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Supply Chain Risk Management of Aftermarket Products in Automotive Spare Parts Manufacturing Companies Using the House of Risk (HoR) Method

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Abstract. *This study was conducted at an automotive component manufacturing company that produces aftermarket products. This study aims to identify risk events and agents that occur in the supply chain and develop strategies to control existing risks so as to minimize losses. The method used is the House of Risk (HoR). In HoR phase 1, 19 risk events were identified, with 38 risk agents as risk causes. From HoR phase 1, eight priority risks were selected. HoR phase 2 was carried out by determining a mitigation strategy plan with 16 mitigation actions, and then 7 priority mitigation actions were selected based on the effectiveness ratio obtained from the level of difficulty in realizing the mitigation action. Priority mitigation actions that will be carried out include conducting technology evaluations, providing supporting tools such as barcode scanners, creating clear work instructions, reviewing and updating SOPs, conducting three-point checks, conducting systematic quality control, and setting quality limits.*

Keywords: *manufacture, aftermarket, risk, house of risk, supply chain*

I. INTRODUCTION

The automotive industry in Indonesia is currently starting to recover after two years of experiencing a pandemic. According to Laborda & Moral (2014), the automotive industry is one of the sectors with the best performance that provides positive growth for the world economy. Competition between car manufacturers is getting higher. Product quality is the key for manufacturing companies to meet customer satisfaction. Customer demands for quality assurance provided by manufacturers are very high; this is due to the increasingly tight competition in the business world. All companies compete to provide the best quality assurance.

The company that is the object of this research is one of the manufacturing companies that produces products in the form of spare parts and components for two-wheeled and four-wheeled vehicles. The products produced include car or bus air conditioner units, radiators, spark plugs, alternators, starter motors, etc. These products are categorized into several types, namely original equipment manufacturer (OEM) products, original equipment supplier (OES) products, and aftermarket (AM) products for both the domestic market and the export market. Original Equipment Manufacturer (OEM) products are products that are used directly by customers in their production process. Original Equipment Supplier (OES) products are products that are official spare parts for customer brands. Meanwhile, aftermarket products (AM) are products that are sold directly to end customers. Stability and reliability are two of the reasons why investors show strong interest in the automotive spare parts market, and their interest has paid off (Dubner et al., 2022). However, based on data obtained from the company, it is known that the number of errors produced by aftermarket products is the highest when compared to the other two products, as shown in Figure 1.

In every business activity in a company, there are series of long supply chain processes that have the potential to cause risks that can harm the company. This study aims to identify risk events and risk agents that occur in the supply chain activities of product manufacturing.

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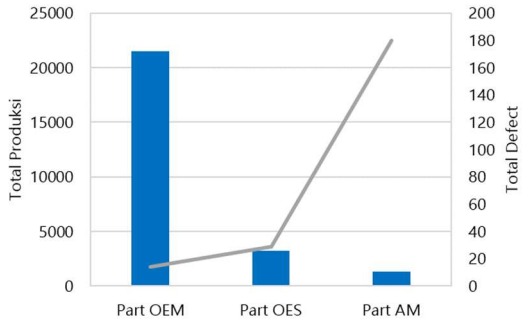

Figure 1. Total Production and Total Defects of OEM, OES, and AM Products

Aftermarket products are products that are sold directly to end consumers (not used directly by consumers in their production process, nor are they official spare parts from consumer brands). In the study by Foshammer et al. (2022), it is known how to overcome the challenges of current component identification and how knowledge management-based component identification is integrated with current operations and supply chains for aftermarket products. The level of error was found in the inspection process before product delivery in the form of inappropriate quantities, inappropriate goods, damaged packaging, delays, and others.

Several studies were conducted using methods such as Supply Chain Resilience Assessment (Afif et al., 2022), other research is improvement of supply chain performance of printing services company based on supply chain operation reference (SCOR) model (Ikatrinasari et al., 2020). Other studies that use the house of risk method include Marchello et al. (2023), Ulfah (2022), Rozidun & Mahbubah (2021), Adhiana & Sibarani (2020), and Ridwan et al. (2020). Therefore, it is necessary to identify, classify, and analyze the risks that occur and develop strategies to prevent and mitigate existing risks so that losses for the company can be minimized.

II. Research Method

Supply Chain Risk Management (SCRM) is a combination of supply chain management and risk management methods. The purpose of SCRM is to ensure that the supply chain will be implemented smoothly without any significant obstacles along the way (Waters, 2007). When there is a risk that can hinder the flow in the supply chain, SCRM will prevent risky events, accept the risks that will occur, and normalize supply chain performance. Effective SCRM is one that aims to manage risk, not eliminate risk. According to Goh et al. (2007), risks in the supply chain consist of two types, namely internal risk and external risk. While Tang (2006) classifies risks into two types, namely operational risk and disruption risk, The House of Risk (HoR) method is a research method that focuses on preventive measures to determine which risk causes are priorities, which will then be given mitigation or risk management actions.

House of Risk (HoR) is an integration of the Failure Modes and Effects Analysis (FMEA) model and the House of Quality (HoQ) model in Quality Function Development (QFD) (Pujawan & Geraldin, 2009). HoR is the newest method for analyzing risk (Magdalena & Vanie, 2019). In practice, HoR uses the FMEA (Failure Mode and Error Analysis) principle to measure risk quantitatively, combined with the House of Quality (HoQ) model to prioritize risk agents that must be given the most effective action to reduce potential risks caused by risk agents. The product function in the QFD method will be replaced with the characteristic function in the HoR model, while the voice of the customer function will be replaced with the identified risk. The HoR method Adapting from the FMEA method, the risk assessment stage that is applied is the Risk Priority Number (RPN), which consists of three factors: the chance of occurrence, the severity of the impact that appears, and detection. In the FMEA model, risk assessment is obtained from the calculation of the Risk Priority Number (RPN), which is influenced by three factors: the probability of risk occurrence (occurrence), the severity of the impact (severity), and the probability of risk occurrence (detection). In the HoR model, the probability of risk occurrence is related to the cause of the risk (the risk agent) and the severity of the impact.

The HoR model underlies risk management with a prevention focus, namely by reducing the possibility of risk agents. The earliest stage in HoR

is to identify risk events and risk agents. Generally, an agent can cause more than one risky event. The House of Risk (HoR) model proposes a work order to proactively control risks, which allows companies to develop proactive activities for addressing risks arising from risk agents. The HoR method only determines the probability of occurrence and the severity of the risk (Waters, 2007).

The stages of the House of Risk are as follows:

1. House of Risk (HoR) Phase 1

HoR phase 1 is the initial stage of the House of Risk method, where HoR phase 1 is the risk identification stage used to determine the risk agents that must be prioritized for preventive action (Kusnindah et al., 2014). The HoR phase 1 framework is carried out to determine the causes of risk (risk agents) that are given priority for risk mitigation actions. In the process of working on it, HoR phase 1 has several stages of work, namely:

a. Identification of risks that may occur in the company's business processes or supply chain activities based on the SCOR model. The SCOR model business process is divided into five parts, namely plan, source, make, delivery, and return. This division of business processes aims to find out where the risk will arise according to its parts.
b. Identification of risks (Risk Event, Ei) for each business process that has been identified in the previous stage. These risks are all events that may arise in the supply chain process that can result in losses.
c. Measurement of the level of impact (severity$i$) of a risk event on the company's business activities or processes. The magnitude of this severity value indicates how much disruption is caused by risk event to the business process. The assessment is carried out with a value range 1–10, when 10 represents an extreme impact.
d. Identification of risk-causing agents (risk agents) namely what factors can be the cause of the identified risk event.
e. Measurement of the value of the occurrence probability (Occurrence, Oi) of a risk agent. This occurrence probability value indicates the level of probability of the frequency of the occurrence of a risk agent so that it can result in one or more risk events that can cause disruption to the business process with a certain level of impact. The assessment of occurrence is carried out with a value range 1–10, 10 represents the cause of the risk often occurring.
f. Measurement of the correlation value between a risk event and the risk-causing agent. If a risk agent causes a risk, then it can be concluded that there is a correlation. The correlation value (Rij) is divided into four levels, namely 0, 1, 3, and 9, where 0 indicates no correlation, 1 indicates a low correlation, 3 indicates a moderate correlation, and 9 indicates a high correlation.
g. Calculation of the risk priority indicator value, or Aggregate Risk Potential of Agent (ARPj), which is the result of multiplying the possibility of a risk-causing event (Oi) and the aggregate impact of the risk event caused by the risk cause. This priority indicator is used as a consideration in determining the priority of rishandling,ng which will later be input into HoR phase 2. The calculation of the ARP value uses the following calculation: $ARPj = Oj \sum SiRij$.
h. Determining the ranking of risk causes based on the largest to smallest ARP values.

2. House of Risk (HoR) Phase 2

HoR phase 2, or risk treatment phase, aims to determine the priority of actions to be given by taking into account resources with effective costs (Ulfah et al, 2017). HoR phase 2 is a mitigation strategy planning used to carry out risk treatment for identified risk agents, some at the priority risk level. The implementation of HoR phase 2 includes several stages of work, namely:

a. Selecting the priority of risk agents by sorting risk agents from the highest to the lowest ARP value according to the Pareto analysis of the Aggregate Risk Potential of agents (ARPj). Risk agents that are included in the high priority category will be input for

HoR phase 2. The determination of the priority risk agent category is carried out using Pareto's law. By controlling 20% of these risks, it is hoped that 80% of the company's risk impacts can be suppressed or even overcome.

b. Identifying appropriate mitigation actions (PAk) against the causes of the risks that arise. Risk management can apply to one or more of the risk causes,
c. Measurement of the correlation between a risk cause and risk management. The correlation relationship will be the assessment material in determining the degree of effectiveness in suppressing the emergence of risk agents. This correlation is symbolized by Ejk. The correlation value (Ejk) is divided into four levels, namely 0 indicates no correlation relationship, 1 indicates a low correlation relationship, 3 indicates a moderate correlation relationship, and 9 indicates a high correlation.
d. Calculate the total value of effectiveness (TEk) for each mitigation action in the risk mitigation strategy using the formula

$$TEk = \sum ARPjEjk, \quad \text{..... (1)}$$

e. Measuring the level of difficulty of implementing mitigation actions (Dk) in an effort to reduce the occurrence of risk causes,
f. Calculate the ratio of the total value of the effectiveness of implementing mitigation actions to the level of difficulty of mitigation actions, or effectiveness to difficulty ratio ($ETDk$) with the following formula: $ETDk = TEk/Dk$. Description: $ETDk$ = Effectiveness to difficulty of ratio TEk = Total effectiveness,
g. Sort the priority of risk mitigation actions from the highest to the lowest ETDk value. The priority value of the main mitigation action is selected based on the highest ETDk value.

III. Result and Discussion

The study begins by defining the aftermarket supply chain in automotive manufacturing companies, identifying the stakeholders, and initially identifying potential risks based on research related to risks in manufacturing replacement products. The supply chain activities studied in this case are the final stages after the production process has been completed. The studied supply chain can be illustrated in Figure 2.

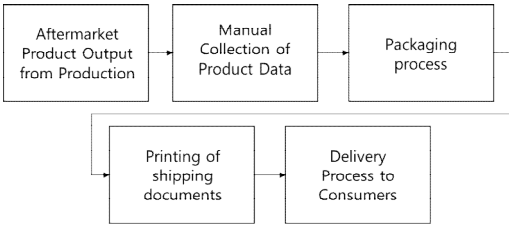

Figure 2. Supply Chain Scope

Table 1. Supply Chain Activity Mapping with SCOR Model

Business Process (SCOR)	Supply Chain Sub Process
Plan	Standard Operating Procedure Design
Source	Raw Material Procurement Incoming Material Inspection
Make	Production Equipment Production Manpower Production Process Control
Deliver	Product Delivery
Return	Product Returns from Customers

The first stage in risk identification begins with mapping supply chain activities with the SCOR (Supply Chain Operation Reference) Model as shown in Table 1. In the Plan activity, the designed SOP covers the process of collecting product data, product packaging, document printing, and delivery to consumers. The Source activity is mapped into the procurement of raw materials for packaging and inspection of materials coming from suppliers. Then in the Make activity it covers equipment, labor, and quality control in the production area in this case covering product packaging. The Deliver and Return activities cover product delivery to consumers and product returns from consumers.

Table 2. Risk Events Identification

Risk Events	Ei
Inaccurate forecast	E1
Employee violation	E2
Poor packaging material quality	E3
Joking at work (Bad behaviour)	E4
Waste time	E5
Human error	E6
Employee burnout	E7
Redundants efforts	E8
Many defects occur	E9
Inneficient manual process	E10
Truck breakdowns	E11
Truck roof leaks	E12
Damaged packaging	E13
Mixed parts	E14
Manual handling injuries	E15
Delivery delay	E16
Delivery code error	E17
Quantity discrepancy	E18
Product returns	E19

After the supply chain activities are mapped, the next step is to identify risks and risk agents based on the supply chain activities. The identification of risks and risk agents is shown in Table 2.

There are 19 risk events in the supply chain that have been successfully identified. Each risk event is a mapping of the SCOR that was carried out at the beginning.

Meanwhile, the risk agents are shown in Table 3. There are 38 risk agents that have been successfully identified from the existing risk events. Each event has at least one or more risk agents.

The relationship between risk events and risk agents is assessed by severity (Si), occurrence (Oj), and aggregate risk potential of risk agents (ARPj) which are mapped with the House of Risk (HoR) Phase 1 as in Table 4.

In order to more easily identify the most influential risk causes, a Pareto diagram is created as in Figure 3 based on the ARPj figures resulting from the calculations.

After the Pareto diagram is made, the next step is to determine the causes of priority risks as

Table 3. Risk Agents Identification

Risk Agents	Aj
Production planning	A1
Packaging material supply	A2
SOP understanding	A3
The employee are less responsible	A4
No clear work discipline rules	A5
No supervision	A6
Lack of employee competences	A7
No standard working hours	A8
Unequal division of labor	A9
The design of SOP	A10
SOP is not clear	A11
QC process is not running well	A12
Employees are not focused	A13
Acceptable quality level	A14
The technology does not support	A15
The equipment is obsolete	A16
The truck not roadworthy	A17
Limited number of trucks	A18
Lack of truck maintenance	A19
The packaging quality is not good	A20
The packaging is not waterproof	A21
Messy storage of packaging	A22
Messy storage of products	A23
Item code cannot be identified	A24
No classification of parts	A25
Excess inventory	A26
No inventory management	A27
Small warehouse area	A28
Warehouse layout	A29
There are many models and types	A30
No classification of codes	A31
There is no quantity checking process	A32
Errors in calculating	A33
No specification checking process	A34
Specification information	A35
Poor delivery management	A36
Truck fleet delayed	A37
Shipping load	A38

shown in Table 5. There are 8 priority risks selected, 20% of which are risks caused by unsupported technology and SOP design, while the rest are risks related to equipment, truck fleet, quality control processes and the quality of packaging materials.

Mitigation actions against the risk causes will be determined against the selected risk causes. The selection of mitigation actions is obtained by

Table 4. House of Risk Phase 2

	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	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	Si
E1	9									3																														3
E2			3	1	3																																			2
E3		3								1											3																			4
E4				1	1																																		1
E5				1	3	3		9	1	1																														4
E6						1	1						1																												3
E7								3																																2
E8							1			9	3		1																											5
E9						3					1	9	3	3	3	3																									8
E10												1		3	9	9																									9
E11																	9	3																							8
E12																	1		3																						5
E13																	1		1	3	9																				6
E14																						1	1	3	3	9	3														7
E15																												3	3												6
E16																		3												1			1					3	3	3	6
E17																							3	1	1						3	3			9	3				5
E18																																	9	3			3			7
E19																				1	1													3	3	1	1				6
Oj	2	3	5	2	3	5	4	6	4	8	8	7	3	4	9	8	8	6	5	4	6	5	4	6	4	5	4	4	6	2	6	8	7	6	5	6	5	5	
ARPj	36	36	30	14	57	195	32	216	40	496	184	567	96	204	945	840	664	252	105	96	432	35	88	156	104	315	84	96	108	30	126	504	273	378	105	270	90	90	

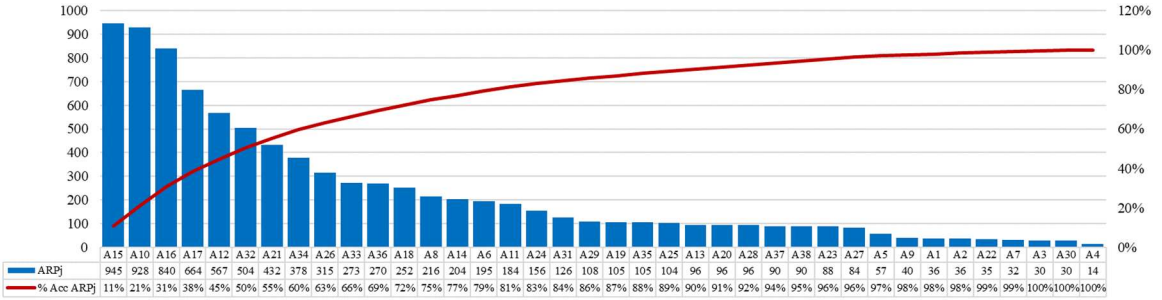

Figure 3. Pareto Diagram of ARP Risk Agents

brainstorming with the affected parties. The selection of mitigation actions can be in the form of reducing, eliminating, or moving the risk causes. A total of 16 mitigation actions proposed by the parties involved can be seen in Table 6.

House of Risk phase 2 is carried out by determining a mitigation strategy plan as shown in Table 7.

After mapping, the next step is to calculate the effectiveness ratio obtained from the level of difficulty of mitigation action realization (Effective to Difficulty Ratio / ETDk). The results of the assessment of the proposed mitigation action can be seen in Figure 4.

Table 5. Priority of Risk Agents

Risk Agents	Aj	ARPj
The technology does not support	A15	945
The design of SOP	A10	928
The equipment is obsolete	A16	840
The truck not roadworthy	A17	664
QC process is not running well	A12	567
There is no quantity checking process	A32	504
The packaging is not waterproof	A21	432
No specification checking process	A34	378

Table 6. Preventive Actions

Preventive Action	PAk
Conducting technology evaluation	PA1
Providing barcode scanner	PA2
Conducting SOP reviews and updates	PA3
Socializing SOPs to employees	PA4
Replacing equipment	PA5
Making agreements with suppliers	PA6
Adding truck fleets	PA7
Conducting balance trucking	PA8
Creating clear work instructions	PA9
Conducting QC with a system	PA10
Conducting three-point checks	PA11
Conducting employee training	PA12
Finding alternative suppliers	PA13
Finding alternative materials	PA14
Giving penalties	PA15
Setting quality limits	PA16

Table 7. House of Risk phase 2

Aj	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	PA10	PA11	PA12	PA13	PA14	PA15	PA16	ARPj
A15	3	3			1												945
A10			9													3	928
A16	9	9			3												840
A17						9	3	3									664
A12			3	1					9	9		1				3	567
A32		1	3						3	1	3	1			3		504
A21													3	9			432
A34			3	1					3	3	9	1					378
TEk	10395	10899	12699	945	3465	5976	1992	1992	7749	6741	4914	1449	1296	3888	1512	4485	
Dk	3	4	5	2	4	4	5	2	3	3	2	1	2	3	2	2	
ETDk	3465	2724.75	2539.8	473	866.25	1494	398.4	996	2583	2247	2457	1449	648	1296	756	2242.5	

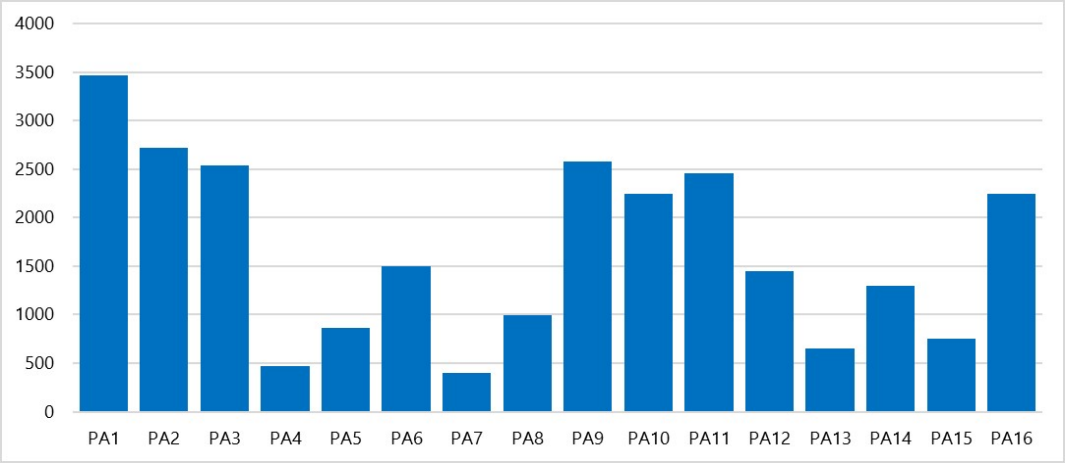

Figure 4. ETDk calculation results for HoR Phase 2

Based on the results of the ETDk HoR phase 2 calculations, 7 priorities were determined as shown in Table 8.

Mitigation actions that will be taken include conducting technology evaluations, providing supporting tools such as barcode scanners, creating clear work instructions, reviewing and updating SOPs, conducting three-point checks, conducting systematic quality control, and setting quality limits. According to Kubáňová et al. (2022), the company initially considered using RFID technology, however, chose to use barcodes because it is a well-known work technology. The use of barcodes must also be continuously improved and repaired to ensure compliance with standards because failure will affect the entire supply chain (Alli, 2021). In terms of work instructions, companies can try digital work instructions such as in research (Letmathe & Rößler, 2021). which states that digital work instructions provide better results in understanding workers in the manufacturing industry. Likewise, Leder et al. (2022) who studied the digitalization of work instructions, for

Table 8. Prioritas Usulan Tindakan Mitigasi

Priority	Business Process (SCOR)	Preventive Action
1	Make	Conducting technology evaluation
2	Make	Providing barcode scanner
3	Make	Creating clear work instructions
4	Plan	Conducting SOP reviews and updates
5	Return	Conducting three-point checks
6	Make	Conducting QC with a system
7	Return	Setting quality limits

example, in assembly or maintenance related to the potential for optimization and increasing product complexity and variety.

Regarding working time, Manaruzzaki et al. (2022) states that it is important to measure working time in the manufacturing industry to increase company productivity. According to Pawar et al. (2023), SOPs must be reviewed, signed, and approved periodically if necessary. In addition, it is very important to produce a Business Management SOP that can be used as a guideline in managing a business better and more accurately in accordance with existing procedures (Oktriyani & Hati, 2019). The next prioritized mitigation strategy is regarding quality, one study (Markotos & Mousavi, 2023), highlights the advantages and disadvantages of the approach widely used in the industrial manufacturing line 4.0 for monitoring and predicting quality. In addition, quality control methods and techniques have been studied in various manufacturing fields over the past few decades Papavasileiou et al. (2024). Therefore, companies must make improvements to the quality control system considering that current technological developments are increasingly advanced.

IV. CONCLUSION

In HoR phase 1, 19 risk events were identified with 38 risk agents as the risk causes. From HoR phase 1, 8 priority risks were selected. HoR phase 2 was carried out by determining a mitigation strategy plan with 16 mitigation actions, then 7 priority mitigation actions were selected based on the effectiveness ratio obtained from the level of difficulty of realizing the mitigation action. Priority mitigation actions to be carried out include conducting technology evaluations, providing supporting tools such as barcode scanners, creating clear work instructions, reviewing and updating SOPs, conducting three-point checks, conducting systematic quality control, and setting quality limits.

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