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An integrated approach for supply chain risk management

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ABSTRACT
Currently, every company is competing to improve the performance of their supply chain, and the efforts include loss mitigation, which requires risk management. This study aims to identify risks and develop risk mitigation strategies for Indonesia's "PT. SPLP" company. First, this study identifies every risk in the Supply Chain Operation Reference to determine the causes. A mitigation strategy is formulated based on the criteria. According to the study results, each division faced specific risks, and the best mitigation strategy was a briefing at the beginning of each shift. The results indicate that different data processing methods used by companies lead to various risks and mitigation strategy results. Risk management is carried out and evaluated at "PT. SPLP" regularly.

KEY WORDS
supply chain, risk management, house of risk, analytical hierarchy process

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Introduction

Globalisation made supply chains longer and more complex (Behzadi et al., 2018). They consist of every party, directly or indirectly involved in fulfilling a customer's request, including the system of organisations, people, activities, information and resources (Chopra, 2016; Singh & Verma, 2018; Madani & Wajeetongratana, 2019). Therefore, supply chain management can be defined as the integration of all involved business processes (Junior et al., 2018). Sup-

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ply chain management aims to increase the products' value (Militaru, 2019), facilitate the flows of goods, information and money through their design, management and coordination (Zhang et al., 2019; Soheilirad et al., 2017).

Undoubtedly, every supply chain management activity is related to risks, which can be defined as a combination of a hazardous event's likelihood and the severity of its consequences (Toyfur & Pribadi, 2016). Therefore, supply chains require risk management.

Risk management consists of planning, organising, leading, and overseeing risk management programmes (Maralis & Triyono, 2019). Supply chain risk management is an activity seeking to eliminate, reduce and control risks in supply chain activity (Raghunath & Devi, 2018). Supply chain risk management aims to identify, assess, mitigate and monitor the risks which might cause a loss in any part of a supply chain (Baryannis et al., 2019).

The heightened risks in increasingly complex supply chain networks have brought risk management to the forefront of research and managerial efforts. Supply Chain Risk Management (SCRM) refers to the management of supply chain risks through approaches coordinated among supply chain partners (Tummala & Schoenherr, 2011; Toyfur & Pribadi, 2016; Chakraborty, 2015; Komza, 2017).

Several recent articles have discussed the idea of collaborative or integrated risk management along supply chains to enhance performance. Tummala and Schoenherr (2011) performed risk management using the Supply Chain Risk Management Process (SCRMP) approach. This study found that the suggested tool could effectively help managers make strategic decisions. The SCRMP can be divided into several phases: risk identification, risk assessment, risk evaluation, preparation of mitigation plans, risk control and monitoring.

Li and Chen (2014) conducted a risk analysis in supplier selection using the Failure Modes and Effect Analysis method. This study was developed by generating two technical deliverables to support risk analysis. First, a framework was prepared to be filled with risks and an assessment of the criteria. Then, calculations were carried out based on the previous framework, and results were sorted to evaluate each supplier. The study results showed that Company H was the best supplier to meet methanol needs.

Sun et al. (2015) conducted a supply chain risk evaluation by studying risk causes based on the operating mechanism, essential characteristics, and results of previous research. Furthermore, the Fuzzy TOPSIS method with four criteria was proposed to evaluate the supply chain risks. As a result of this study, a Chinese manufacturer can choose the best scheme for its supply chain management with the lowest risk.

Hamid et al. (2017) prepared a risk management framework in the Oil Field Development Project. This study was conducted using the Fishbone Analysis method for finding possible risk causes. The study results indicate that potential risks in the Oil Field Development Project can be found and identified to formulate a mitigation strategy.

Pujawan and Geraldin (2009) proposed a supply chain risk management method by developing a House of Quality (HOQ) model with the calculation of Failure Mode Effect Analysis. It aims to rank the mitigation strategies based on the calculation results so that certain mitigation strategies can be prioritised based only on the effectiveness-to-difficulty ratio. The research demonstrated that conducting strategic negotiations with gas suppliers is the best mitigation strategy.

Some previous studies (Tummala & Schoenherr, 2011; Li & Chen, 2014; Sun et al., 2015; Hamid et al., 2017) found that supply chain risk management requires a process sequence, a tool for managers to make strategic decisions. Furthermore, any risk events and risk causes must be identified and assessed first. Several criteria are required to determine the best mitigation strategy that is also more accurate. Therefore, this study combines the House of Risk (HOR) method that assesses each risk event and risk cause and uses the Analytical Hierarchy Process to determine the best mitigation strategy based on several criteria.

This study also adopts the framework proposed by Ghadge et al. (2013) that includes risk identification, risk assessment, and risk mitigation. Risk identification is the first stage of risk management, which ensures risk management effectiveness. Risk managers need to identify possible losses that challenge the organisation to make the risk manageable (Kiprop, 2017). The risk assessment identifies and analyses the associated hazard and prioritises the risk by considering the available data (Ramesh et al., 2017; Accomaso et al., 2018). Risk mitigation is a stage of decision-making based on risk assessment (Bruinen et al., 2007).

Several more recent contributions are addressing risk management from the logistics perspective, such as managing risk with Supply Chain Risk Management Process (Tummala & Schoenherr, 2011), risk analysis for the supplier using FMEA (Li & Chen, 2014), supply chain risk evaluation based on FUZZY TOPSIS (Sun et al., 2015), risk management in oil field development project using Fishbone Analysis (Hamid et al., 2017), and risk management using House of Risk (Pujawan & Geraldin, 2009).

However, a research gap still exists for investigating risk management with a systemic supply chain perspective, assessing important SCRM issues for severity, occurrence, and correlation between risk and its causes and prioritising the mitigation strategy based on several criteria. Hence, this paper aims to fill the gap by understanding the holistic risk assessment for SCRM by combining the House of Risk's Phase 1 (HOR 1) with the Analytical Hierarchy Process. This study aims to generate identified risks and determine the priority order of risk management strategies.

1. Research methods

This study focuses on the supply chain of the "PT. SPLP" company as a case study. The company specialises in Polyvinyl Chloride (PVC) compounds for cable insulation. The production requires around 3 to 15 tons of material for each customer. "PT. SPLP" runs the production non-stop, in three shifts per day. It has hundreds of customers scattered throughout Indonesia.

"PT. SPLP" has a complex supply chain to meet the needs of its customers. Unfortunately, it does not yet have risk management. Therefore, company divisions encounter risk-related losses, e.g., in 2019, the production met the target in only two months out of ten due to engine failure in the production line. Waste production also exceeded the limit for ten consecutive months due to machine errors and inaccuracy of workers. Risk management is necessary to reduce losses.

This study applied the House of Risk approach proposed by Pujawan and Geraldin (2009). First, the risk is identified and assessed; then, the risk mitigation strategy is formulated. The difference is in the part of the formulated mitigation strategy using various criteria to determine the best alternative.

The first data collection aimed to identify risks and their causes in each business process. The objective was achieved by interviews and questionnaires with each division's manager. The respondents were chosen for their knowledge of internal division business processes.

Once risks and causes were identified, an assessment was performed using the FMEA method, where each risk was measured for its severity, frequency and the level of correlation between the risk and its causes. This assessment process was also carried out using a questionnaire filled out by managers of each division.

Then, calculations were made using the House of Quality method for sorting the Aggregate Risk Potential (ARP) of each risk cause from the largest to the smallest. The risk cause with the largest ARP must be prioritised. Using the 80–20 concept, a Pareto Diagram was drawn to show risk causes with the greatest impact.

Once the risk causes were sorted, a mitigation strategy was drawn up based on interviews with division managers. However, several criteria are required to find mitigation strategies to be prioritised as the best. Therefore, the Analytical Hierarchy Process method was used at this stage to compute the importance of each criterion. Criteria weights were selected by division managers. Then, the managers also selected criteria weights for each mitigation strategy.

This series of methodologies was used to obtain the risks and their causes in each company's division to be prioritised for mitigation, the respective mitigation strategies, and the best mitigation strategies based on several criteria.

2. Results and discussion

In the risk management process, risk identification is required first. Risks existed in each company's division and could occur in every process. Therefore, the first data collection focused on the flow of activities within divisions, referred to as business processes. The benefit of knowing business processes in each division is the ability to explore each sub-process for possible risks. The data collection was organised through interviews with each division manager. Table 1 shows the summary of each division's sub-processes.

As already mentioned, these sub-processes were explored for risks that were assessed for severity and occurrence levels. This data was obtained during interviews with division managers to obtain risks and their causes. Questionnaires were used for division managers to assess severity and occurrence levels using the scale set by Geramian (2019). Table 2 lists the risks in each division, risk causes and severity and occurrence levels. The table provides 17 risk events

Tab. 1. Summary of sub-processes

SCOR process	Sub-process
Plan	Receive order
	Input the order to the ERP system
	Schedule the production
Source	Make sales order
	Receive sales order
	Check the inventory
	Purchase the material
	Receive the material
	Inspect the material
	Store the material
Make	Ask for material
	Prepare and deliver the material
	Process the material
	Test the finished goods
	Store the finished goods
Deliver	Store the finished goods
	Inform the delivery schedule
	Deliver the product
Return	Receive a defect claim
	Receive defect goods
	Create the TGA
	Inspect the goods
	Take the decision
	Retype/Reprocess
	Receive the Retyped/Reprocessed goods
	Deliver back the goods

Source: elaborated by the authors based on interview data.

and 25 risk causes. Severity levels range from one to ten, and occurrence levels range from one to six.

The correlation level between risk events and risk causes is required as it shows the influence of a risk cause in producing a risk event. The scale set by Pujawan and Geraldin (2009) was used to determine the magnitude. This data was also collected through the questionnaire filled out by division managers. Table 3 provides the correlation level between risk events and their risk causes.

The obtained severity, occurrence and correlation levels were processed using HOR 1. The purpose of using the method is to determine the number of ARPs for each risk cause. The risk cause with the largest ARP also indicates the largest calculation result for severity, occurrence and correlation. Thus the mitigation needs to be prioritised. Fig. 1 shows the calculation results for HOR 1, and Table 4 provides the sequence of risk causes with the largest ARP in cumulative percentage to apply the 80–20 concept. According to Fig. 1, RA19, "Low demand supplier", has the largest ARP. Tables 5 and 6 show 10 out of 25 risk causes prioritised to be mitigated based on the 80–20 concept.

Once 10 out of 25 risk causes were prioritised, the strategy for handling these risk causes needed to be planned. Mitigation strategies were also obtained through interviews with division managers. Table 5 shows risk causes and their mitigation strategies.

Several criteria are required to determine the best mitigation strategy. These criteria were obtained dur-

Risk Events	Risk Agents																									Severity
	RA1	RA2	RA3	RA4	RA5	RA6	RA7	RA8	RA9	RA10	RA11	RA12	RA13	RA14	RA15	RA16	RA17	RA18	RA19	RA20	RA21	RA22	RA23	RA24	RA25	
E1	9	3	9	3																						8
E2					9	9																				6
E3							9																			6
E4								9	1																	3
E5										3																5
E6	9		9	3							3															2
E7		1																								9
E8												1	3													10
E9														9												1
E10															9	3										1
E11														9												1
E12																	3	9								1
E13																			9	9						10
E14																					9	3				7
E15																							3			5
E16																								3		8
E17																									3	7
Occurrence	3	2	1	3	3	2	5	3	3	1	1	1	1	2	4	1	4	2	6	2	1	1	5	3	3	
ARP	270	66	90	90	162	108	270	81	9	15	6	10	30	36	36	3	12	18	540	180	63	21	75	72	63	
P	2	12	7	8	5	6	3	9	23	20	24	22	17	15	16	25	21	19	1	4	13	18	10	11	14	

Fig. 1. House of risk calculation
Source: elaborated by the authors based on Pujawan & Geraldin (2009).

Tab. 2. Risk activity and causes with severity and occurrence levels

	Risk activity	Severity	Risk causes	Occurrence
Plan	Production is not on schedule	8	Problem in processing machine	3
			Shortage of operator (absent)	2
			Natural disaster	1
			Power outage	3
Make	The finished goods do not match the spec	10	Formula incompatibility	3
			Human error	2
	Imprecise measurement	7	Dirty scales	5
	Damaged products	9	Production process does not match the SOP	3
			Humid environment	3
	Available inventory cannot be utilized	10	Damaged due to time (expired)	1
	Delay in production execution	1	Lack of raw material	1
			Problem in processing machine	3
			Natural disaster	1
			Power outage	3
	An error occurred the number of products produced	1	Shortage of operator (absent)	2
	High scrap rate	1	Change type of product	1
			Engine disassembly required	1
	Leakage of package items	1	Exposed to rain	2
Deliver	Delay in delivery to customers	5	Delivery request is too early	4
			Quality check requires long time	1
	The goods arrived at the customer in poor condition	8	Exposed to rain	2
Source	Delay in delivery raw materials from supplier	6	Material is still in production	4
			Stuck in port	2
	Price fluctuates	5	Low demand on supplier	6
			Exchange rate fluctuation	2
	Damaged raw materials from supplier	2	Bad packaging	1
			Moist in material	1
	Lack of raw material quantity from supplier	6	Material out of stock	5
	Difficulty in looking for items with appropriate spec	3	Not sold by all places	3
Return	Delay in return product to customer	7	Lot of production schedule	3

Source: elaborated by the authors based on questionnaire data and Geramian (2019).

ing interviews through the questionnaire on criteria weights. The Superdecision software and the Pairwise Comparison method were used for calculations. Fig. 2 shows the weight for each criterion. The most important criterion based on the Pairwise Comparison computation was "The result can be seen quickly".

Once criteria weights were found, mitigation strategies could be compared. The weighting was also done through questionnaires filled out by division managers. Weights of each mitigation strategy were also computed using the Superdecision software and the Pairwise Comparison method. Figs. 3–5 show the results of the mitigation strategy comparison.

According to Fig. 3, "Hold a briefing at the beginning of every shift" was the best mitigation strategy based on "easy to apply" criteria. It was also the best mitigation strategy based on "higher benefit-cost" criteria (Fig. 4). Based on criteria "The result can be

Tab. 3. Risk activity and agents correlation level

Risk event-code	Risk activity	Risk agent codes	Risk agents	Correla-tion
E1	Production is not on schedule	RA1	Problem in processing machine	9
		RA2	Shortage of operator (absent)	3
		RA3	Natural disaster	9
		RA4	Power outage	3
E2	The finished goods do not match the spec	RAS	Formula incompatibility	9
		RAS	Human error	9
E3	Imprecise measurement	RA7	Dirty scales	9
E4	Damaged products	RAS	Production process does not match the SOP	9
		RA9	Humid environment	1
E5	Available inventory cannot be utilized	RA10	Damaged due to time (expired)	3
E6	Delay in production execution	RA11	Lack of raw material	3
		RA1	Problem in processing machine	9
		RA3	Natural disaster	9
		RA4	Power outage	3
E7	An error occurred the number of products produced	RA2	Shortage of operator (absent)	1
E8	High scrap rate	RA12	Change type of product in the machine	1
		RA13	Engine disassembly required	3
E9	Leakage of package items	RA14	Exposed to rain	9
E10	Delay in delivery to customer	RA15	Delivery request is to early	9
		RA16	Quality check requires long time	3
E11	The goods arrived at the customer in poor condition	RA14	Exposed to rain	9
E12	Delay in delivery raw materials from sup-plier	RA17	Material is still in production	3
		RA18	Stuck in port	9
E13	Price fluctuates	RA19	Low demand on supplier	9
		RA20	Exchange rate fluctuation	9
E14	Damaged raw materials From supplier	RA21	Bad packaging	9
		RA22	Moist in material	3
E15	Lack of raw material quantity from sup-pliers	RA23	Material out of stock	3
E16	Difficulty in looking for items with appro-priate spec	RA24	Not sold by all plates	3
E17	Delay in return product to customer	RA25	Lot of production schedule	3

Source: elaborated by the authors based on questionnaire data and Pujawan and Geraldin (2009).

seen quickly", "Apply the PLC programme" was the best mitigation strategy (Fig. 5).

Figs. 3–5 show the best mitigation strategy for each criterion. Fig. 6 is the computation result that determined the best strategy based on all the previously weighted criteria. It shows that "Hold a briefing at the beginning of every shift" is the best mitigation strategy based on all the criteria combined.

Supply chain management is an important concept at the "PT. SPLP" company. It aims to eliminate losses from risks in supply chain activities. Therefore, the company requires supply chain risk management to reduce the possibility of risks.

The first step in risk management is to identify risks in each company's division. Based on data in Table 2, 17 risk events were found in all supply chain

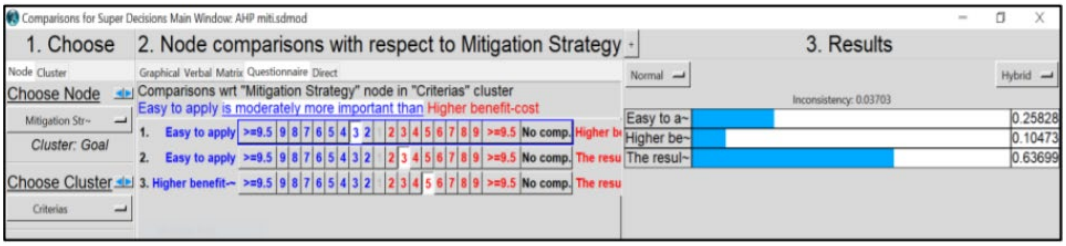


Fig. 2. Mitigation strategy criteria weight
Source: elaborated by the authors using the Superdecision software.

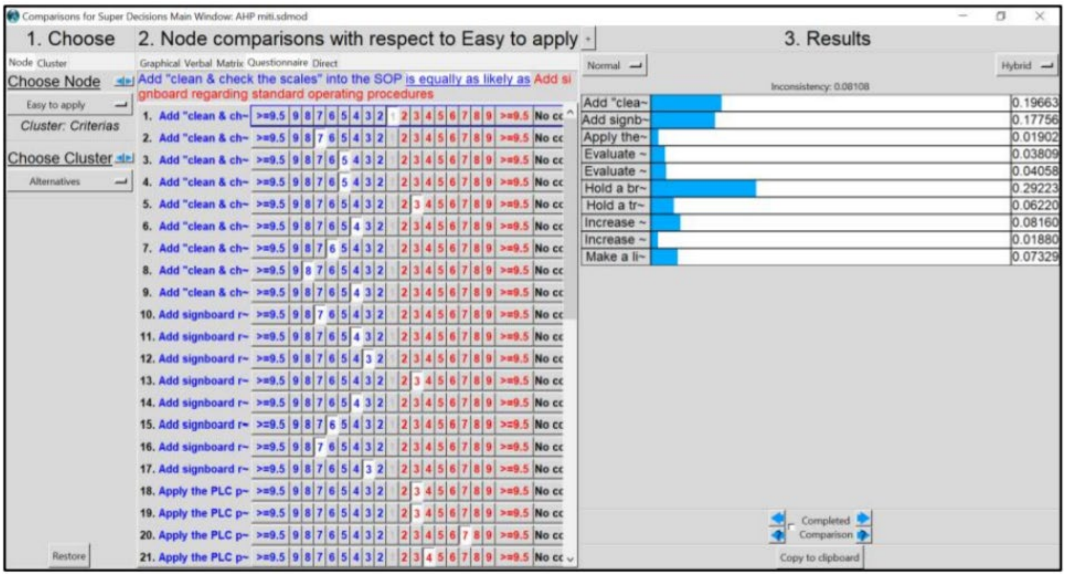
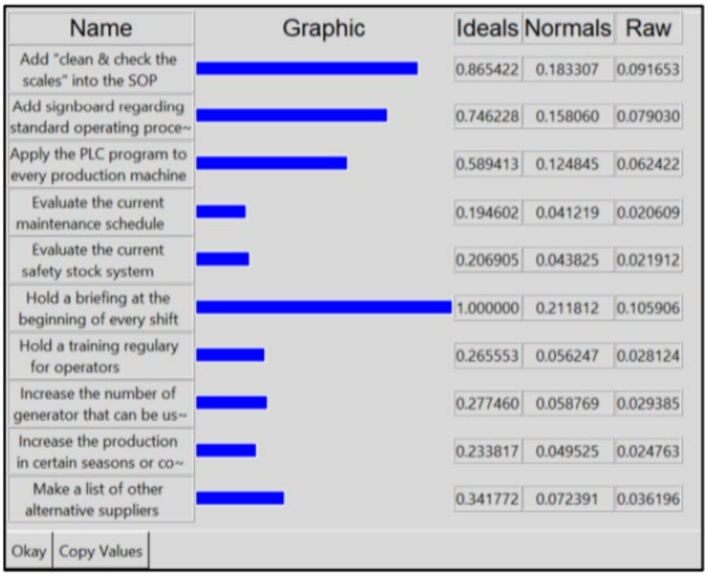


Fig. 3. Mitigation strategy comparison using first criteria
Source: elaborated by the authors using the Superdecision software.

Fig. 4. Mitigation strategy comparison using second criteria
Source: elaborated by the authors using the Superdecision software.

Fig. 5. Mitigation strategy comparison using third criteria
Source: elaborated by the authors using the Superdecision software.



Name	Ideals	Normals	Raw
Add "clean & check the scales" into the SOP	0.865422	0.183307	0.091653
Add signboard regarding standard operating proce~	0.746228	0.158060	0.079030
Apply the PLC program to every production machine	0.589413	0.124845	0.062422
Evaluate the current maintenance schedule	0.194602	0.041219	0.020609
Evaluate the current safety stock system	0.206905	0.043825	0.021912
Hold a briefing at the beginning of every shift	1.000000	0.211812	0.105906
Hold a training regulary for operators	0.265553	0.056247	0.028124
Increase the number of generator that can be us~	0.277460	0.058769	0.029385
Increase the production in certain seasons or co~	0.233817	0.049525	0.024763
Make a list of other alternative suppliers	0.341772	0.072391	0.036196

Fig. 6. Mitigation strategy computation result
Source: elaborated by the author using the Superdecision software.

activities. Most risk events were in the production process, which is not fully automated and works non-stop. All risk causes were assessed for their severity, and those with the highest level were related to the inability to use the inventory and finished goods not matching the specification. Such risks cause financial losses due to wasted production material.

Once risk events were identified, their causes had to be determined. Based on Table 2, 25 risk causes were found for 17 risk events, and some risk causes produced several risk events simultaneously. The risk causes with the highest occurrence level were related to low demand on suppliers resulting in fluctuating material prices. The correlation between risk causes and risk events was assessed and confirmed.

This study prioritised some risks by using the House of Risk method calculating severity, occurrence, and correlation levels. Then, using the 80–20

Tab. 4. Risk agent rank with cumulative percentage

P	Risk agent codes	Risk agents	ARP	%	%Cum
1	RA19	Low demand on supplier	540	23.22	23,22
2	RA1	Problem in processing machine	270	11.61	34,82
3	RA7	Dirty scales	270	11.61	46,43
4	RA20	Exchange rate fluctuation	180	7.74	54,17
5	RA5	Formula incompatibility	162	6.96	61,13
6	RA6	Human error	108	4.64	65,78
7	RA3	Natural disaster	90	3.87	69,65
8	RA4	Power outage	90	3.87	73,52
9	RA8	Production process does not match the SOP	81	3.48	77,00
10	RA23	Material out of stock	75	3.22	80,22
11	RA24	Not sold by all places	72	3.10	83,32
12	RA2	Shortage of operator (absent)	66	2.84	86,16
13	RA21	Bad packaging	63	2.71	88,87
14	RA25	Lot of production schedule	63	2.71	91,57
15	RA15	Delivery request is to early	36	1.55	93,12
16	RA14	Exposed to rain	36	1.55	94,67
17	RA13	Engine disassembly required	30	1.29	95,96
18	RA22	Moist in material	21	0.90	96,86
19	RA18	Stuck in port	18	0.77	97,64
20	RA10	Damaged due to time (expired)	15	0.64	98,28
21	RA17	Material still in production	12	0.52	98,80
22	RA12	Change type of product in the machine	10	0.43	99,23
23	RA9	Humid environment	9	0.39	99,61
24	RA11	Lack of raw material	6	0.26	99,87
25	RA16	Quality check requires long time	3	0.13	100,00
Total			2326	100.00	

Source: elaborated by the authors based on Pujawan and Geraldin (2009).

Tab. 5. Risk mitigation strategies

No	Risk codes	Risk agents	Mitigation strategy
1	RA19	Low demand on supplier	Make a list of other alternative suppliers
			Evaluate the current safety stock system
2	RA1	Problem in processing machine	Evaluate the current maintenance schedules
3	RA7	Dirty scales	Add “clean & check the scales” into the SOP
4	RA20	Exchange rate fluctuation	Evaluate the current safety stock system
5	RA5	Formula incompatibility	Apply the PLC program to every production machine
6	RA6	Human error	Hold a briefing at the beginning of every shift
			Hold a training regularly for operators
7	RA3	Natural disaster	Increase production in certain seasons or conditions
8	RA4	Power outage	Increase the number of generators that can be used
9	RA8	Production process does not match the SOP	Hold a briefing at the beginning of every shift
			Add signboard regarding standard operating procedures
10	RA23	Material out of stock	Make a list of other alternative suppliers

Source: elaborated by the authors based on interview data.

concept, ten risk causes were prioritised out of 25. The next step in risk management is to develop a mitigation strategy for each risk cause and obtain ten mitigation strategies in total. Several risk causes could be handled with several mitigation strategies, but one mitigation strategy can also handle several risk causes.

In determining the best mitigation strategy, several considerations are required in the form of criteria that are considered important. Three criteria were determined, and the Superdecision software was used to find that "the result can be seen quickly" was the best option. Furthermore, each mitigation strategy was compared with others based on criteria showing the best mitigation strategy for each criterion. "Hold a briefing at the beginning of every shift" was deemed the best mitigation strategy.

This study demonstrated that risk events and causes must be prioritised to be addressed by the best mitigation strategy based on several predetermined criteria. Therefore, it demonstrated the significance of supply chain risk management at the "PT. SPLP" company, which needs to be implemented, maintained and evaluated regularly.

In the supply chain literature, the risk management process has been proposed as a highly relevant theoretical lens to inspect SCRM issues, therefore, deserving more research. This study contributes to the SCRM literature by investigating risk management with a systemic supply chain perspective and assessing important SCRM issues from the standpoint of their severity, occurrence, and correlation between risks and their causes, also prioritising the best mitigation strategy based on several criteria. Moreover, this study contributes to the literature by empirically identifying risks and developing risk mitigation strategies at "PT. SPLP".

To the best knowledge of the authors, there are very few studies in SCRM literature that focus on the empirical investigation of the holistic method's role in mitigating supply chain risks and prioritising mitigation strategies. By doing so, this study seeks to address the call in the literature to test the integrated method on the SCRM effectiveness and, consequently, on performance outcomes (Tummala & Schoenherr, 2011; Li & Chen, 2014; Sun et al., 2015; Hamid et al., 2017; Chaudhuri et al., 2018).

The study findings suggest that integration of HOR 1 and AHP is important for assessing the supply chain risk and developing appropriate mitigation strategies. This finding extends the existing literature, which mainly focuses on the importance of an integrative method for a risk mitigation strategy. Furthermore, the results reveal that the proposed model builds for effective risk management and enhanced performance.

Conclusions

This study ranks identified risk causes based on severity, occurrence and correlation levels calculated using the House of Risk (HOR) method. Mitigation strategies for each risk cause were identified and sorted based on the criteria that are considered most important using the Analytical Hierarchy Process (AHP) method with the Superdecision software.

Based on data processing results collected in the studied company using a risk confirmation questionnaire, 17 possible risk events were identified in SCOR processes. One risk event was identified in "Plan" process, five — in the "Source" process, seven — in the "Make" process, two — in the "Deliver" process, and one — the "Return" process.

Questionnaire results indicated 25 risk causes, and ten of them were prioritised using HOR calculations. Ten mitigation strategies were identified based on ten risk causes that were prioritised previously.

Based on the results of the Analytical Hierarchy Process (AHP) using the Superdecision software, the best mitigation strategy is to hold a briefing at the beginning of every shift. This measure met all mitigation strategy criteria the most, followed by "Add 'clean & check the scales' into the SOP", "Add signboard regarding standard operating procedures", "Apply the PLC program to every production machine", "Make a list of other alternative suppliers", "Increase the number of generators that can be used", "Hold a training regularly for operators", "Increase production in certain seasons or conditions", "Evaluate the current safety stock system", and "Evaluate the current maintenance schedule".

Further research requires focusing on the relationship between risk causes as they may trigger other risk causes. Then, a programme can also simplify the calculation of supply chain risk management.

There are also some suggestions for the "PT. SPLP" company is to follow the practical implication contained in this study and establish supply chain risk management as a regular exercise.

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