous chapter. The results of the severity value can be seen in Table 5.

Table 5. Severity Level Value of Risk Events at PT. Fertilizer Iskandar Muda

Risk Event	Code (Ej)	Severity (Si)
Discrepancy between recorded and available stock	E1	5
Minimum-maximum stock not updated	E2	5
Required Spare Parts are obsolete (No longer produced)	E3	6
Untimely order	E4	7
Self-Estimated Price Clarification	E5	4
Inaccurate inventory parameters	E6	6
Specification writing errors	E7	5
Unscheduled Shutdown	E8	7

Source : Data collection

Determining the Probability Level of Risk Causes

By conducting a risk agent assessment, the company can understand and manage risks more effectively, a risk cause with a high probability value, the company must be able to minimize and allocate resources for risk mitigation that causes risk events/events.

The *Risk Agent assessment* is carried out by assessing the level of chance of *occurrence* of a risk cause. This risk agent assessment was carried out during the interview by providing questionnaires to stakeholders of related business processes at PT. Fertilizer Iskandar Muda by giving an occurrence value to the *form*. The respondents will fill out the Probability Level assessment questionnaire using a predetermined measurement scale, which is 1–1.

The amount of this risk value is greatly influenced by the subjectivity of the three stakeholders who fill out the questionnaire. The recapitulation of the assessment can be seen in Table 6.

Table 6. Value of Probability Level of Risk Cause at PT. Fertilizer Iskandar Muda

No	Risk Agent	Code (Aj)	Occurrence
1	Increased demand	A1	5
2	Inaccurate goods requirement planning	A2	7
3	Information and communication errors	A3	3
4	Sudden spare parts request	A4	7
5	Predictive Maintenance not yet optimal	A5	7
6	Lack of coordination between related work units	A6	2
7	Incomplete equipment repair history data	A7	5
8	Equipment master not updated	A8	5
9	Material master data not updated	A9	6
10	Material is obsolete	A10	6
11	Planner's negligence in reordering	A11	6
12	Planner's inaccuracy in planning requests	A12	6

Source : Data collection

Determining the Correlation (Relationship) between Risk Events and Risk Causes

The Relationship Level Assessment *is carried out by looking at the relationship between* the risk event *and* the risk agent. The assessment of the level of risk *event relationship* with *risk agents* was carried out during interviews with *business process* stakeholders *at PT.* Pupuk Iskandar Muda by giving *a relatonship score* on the *questionnaire form.* The recapitulation of the assessment can be seen in Table 7.

Table 7. *Relationship* Value between Risk Events and Risk Causes in

PT. Fertilizer Iskandar Muda

Kejadian	Penyebab Risiko (Aj)																								
Risiko	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
E1		1	2	3	3	3	1	2				1													
E2	3	1	1	3	1	1	1	1	9		1	3													
E3		3	1	1		3	1		9	9								1							
E4		1		9		3					3	3				3									
E5												3	9	9	9		3								
E6	3	3	1	9		1		3	9	3	1	3				1		1							
E7		1				1	1		3		1	3				3		3							
E8		1		9	3	3	3																		
E9	3	3		9	9	3	1	1																	
E10	3	3	3	9	9	3	3		1			1													
E11						3										3		1		1					
E12						1													1	3					
E13																3				3	3				
E14																			1	3	1			1	
E15													9	9	9		3								
E16																				3	3	1			
E17																		3						1	
E18																			1	1	1	1			
E19																			1		1	3	9	9	
E20																1		1	1	3	1	1			3
E21																			3	3	3	3	9	3	1
E22																						3	3	3	
E23																						3	3		
E24																						3	3		
E25																				2		3	9	3	
E26																				1	1	1	3		

Source : Data collection

Discussion Risk Analysis

The risk analysis stage aims to analyze the results of the assessment of *the severity* of a *risk event*, *the occurrence of* a *risk agent* and *the relationship* between *the risk event* and *the risk agent* obtained from the results of the interview. The *severity*, *occurrenceance* and *relationship* values were then combined in the *House of Risk* (HOR) matrix phase I.

- Account *Aggregate Risk Potential* (ARP)

The calculation of ARP is obtained based on the formula: **ARPj = Oj Σ Si Rij**

Information:
ARPj : *Aggregate Risk Potential*
Oj : Occurrence
The : Severity
Row : Relationship

Examples of ARP1 calculations are as follows:

ARPj = 0j Σi SiRij

ARP1 = 5 × Σ[(3×5) + (3×6) + (3×6) + (3×5)

ARP1 = 5 × (15 + 18 + 18 + 15)

ARP1 = 5 × (66)

ARP1 = 330

Furthermore, the results of the ARP are included in the *House of Risk* Phase 1 table which can be seen in table 4.11.

Risk Evaluation

At this stage, the Risk Agent priority is determined by looking at the highest ARP value using the 80:20 Pareto Chart.

It is known *that Risk Agents* have an influence of 80% on the ARP value for mitigation action planning.

It is known that the highest ARP value is 2205 in A4 risk agent and the lowest ARP value is in A25 risk agent with a value of 75.

With the pareto chart approach, the ARP value of each Risk agent was 14 risk agents (56%) which had an impact of 81.32% on the potential risk of the total ARP value. The 14 (fourteen) Risk Agents are as follows:

1. A4 : Sudden spare parts demand
2. A23 : Partner who is negligent in performing the job
3. A9 : Master material data not updated
4. A5 : Predictive Maintenance is not running optimally
5. A24 : Partners unable to supply PO
6. A2 : Planning Needs of goods are not right
7. A15 : Material prices suddenly rise in the market
8. A22 : Partner defaults in providing bidding documents
9. A13 : Inaccurate price source
10. A12 : Planner's inaccuracy in planning requests
11. A16 : High job load
12. A10 : Obsolete material
13. A20 : Buyer is negligent in carrying out the procurement implementation process
14. A14 : Error in the calculation of the estimated price of goods

Risk Handling

This stage is a stage in *the House of Risk* Phase II which aims to produce risk mitigation actions to deal with priority *risk agents* in HOR Phase I. The risk mitigation strategy in this study identifies the cause of risk that is the root of a risk to factory equipment operations. Risk prevention and handling measures aim to reduce the probability of the emergence of these risk causes, where in the House of risk phase 1 there have been 14 priority risk causes that will be handled with risk mitigation actions.

In the House of risk Phase 2 process, it was carried out through discussions, interviews and filling out questionnaires with stakeholders in the MRO spare parts supply chain business process from factory equipment, namely *Vice President* of Procurement of Goods & Services, *Vice President* of Receipt & Warehousing Planning, *Vice President* of Maintenance Planning and Reliability Managerto risk mitigation actions, assessment of the relationship between risk mitigation actions and risk causes, and assessment of the level of difficulty in carrying out risk mitigation actions.

The Relationship between Risk Mitigation Actions and Risk Causes (Ejk)

Based on the results of the correlation assessment between mitigation actions and risk causes, it can be seen in Table 8.

Table 8. Correlation of risk mitigation actions with risk causes

Penyebab Risiko (Aj)	Aksi Mitigasi Risiko (PA*k*)															ARP
	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	PA10	PA11	PA12	PA13	PA14	PA15	
A4	3	3	1					1			3			3	1	2205
A23				1												1080
A9			1						1					1	3	1038
A5		1						1	1		3				1	980
A24				1	3	1										786
A2	3	3	3				1		3	3		3	1	3	1	686
A15												1	1			648
A22				1	1	1										568
A13												9	1			567
A12			3						1	9			1	1	1	546
A16			1				1		1							528
A10			1					9	3	1						432
A20					1	9									1	420
A14										3		3	3		1	405

Source : Data collection

Difficulty Assessment of Risk Mitigation Actions (Dk)

The difficulty level assessment was carried out on 3 category scales, namely low with a value of 3, medium with a value of 4 and high with a value of 5. The results of the assessment of the difficulty level of risk mitigation actions can be seen in table 9.

Table 9. Difficulty Level Assessment (Dk) for Risk Mitigation Actions

Code	Risk Mitigation Action (Preventive Action/PA)	Difficulty Level (Dk)
PA1	Sufficient Spare Part Provision	4
PA2	Demand forecasting based on equipment maintenance strategy	5
PA3	Improve the performance of the planning department	4
PA4	Standardize Communication with Partners via email, applications, etc.	3
PA5	Partner selection based on partner performance ranking	3
PA6	Improve the performance of the procurement department	3
PA7	Conduct Benchmarking with similar companies	3
PA8	Substitute factory equipment/spare parts	5
PA9	Coordination and communication of spare part specifications with users	3
PA10	Increase employee competence in the planning field	4
PA11	Scheduled Preventive and Predictive maintenance	4

Code	Risk Mitigation Action (Preventive Action/PA)	Difficulty Level (Dk)
PA12	Conduct spare part price surveys from official sources (producers, distributors, etc.)	5
PA13	Standardize HPS (Owner's Estimate) calculation based on purchase history and updated market prices	4
PA14	Periodically evaluate stock levels with maintenance users	4
PA15	SOP implemented optimally with rewards and punishments	4

Source: Data collection

Determining the Total Effectiveness of Each Risk Mitigation Action (TEk)
The determination of total effectiveness is obtained using the formula:

TEk = ΣjARPjEjk

Where:
Tech : Total Effectiveness (*Total Effectiveness*) of mitigation actions *k*
ARPj : Aggregate Potential Risk of Risk Causes *j*
Ejk : Correlation of the relationship between mitigation actions and risk causes

By calculating the TEk for each mitigation action, we can assess how effective the mitigation actions are as a whole in minimizing the risks that occur and how difficult it is to implement. Here's an example of the TE1 calculation:

Tech : ΣjARPjEjk
TE1 : Σ [(3x2205) + (3x686)]
TE1 : 6615+2058
TE1 : 8673

Furthermore, the value of the Total Effectiveness calculation (**Tech**) obtained will be entered into the *House of Risk* Phase 2.

Calculating the Total Effectiveness Ratio (ETDk) to Difficulty Level
The formula used to calculate (ETDk) using the following formula:

$$\textbf{ETDk} : \frac{TEk}{Dk}$$

ETDk : Total Effectiveness to Difficulty Level Ratio (Dk)
Tech : Total Effectiveness (*Total Effectiveness*) of mitigation actions *k*
Dk : Difficulty level (*Difficulty*) of Risk mitigation actions

Furthermore, the priority of risk management will be determined using a pareto chart using the 80:20 rule, where the ETDk value will be ranked to determine the priority of risk management. Risk mitigation actions with the highest ETDk value will be the first priority for preventive measures or risk mitigation strategies that have been determined. Based on the Pareto 80:20 analysis above, the prioritized risk mitigation actions to reduce the causes of the risks that occur are as follows:

1. PA14 : Sufficient Spare Parts Supply
2. PA11 : Demand forecasting based on equipment strategy maintenance
3. PA1 : Improve the performance of the planning section
4. PA10 : Standardize Communication with Associates via email, application etc
5. PA9 : Selection of partners based on partner performance ranking
6. PA15 : Improve the performance of the procurement part
7. PA3 : Benchmarking with similar companies
8. PA2 : Substituting factory equipment/spare parts
9. PA12 : Coordination and communication of spare parts specifications with users

Details of Mitigation Action Formulation

The formulation of mitigation actions is designed to reduce the impact of risks identified in the MRO parts material procurement process. Based on the analysis of the House of Risk (HOR) in table 4.20 Ranking of the Total Effectiveness Ratio to Level (ETDk) value at PT. Pupuk Iskandar Muda , has identified 9 mitigation actions that can minimize the emergence of priority risk agents. These mitigation actions include providing sufficient spare parts, improving the quality of procurement data, developing integrated information systems, training procurement staff, and increasing cooperation with suppliers. With the implementation of these mitigation actions, it is hoped that it can increase the efficiency and effectiveness of the MRO spare parts material procurement process, as well as reduce the risks associated with the process.

Integration of Criticality Assessment (FMEA) and House of Risk (HOR)

The combination of the two C*riticality Assessment* methods based on *Failure Mode Effect Analysis* (FMEA) and *House of Risk* (HOR) forms an efficient and responsive data-based risk mitigation system in the planning and procurement of MRO spare parts materials at PT. Pupuk Iskandar Muda.

CONCLUSION

This study systematically identified and analyzed 26 distinct risk events in the procurement planning process of *Maintenance, Repair & Overhaul* (*MRO*) materials and spare parts for critical equipment at PT Pupuk Iskandar Muda, categorizing them across business planning, sourcing, delivery, and returns. Fourteen priority risk agents were found to account for 81.55% of potential risk occurrences, necessitating immediate mitigation. Using Pareto analysis, nine key mitigation strategies were prioritized, including ensuring adequate spare parts supply, implementing maintenance-based demand forecasting, and enhancing planning section performance, alongside measures such as standardizing communication, performance-based partner selection, and process improvements. These interventions collectively establish a comprehensive risk management framework to strengthen procurement reliability and operational efficiency. For future research, it is recommended to explore the integration of advanced digital tools—such as predictive analytics and artificial intelligence—in risk monitoring and mitigation, as well as to assess the long-term effectiveness of these strategies through continuous performance evaluation and benchmarking against industry best practices.

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