SITEKIN: Jurnal Sains, Teknologi dan Industri, Vol. 21, No. 2, June 2024, pp.325 - 334
ISSN 2407-0939 print/ISSN 2721-2041 online

RISK MITIGATION IN PLANNING AND WAREHOUSING ACTIVITIES OF FERTILIZER FACTORY SPARE PARTS

(Case Study: PT. Pupuk Iskandar Muda)

Ibnu Anugrah[1], Rika Ampuh Hadiguna[2], Elita Amrina[3]
[1.] Master Program in Industrial Engineering, Department of Industrial Engineering, Faculty of Engineering,University of Andalas Jl. Limau Manis, Pauh Kota Padang
Email: Ibnuanugrah11@gmail.com,

[2.3] Department of Industrial Engineering, Faculty of Engineering,University of Andalas
Jl. Limau Manis, Pauh Kota Padang
Email: Hadiguna@eng.unand.ac.id, Elita@eng.unand.ac.id

ABSTRACT

In an industry that operates continuously, spare parts are one of the important aspects that must be managed properly because the availability of spare parts is needed to help maintain operations so that they can support production efficiency. Spare parts warehousing activities often find several unexpected events such as not being able to prioritize the purchase of spare parts, there are unexpected events so that the requested spare parts needs are not met and various unknown risks. Since spare parts warehousing operations always contain risks, it is necessary to identify risks and create ways to reduce them. This research aims to find the risks that may occur in the business activities of planning and warehousing fertilizer plant spare parts at PT. Pupuk Iskandar Muda and determine the mitigation actions. This research uses an integrated Fuzzy Logic, House of Risk (HOR), and Supply Chain Operation Reference (SCOR) approach. Interviews, focus group discussions, and questionnaires are the data collection methods used. From the results of data processing, 19 risk events and 27 risk agents were obtained. From the results of the pareto charts, 14 risk agents were selected to focus on risk mitigation and have the ability to direct the risk reduction. Furthermore, from 14 risk agents developed into 28 mitigation strategies and there are 10 mitigation strategies.

Keywords: Fuzzy Logic, HOR, Pareto Charts, Risk Mitigation, SCOR, Warehousing.

Introduction

To meet the needs of market demand, requires the participation of many stakeholders in business activities [1]. All of this can be achieved with proper supply chain management so that when conducting business activities, the business can operate efficiently and effectively [2]. Supply chain management regulates the flow of materials or goods from suppliers to interconnected end users [3]. In the process of meeting needs in the supply chain, the warehouse is one of the most important parts. An efficiently functioning warehouse allows the company to run its operations smoothly [4]. Warehouses have three main processes namely receiving, storing, and distributing [5]. Because the warehouse processes the processing of inputs into outputs, warehouse needs are certainly very important to help companies achieve their goals [6]. As for illustrating that warehouse efficiency has now turned into a center of competence or strategic weapons.

In industries characterized by continuous operation, the management of parts is typically segmented into two distinct categories: routine parts and non-routine parts [7]. Routine spare parts are those meticulously managed by the warehouse and seamlessly integrated into the operational cycle. These parts undergo a streamlined process of picking (or good issue) within the warehouse and are readily accessible to all users across various departments and functions. Conversely, non-routine parts present a different set of challenges. Their usage is less predictable and may occur sporadically, often in response to unexpected breakdowns or maintenance requirements[8]. Consequently, the absence of these critical spare parts or the presence of an insufficient quantity can lead to significant disruptions in operations, resulting in downtime and substantial financial losses. Recognizing the pivotal role spare parts play in maintaining operational continuity, it becomes imperative for industries to anticipate and mitigate potential risk [9]. This involves meticulous planning and forecasting to ensure adequate inventory levels of both routine and non-routine parts. By proactively addressing potential shortages or excesses, organizations can safeguard against operational disruptions and minimize the associated financial impact, thereby fostering a more resilient and efficient operational environment. [10].

Managing spare parts warehousing activities often encounters unexpected events that can disrupt workflow. One event that frequently occurs as seen in Figure 1 is the entry of purchase transactions from various work units. This large number of transactions creates challenges for the spare parts planning unit, due

to difficulties in prioritizing the delivery of items that are urgently needed amidst the large number of orders. In addition, delays often arise due to information bottlenecks. Work units processing spare parts requests may experience delays in accessing critical information, hampering their ability to determine priority levels effectively. This information delay, in turn, causes a delay in fulfilling requests. In the field of maintenance, correct estimates are critical [11]. Work units must accurately reflect the number of spare parts required based on various factors, including function, type, time of request, time of purchase, time of arrival, and time of installation of parts. Careful planning is required to ensure optimal inventory management and facilitate timely maintenance activities [10].

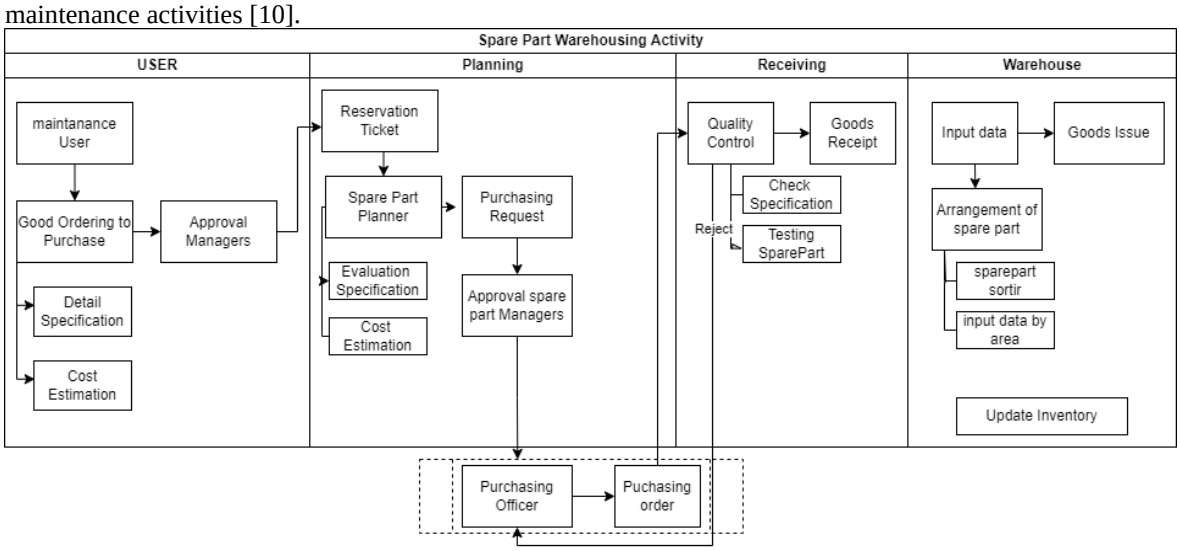

Figure 1. Activities in Spare Part Warehousing

A set of measures and techniques known as risk management are used to identify, measure, monitor, and control risks arising from the business operations of an organization [12]. The risk management implementation objective is the reduction of the various risks involved at a level acceptable to them in their chosen field these risk threats can come from the environment, technology, individuals, organizations, and politics. Target Risk management of the company should be avoided Protect against mistakes, increase profits and reduce production costs [13].

Several previous research results have discussed supply chain risk management and suggest that further research should discuss and analyze the risks of each supply chain element [14][15]. This research raises the research object in the warehousing section. Planning and warehousing are crucial for industrial efficiency and spare part availability. However, risks like delays, mismatched stock, price changes, and safety issues can threaten efficiency and cause significant losses. Uncertainty in the supply chain can lead to overstocks or understocks. This research focuses on identifying and mitigating risks in the spare parts planning and warehousing process using Fuzzy Logic, House of Risk (HOR), and Supply Chain Operation Reference models. It emphasizes the importance of implementing effective mitigation plans, ensuring operational continuity, and avoiding unintended losses. The findings will aid policy-making in determining the most appropriate risk mitigation actions.

Research Methods

In this study, the approach chosen was *Supply Chain Operation Reference* (SCOR), *House of Risk* (HOR) and *Fuzzy Logic*. This selection is based on supporting literature and studies that have been conducted. In the process of identifying risks in the Planning, Receiving and Warehousing Department of PT. Pupuk Iskandar Muda requires a process of mapping business activities and describing activities that occur in the department, the selection of this SCOR method can be used because of mapping and describing supply chain business activities in detail based on the SCOR model. Furthermore, the HOR method was chosen to identify *risk events* and *risk agents*. This HOR produces a list of risks obtained from the process of identifying *risk agents* and *risk events*, then this HOR will provide a sequence of risks based on the amount of impact caused. The fuzzy logic method is the right approach to connect input and output spaces that have continuous values. The extent to which the truth and membership of an entity are measured, this is called fuzzy. With fuzzy logic, linguistic variables that have binary values (yes/no) and degrees of membership in a particular category can be used.

Object of Research

The object of this research is supply chain activities carried out by the Planning, Receipt, and Warehousing Department of PT. Pupuk Iskandar Muda. This study is to analyze, identify and measure risks in the activities of the department itself, because these risks can be seen from all planning activities of all spare parts, auxiliary chemicals and other spare parts for plant operations then the process of receiving spare parts that have been sent to the process of storing and dispensing goods carried out in the warehouse.

Results and Discussion

Spare parts supply chain activity mapping

To start the data collection process, *a Supply Chain Operation Reference* (SCOR) is used to identify supply chain activities. The next step is to identify supply chain activities to determine the risks that may arise from the company's operations and how they impact supply chain activities.

Table 1. Dept. Planning and Warehouse Activity Mapping

SCOR Process	Sub Business
Plan	Planning the purchase of spare parts
	Plan the budget needed
	Planning for arrival times Spare parts
	Calculate the estimated price of spare parts
	Planning stock *re-orders*
Source	Schedule shipments from suppliers
	Setting Up *Purchese Order*
	Store spare parts in a warehouse
	Stock fulfillment according to *min-max*
Make	Receive spare parts from suppliers
	Check the completeness of incoming parts
	Create a part number
	Doing *Stock Opname*
Delivery	Accept reservations from users
	Removing spare parts
Return	Return parts to vendors

Risk Identification

Based on the ARP value, it can be determined risks that have significant potential harm and require preventive measures, while small risks require only minor modifications. Table 2 shows the results of *risk agent ranking*.

Table 2. *Ranking Risk Agent*

No	*Risk Variable*	*Risk Agent*	ARP	%Cumulative
1	Request emergency spare parts from *user*	A2	1003,8	9%
2	Request changed due *to unexpected* event	A10	864,9	17%
3	Vendor delays in the distribution process	A13	758,7	25%
4	*Inventory control* is not working well	A17	612,3	30%
5	Parts numbering does not conform to *catalogic standards*	A23	566,3	36%
6	The spare parts specification master data does not conform to *the catalogic system*	A8	531,5	41%
7	The specifications of the spare parts planned by the user are not yet clear	A7	507,1	45%
8	Spare parts come When they are not needed	A18	497,0	50%
9	Delay in the process *of posting in-out* spare parts	A24	487,8	55%
10	Previous PO is non-compliant	A4	473,6	59%
11	Don't have a reference for a new item yet	A9	388,5	63%

No	*Risk Variable*	*Risk Agent*	ARP	%Cumulative
12	Repetition of the purchase procedure that takes a long time	A27	383,1	66%
13	The *budgetary* process was not fully approved	A6	358,1	70%
14	*Unsafe condition* dan *unsafe action*	A20	348,3	73%
15	The treatment of parts does not match the condition of the parts	A21	327,1	76%
16	Disruption of the system for *approval*	A15	324,6	79%
17	Invalid spare parts reference	A3	321,4	82%
18	The parts received do not conform to the Specifications or defective parts	A26	319,8	85%
19	Long Quality Control process	A16	298,7	88%
20	The Quality Control process is less than optimal	A22	273,5	90%
21	The large number of spare parts needs is not met	A25	212,3	92%
22	Busyness from superiors	A14	201,8	94%
23	Unexpected events in repair operations	A19	176,8	96%
24	Currency rate increase	A1	173,6	97%
25	The draft order for spare parts does not comply with the purchasing standards used	A11	132,6	99%
26	*User* does not *update* about the development of used parts	A12	101,8	99%
27	Selection in priority fulfillment of needs is not right	A5	41,0	100%

The risk ratings generated by HOR phase 1 are prioritized using Pareto charts to find the most dominant component or cause of a problem. Pareto charts provide the information needed to prioritize risks and subsequently mitigate them.

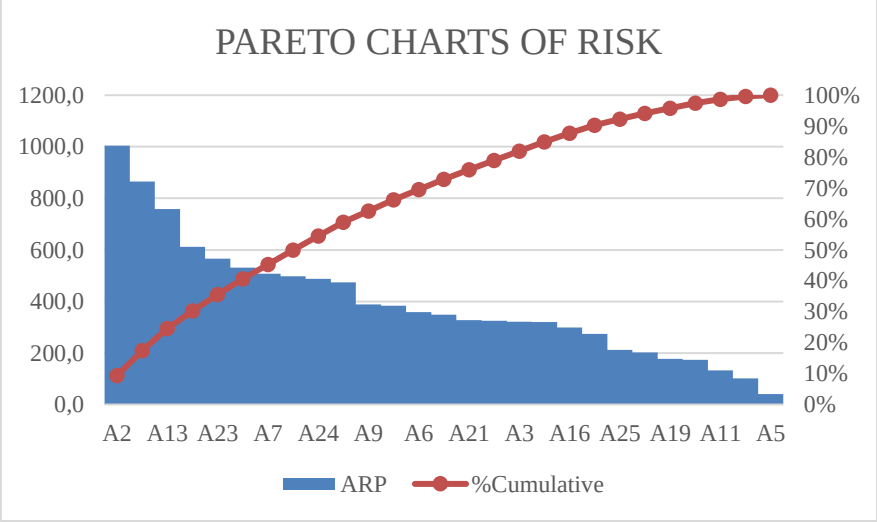

Figure 2. Pareto Charts

The Pareto charts is a graphical representation of House *of Risk* (HOR) phase 1. The priority risk agent will then proceed to the next stage, namely using *House of Risk* phase 2. These priority risks must be analyzed so that mitigation strategies can be carried out. to be effective. Mitigation actions are often carried out through strategic or tactical measures. According to [16] states that planning should focus on increasing flexibility, avoiding internal and external risks of the company, and controlling risks to provide mitigation. The calculation technique of HOR 2 is almost the same as HOR 1, it's just that the difference in calculations on both input variables. In HOR 1, risk event data and agents are used as inputs, but in HOR 2, the inputs include risk agents with high ARP values and data from mitigation actions.

Risk Management

This stage is carried out using the HOR 2 method. Risk mitigation or risk management involves efforts to reduce risk after the event occurs, with the aim of controlling the risks that may occur [17]. Once the most important risk agents for mitigation have been identified, the next step is to take preventive action to limit or eliminate the possibility of them emerging. This stage is carried out through interviews and in-depth discussions with relevant experts to get professional advice. Furthermore, a strategic approach to prioritize risk mitigation by considering the level of implementation difficulty, innovation, and human resource involvement adds a new dimension to risk management knowledge. This evaluation recognizes that risk mitigation is not a static task, but is dynamic and requires a holistic approach. By taking into account factors such as the level of implementation difficulty, innovation, and human resource involvement, companies can develop mitigation strategies that are more adaptive and responsive to changing operational conditions.

Calculation of Effectiveness to Difficulty Ratio

To find out how effective each handling approach will be applied, a total effectiveness calculation of 32 risk agent mitigation strategies has been made. To do this, the Aggregate Risk Potential (ARP) value and the correlation value are dialed until the values are available for n. The following equation is used:

$$TE_k = \sum ARP_j \, . E_{jk}$$

Effectiveness to Difficulty Ratio is used to select the right risk mitigation strategy. This risk mitigation is determined by the greatest effectiveness to difficulty rating. To calculate the *Effectiveness to Difficulty Ratio* the following equation is used:

$$ETD_k = TE_k / D_k$$

House of Risk Fase 1

The phase 1 HOR table contains information on risk events, risk factors, intensity, and occurrences. The Aggregate Risk Potential (ARP) value is used to determine the source of risk that will get the first treatment. To select a source of risk for handling, the rule of the risk house method is an 80:20 paretto charts, which means addressing 20% of risk will improve the other 80%. The head of the planning, receiving and warehousing department has determined 16 risk agents with a percentage of 79%. It is based on the idea that these risk agents are chosen to concentrate on risk countermeasures and have the ability to direct this risk reduction to the planning, receiving and warehousing departments.

Fuzzy Logic Process

The initial step is to do fuzzy risk estimates by categorizing into the fuzzy model. The questionnaire serves as both the input and output for this study's mapping. This phase also determines the range parameter to be utilized in the fuzzy (0-5). The next step is to conduct a risk assessment to evaluate the severity and frequency of each questionnaire [18]. The outcomes of this method will be utilized as the primary input for fuzzy processing, resulting in a legitimate severity and occurrence score.

Following the determination of the mapping and range parameter, the next step is to develop rules in Matlab. In this study, the rule-based approach will be employed in conjunction with IF-THEN laws, which serve as the foundation for Mamdani Fuzzification. Defuzzification is the end result of the fuzzy logic process. After filling out the fuzzy rules and range parameter input and output, the final stage is defuzzification, or determining the true values of the score severity and occurrence using the house of risk.

This fuzzy logic 2 (for mitigation action) calculating technique determines the degree of difficulty or level of difficulty based on mitigation action. This stage makes use of fuzzy logic with innovation and human resources as parameters. The major goal of this stage is to get a validity score of mitigating action.

House of Risk Fase 2

Phase 2 *of the House of Risk* is the priority phase of risk agent handling in Phase 1 of HOR. In Phase 2 of HOR, a coping strategy is determined through in-depth interviews and discussions with department heads. After

determining the mitigation method, the next stage is to determine the level of difficulty (Dk). This research uses fuzzy logic to establish the true level of difficulty based on innovation and the involvement of human resources to determine the level of difficulty. Later, after determining the difficulty score, the next step will be displayed house of risk phase 2 and measure the correlation value between mitigation and the selected risk agent, then calculate the Total Effectiveness (TEK) value by multiplying the correlation value between risk agent (j) and preventive action (k). The goal is to determine the effectiveness of the implementation of mitigation strategies.

To rank the precautions to be taken, HOR2 is used. The selection of mitigation strategies must consider how effective the countermeasures are, as well as how much innovation and human resources are needed to implement them. The rating of preventive measures is based on the order of total effectiveness to difficulty (ETD) scores. A higher ETD value indicates that the chosen mitigation has the ability to deal effectively with risk. It is expected that the selection of appropriate mitigations will reduce the likelihood of risk factors occurring, thereby reducing the number of potentially dangerous events. The success of expected mitigation outcomes depends on the organization's ability to allocate its resources. The hard value (Dk) is the amount of resources required to handle the risk.

After determining the most important mitigation strategies, a pareto chart is used to determine the main mitigation strategies. Using the pareto 60:40 concept, it is expected that 40 percent of mitigation strategies will result in 60 percent of effective mitigation strategies. There are 11 key mitigation strategies that can be implemented out of 32 priority mitigation strategies, resulting in an effectiveness of 63%. Table 3. is an explanation of the 11 mitigations prioritized and selected by the head of the department. The selection of prioritized mitigation is also based on the results of risk mitigation mapping with 4 quadrants.

Table 3. Mitigation Action Analysis

Code	Mitigation Action	Code	Risk Agent
PA1	Conduct emergency incident analysis for spare parts stock needs	A2	Request emergency spare parts from *user*
		A18	Spare parts come When they are not needed
		A24	Delay in the process of posting in-out spare parts
		A27	Spare parts come When they are not needed
Analyzes: PA1 is very effective in counteracting the negative impact of risk A2,A24,A18,A27. By conducting an in-depth analysis of emergency events , the process of fulfilling spare parts stocks can run smoothly even in an *emergency*. The results of mapping PA3 risk mitigation actions are included in quadrant 2, where it is not difficult to carry out these mitigation actions, it does not need to require a lot of innovation and HR involvement in carrying out this action. This is very effective in overcoming various risks related to the fulfillment of spare parts.			
PA6	Establish strong and regular communication with vendors.	A10	Request changed due to unexpected event
		A13	Vendor delays in the distribution process
		A9	Don't have a reference for a new item yet
		A27	Repetition of the purchase procedure that takes a long time
Analyzes: Establishing strong and regular communication with vendors is a very effective strategy in mitigating risks related to emergency requests from users and delays in the distribution process. Through good communication, companies can be better prepared for emergency situations, better plan production and distribution, and handle delays responsively. It also helps build a better and mutually beneficial relationship between the company and the vendor.			
PA5	Vendor performance audits	A13	Vendor delays in the distribution process
		A27	Repetition of the purchase procedure that takes a long time
Analysis			

Code	Mitigation Action	Code	Risk Agent
Vendor audits are an effective and relatively simple strategy to be implemented by departments to mitigate the risk of vendor delays during the distribution process. Businesses may be more proactive in addressing risks arising from vendor delays by reducing labor costs, identifying potential problems, and increasing accountability. With the right corrective measures, performance audits can help improve overall supply chain efficiency.			
PA11	Implement a controlled change process	A10	Request changed due to unexpected event
		A23	Parts numbering does not conform to catalogic standards
		A8	The spare parts specification master data does not conform to the catalogic system
		A7	The specifications of the spare parts planned by the user are not yet clear
		A4	Previous PO is non-compliant
		A9	Don't have a reference for a new item yet
Analyzes: Implementing a controlled change process is a highly effective strategy in overcoming the risk of errors in Purchase Orders (POs) and data discrepancies. With a structured approach, teams can identify, address, and prevent data-related issues that can lead to errors in business processes. A controlled change process also ensures that the solutions implemented are appropriate to the needs and reduces the negative impact on business processes.			
PA15	Review inventory levels, usage rates, and actual needs to ensure ordered parts match your needs	A2	Request emergency spare parts from *user*
		A10	Request emergency spare parts from *user*
		A17	Inventory control is not working well
		A18	Spare parts come When they are not needed
		A6	The *budgetary* process was not fully approved
Analyzes: By conducting regular reviews, this strategy is able to manage risks related to spare parts inventory management. This risk mitigation can identify early the demand for spare parts when there is an *emergency event* and can anticipate the arrival of spare parts not in accordance with the *delivery date*, so that needs can be met and spare parts inventory can run well. This mitigation is effective in minimizing the shortage of spare parts needs in emergencies.			
PA2	Identification of the most important and critical parts for business operations in emergency situations	A2	Request emergency spare parts from *user*
		A10	Request changed due to unexpected event
		A3	Invalid spare parts reference
		A18	Spare parts come When they are not needed
		A16	long quality control process
Analyzes: The next effective risk mitigation approach is to identify critical business operational parts in an emergency. The Planning, Receiving and warehousing department can reduce risks arising from A10,A2,A3,A18,A16 risk disruptions by identifying and evaluating spare parts needed during emergencies. Continue to update and implement the plan as a starting point to manage operational continuity in risky conditions.			
PA7	Regular monitoring of setup data.	A2	Request emergency spare parts from *user*
		A10	Request changed due to unexpected event
		A17	Inventory control is not working well
		A24	Delay in the process of posting in-out spare parts
		A27	Repetition of the purchase procedure that takes a long time
Analyzes:			

Code	Mitigation Action	Code	Risk Agent
By monitoring inventory data regularly, departments can understand changes in inventory levels. This risk mitigation measure can also overcome emergency events that require sudden spare parts and are available in warehouses. Through this mitigation, the department can improve accuracy in managing inventory risk, optimize spare parts availability and improve response to changing parts needs.			
PA3	Collaboration with industry organizations	A10	Request changed due to unexpected event
		A23	Parts numbering does not conform to catalogic standards
		A8	The spare parts specification master data does not conform to the catalogic system
		A9	Don't have a reference for a new item yet
Analyzes: Collaboration with fertilizer industry organizations can result in effective risk management strategies in addressing urgent and emergency parts requests and the need to identify new parts references. Organizations can mitigate the negative impact of urgent situations and better maintain sustainable operations by leveraging the knowledge, resources, alternative supply chains, and speed of response from fertilizer industry organizations. However, it is important to ensure that the materials used continue to meet the required quality and robustness standards.			
PA25	Communicate effectively and openly with leaders	A13	Vendor delays in the distribution process
		A18	Spare parts come When they are not needed
		A4	Previous PO is non-compliant
		A9	Don't have a reference for a new item yet
		A27	Repetition of the purchase procedure that takes a long time
		A6	The *budgetary* process was not fully approved
		A15	Disruption of the system for *approval*
Analyzes: This risk mitigation strategy is an important strategy for managing organizational risk. By communicating information openly, leaders can be aware of potential risks and their impacts. Leaders can have an open dialogue with employees to explore potential risks. By discussing openly, department employees can be comfortable reporting issues and providing risk-related feedback. Conducting effective and open communication with leaders can build a strong foundation to respond to risk.			
PA4	Development of alternative use of spare parts	A10	Request changed due to unexpected event
		A23	Parts numbering does not conform to catalogic standards
		A8	The spare parts specification master data does not conform to the catalogic system
		A9	Don't have a reference for a new item yet
Analyzes: Risk mitigation actions for the development of alternative use of spare parts involve the process of identification, development and implementation of alternative use of spare parts. Identifying alternative parts can reduce reliance on the same type of parts and overcome potential scarcity or price increases. This risk mitigation action can also ensure the availability of spare parts if there is a change in the type of parts used. Implementing these risk mitigation actions can gain an advantage in managing risks related to spare parts availability, parts that are not in accordance with standards and flexibility of changing the use of spare parts.			
PA17	Review existing policies and procedures, and update them as needed	A17	Inventory control is not working well
		A18	Spare parts come When they are not needed
		A24	Delay in the process of posting in-out spare parts
		A4	Previous PO is non-compliant
		A6	The *budgetary* process was not fully approved

Code	Mitigation Action	Code	Risk Agent
		A20	*Unsafe condition* and *unsafe action*
Analyzes: Review of existing policies and procedures are measures to anticipate departmental operational risks. By identifying potential risks associated with policies and procedures, you can design risk mitigation measures. By optimizing policies and procedures, it can improve the operational efficiency of the department. Regular reviews and updates help departments to remain adaptive to changes in the business environment.			

Managerial Implications

By identifying 19 risk events and 27 risk agents in parts planning and warehousing activities, the study provides a robust framework for more effective risk management. Risk prioritization based on Aggregate Risk Potential (ARP) and the Pareto 80:20 concept provides practical guidelines for companies in allocating resources more efficiently. Managerial companies can use these findings as a basis for making more informed decisions in managing the most impactful risks, improving operational efficiency, and reducing potential losses. In addition to managerial benefits, this research also makes an important contribution to the development of risk management science. The introduction of effective risk management methods, especially in the context of parts planning and warehousing, can pave the way for the development of new methodologies and the improvement of risk management practices in various industries. The application of the Pareto concept in risk management and the use of metrics such as Aggregate Risk Potential (ARP) create a foundation for further research in more sophisticated risk measurement. This contribution can enrich the risk management literature and encourage greater awareness of the importance of risk management among academics and business practitioners. As such, the study's findings not only provide practical guidance for companies, but also play an important role in advancing knowledge of risk management more broadly.

Conclusion

After determining the most important mitigation strategy, the Pareto charts is used to determine the main mitigation strategy. By using the Pareto 60:40 concept, it is hoped that 40 percent of mitigation strategies will produce 60 percent of effective mitigation strategies. There are 11 main mitigation strategies that can be implemented from 32 priority mitigation strategies, resulting in an effectiveness of 63%. However, effective risk management in parts planning and warehousing activities is essential to reduce losses and increase efficiency. Risk identification in the Planning, Receiving and Warehousing Department of PT. Pupuk Iskandar Muda resulted in 19 risk events and 27 risk agents, which were then prioritized based on the *Aggregate Risk Potential* (ARP) value and the Pareto 80:20 concept.

Within this framework, reviewing existing policies and procedures will ensure that the company always follows best practices and can adapt to environmental changes. Overall, this approach not only focuses on mitigating current risks, but also involves forward-looking strategic aspects to anticipate potential future risks. By implementing this strategy, companies can build strong and adaptive operational sustainability amidst the uncertainty of the industrial environment.

Suggestion

Further research on the development of predictive models of risk is needed to utilize *machine learning* technologies. This refers to sources of risk that have been identified in previous studies. More sophisticated models can involve complex algorithms and ensemble learning techniques, improving prediction accuracy. Utilization of discovered risk sources ensures the model considers relevant and significant risk factors. This research enables organizations to manage risk effectively and proactively in an ever-changing environment.

References

[1] Erlina, "Analisa Pengukuran Kinerja Rantai Pasok Dengan Model Supply Chain Operation Reference (SCOR) PT. XYZ Di Bogor," *J. Ilm. Manaj. dan Bisnis (Scientific J. Manag. Business)*, vol. 4, no. 2, pp. 1–23, 2020, doi: 10.22441/indikator.v4i2.10001.

[2] S. Aćimović, "Understanding the Supply Chain," *Sci. Pap.*, vol. 51, no. 170, pp. 67–89, 2006, doi: 10.2298/EKA0670067A.

[3] R. A. Hadiguna, *Manajemen Rantai Pasok Agroindustri: Pendekatan Berkelanjutan untuk Pengukuran Kinerja dan Penilaian Risiko*, 1st ed. Padang: Andalas University Press, 2016.
[4] S. Cebi and E. Ilbahar, "Warehouse risk assessment using interval valued intuitionistic fuzzy AHP," *Int. J. Anal. Hierarchy Process*, vol. 10, no. 2, pp. 243–253, 2018, doi: 10.13033/ijahp.v10i2.549.
[5] M. Albar and W. Winarno, "Analisis Penyebab Terjadinya Selisih Jumlah Persediaan Suku Cadang di Gudang Perusahaan Jasa Alat Berat," *J. Serambi Eng.*, vol. 8, no. 3, pp. 6365–6370, 2023, doi: 10.32672/jse.v8i3.6247.
[6] K. Jermsittiparsert, J. Sutduean, and T. Sriyakul, "Role of warehouse attributes in supply chain warehouse efficiency in Indonesia," *Int. J. Innov. Creat. Chang.*, vol. 5, no. 2, pp. 786–802, 2019.
[7] D. ERMAWANTO, "Pengelolaan Spare Parts Inventory Dengan Metode Continuous Review, Periodic Review Dan Reliability di Warehouse PT. XYZ," 2020.
[8] M. M. Hamasha *et al.*, "Strategical selection of maintenance type under different conditions," *Sci. Rep.*, vol. 13, no. 1, pp. 1–19, 2023, doi: 10.1038/s41598-023-42751-5.
[9] R. Ahmed, "Risk Mitigation Strategies in Innovative Projects," *INTECH Open Ltd.*, no. 2017, pp. 267–322, 2017.
[10] M. İfraz, A. Aktepe, S. Ersöz, and T. Çetinyokuş, "Demand forecasting of spare parts with regression and machine learning methods: Application in a bus fleet," *J. Eng. Res.*, vol. 11, no. 2, 2023, doi: 10.1016/j.jer.2023.100057.
[11] Z. M. Çınar, A. A. Nuhu, Q. Zeeshan, and O. Korhan, "Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0," *Sustainability*, no. 12, 2020.
[12] R. Utari, "Perancangan Strategi Mitigasi Resiko Supply Chain Di PT Atlas Copco Nusantara Dengan Metoda House of Risk," Institut Teknologi Sepuluh Nopember, Surabaya, 2015.
[13] M. F. A. Maulana, "Analisis Manajemen Risiko pada Aktivitas Supply Chain Dengan Pendekatan Supply Chain Risk Management (Studi Kasus: CV. Tunas Karya)," 2020. .
[14] X. Zhu, Z. Wen, D. Regan, and J. Zhu, "A systematic analysis of supply chain risk management literature: 2012-2021," pp. 2012–2021, 2023.
[15] M. F. Sugihartanto, M. R. Mahendra, I. Baihaqi, and H. Rizaldy, "Supply Chain Risk Management Assessment and Strategy: Case Study in a Hospital Pharmacy," *J. Teknol. dan Manaj.*, vol. 22, no. 1, pp. 35–44, 2024, doi: 10.52330/jtm.v22i1.230.
[16] C. S. Tang, "Perspectives in supply chain risk management," *Int. J. Prod. Econ.*, vol. 103, no. 2, pp. 451–488, 2006, doi: 10.1016/j.ijpe.2005.12.006.
[17] Z. Getu and S. Mengistu, "Risk Management For Sporting Events," *J. Res. Soc. Sci. Econ. Manag.*, vol. 2, no. 3, pp. 391–402, 2022, doi: 10.59141/jrssem.v2i03.292.
[18] Y. S. Al-Nahhas, L. A. Hadidi, M. S. Islam, M. Skitmore, and Z. Abunada, "Modified Mamdani-fuzzy inference system for predicting the cost overrun of construction projects," *Appl. Soft Comput.*, vol. 151, no. May 2023, p. 111152, 2024, doi: 10.1016/j.asoc.2023.111152.