RISK MITIGATION IN SUPPLY CHAIN RPET MANUFACTURING WITH FUZZY LOGIC BASED HOUSE OF RISK (HOR) APPROACH

THESIS

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AUTHENTICITY STATEMENT

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Yogyakarta, March 2022

Maeva Apriza Putri

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DEDICATION

This thesis is dedicated for my family and friends in Teknik Industri Universitas Islam Indonesia, who encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started. Thank you for everything. My prayer and love for all of you can never be quantified.

MOTTO

"So verily, with the hardship, there is a relief. Verily, with the hardship, there is relief (i.e. there is one hardship with two reliefs, so one hardship cannot overcome two reliefs)."

– QS. Insyirah : 5-6

PREFACE

Assalamu'alaikum Wr. Wb.

Alhamdulillahirrobbilalamin and gratitude are presented to Allah the Highest, while blessings and greetings mahabbah are also delegated to the Prophet Muhammad. With all humility let the Author expresses gratitude and highest appreciation to all those who have been supporting and motivating to complete this Thesis. The Author would like to say thanks to:

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The author realizes this report is not perfect. Thus, suggestions and critics are fully expected.

Wassalamu'alaikum Wr. Wb.

Yogyakarta, March 2022

Maeva Apriza Putri

ABSTRACT

In this developing era, business competition is no longer a competition between companies independently but has been dominated by competition between management in the supply chain. One of the challenges for companies today is managing and tackling the risks that exist in the series of processes carried out. That is why this research aims to identify, prioritize, evaluate, and mitigate the risks that might occur in the supply chain process of PT. XYZ. To collect the data, the researcher perform interviews, Focus Group Discussion (FGD), and questionnaires. Then, the data are mapped into the SCOR model to identify the risk event and agent. This research is using Fuzzy logic to identify the severity and occurrence of its risks. It will be followed by the House of Risk (HOR) first and the second phase to evaluate and mitigate the risks. From the method that has been applied and calculated, the results reveal 11 risk agents. To get mitigation actions, there are 16 actions based on the result of HOR phase 2 that has been conducted.

Keywords: Fuzzy, House of Risk, Mitigation, SCOR

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CHAPTER I

INTRODUCTION

This chapter, explains a brief introduction that elaborates the background, problem formulation, purpose, scope, and benefit of the research, as well as the systematic writing.

1.1 Background

The changing of the economic, social, political, and environmental conditions directly affects the industry. Many companies that previously were big then became small companies or experienced bankruptcy because they could not adapt to the situation and analyze the potential risk from many sides. Chang & Cheng (2010) stated that to maintain the competitive edge of an enterprise, that will guarantee the product quality, cost, and timing fit with market demand. It means that the operational or performance of the company should be monitored and controlled because improving the operating performance company will affect the industries or enterprise in increasing the profit. Many methods were used by the company that possibly of gaining operational or performance excellence. The critical role of the supply chain as one of the processes in the company's operations covers the fulfillment of needs, namely the purchase of raw materials to the fulfillment of consumer needs. According to Anasfasia (2017), the supply chain is crucial to developing a competitive business.

However, frequent bottlenecks in the supply chain lead to the emergence of unplanned and planned risks. In running the supply chain, a company is confronted with various risks in the process chain and supply chain members. In simple terms, the risk is a condition where there is a possibility of deviation from an expected result. According to Hendricks and Singhal (2003), supply chain disruptions can have a long-term negative impact on companies which often results in many companies not recovering from these risks.

This supply chain risk can be minimized if the company applies good supply chain rules. One of them is applying the Supply Chain Operation Reference (SCOR) Model. This model was developed to use self-assessment methods and a comparison of supply chain activities and performance. The focus of this model is the framework of business processes and best practices, and information technology from a supply chain to increase the effectiveness of supply chain management and optimize the chain.

PT.XYZ is a multinational company that has expertise in producing Recycled polyethylene terephthalate (RPET). Collaborated with the biggest food and beverage company in Indonesia. This company is situated in East java and become the biggest Recycled polyethylene terephthalate (RPET) company in Asia. Currently, the company's problem is identified for the absence of structured risk management to identify and mitigate risks, especially in the supply chain process. Based on the field survey that was conducted by the researcher, this company has several problems that should be solved. The most frequent problem is the delay or high lead time due to risk happening in the production process so it impacts on the whole process of the supply chain. This problem leads to the inability to meet the demand and missed scheduling of delivery of finished goods that already stated in the agreement, which will cause a loss of sales. Moreover, the company may get a penalty for this problem. So that, it might loose the trust from clients and suffer loss, financially.

Risks are generated from the supply chain, so the people in charge of the processes should be aware of those risks (Oliveira, Leiras A & Ceryno P, 2019). Risk assessment may be used to increase decision-making effectiveness to conduct and implement risk reduction actions (Jung SY, Repetti T, Chatfield HK (Grace), Dalibor M & Chatfield R, 2019). Therefore, it is necessary to conduct research to identify and analyse the risks that may arise in the supply chain and mitigate these risks by implementing the House of Risk method. Therefore, a risk assessment is needed so that in the future, they will familiar with problems ranging from minor to primary, which can hinder the process of supply chain flow at the company. Risk assessment is a part of risk management, which is critical to completing a project (Chaouch S, Mejri A & Ghannouchi SA, 2019). This research will be focused on risk assessment and preventive action in PT. XYZ, is a Recycled polyethylene terephthalate (RPET) company in Pasuruan, Indonesia. Gaspersz (2005) stated that performance measurement plays a significant role in improving the company towards a better direction.

Many experts have discussed the matters of supply chain risk mitigation. In the journal, one of them was put forward by I. Nyoman Pujawan and Laudine H. Geraldin (2009), stated that companies need to have proper risk management or supply chain to survive in a challenging business environment. If handled poorly, disruptions in the supply chain can result in costly delays leading to low service levels and high costs (Blackhurst et al., 2008).

House of risk is a suitable method to identify risks in the supply chain process of PT. XYZ. The house of risk approach presents the final result, namely risk management actions in order of priority. The final result is only seen from the correlation between preventive action and risk agent. In practice, regarding risk management, several researcher have used the HOR approach. One of them was Putri (2017), however, while taking the severity and occurrence questionnaire data using a Likert scale of 1-5, doubts arose in determining the answer. When compared with other logic systems, fuzzy logic can produce fairer decisions. It is supported by Kusumadewi (2016) that fuzzy logic has tolerance for inappropriate data. Thus, a fuzzy logic approach is needed in this study to confirm the fuzzy membership value. Fuzzy logic models intuition or feelings during the fuzzification stage and then incorporates them into fuzzy rules based on knowledge. In addition, the function of fuzzy logic is also to accommodate fundamental human nature, which is difficult to determine with certainty or doubt. According to policymakers, hopefully, this fuzzy approach can influence the right and good results based on what is happening in the company's internal supply chain lines.

1.2 Problem Formulation

After describing the problems that occur and the main focus to be studied, the researcher have formulated the problems faced in this study, including the following:

1. What are the risk factors that may occur in the Supply chain process based on the fuzzy house of risk?
2. What are the mitigation strategies in order to eliminate the risk based on a fuzzy house of risk?

1.3 Objective Research

Based on the problem formulation above, the objectives of the research can be arranged as follows:

1. Identifying and prioritizing the risk factors that occur in the supply chain process of PT.XYZ
2. Evaluating and mitigating the risk that occurs in the supply chain process of PT.XYZ

1.4 Scope of Problem

The scope of a problem is a restriction or limitation of problems to make a border in the research in order to keep the research inside the scope. There are some limitations as follows:

1. This research was conducted in PT. XYZ.
2. This research uses Fuzzy Logic, SCOR, and HOR method as a tool for analyzing the problem.
3. The data used are primary and secondary data provided entirely by companies and individuals related to the company.
4. The scope of research only focuses on the company's internal supply chain.

1.5 Benefit of Research

The benefits expected from the implementation of this research work are:

A. Benefit for students

1. To obtain overview of the risks and ways to overcome them when working later. especially regarding supply chain management.

B. Benefits for the company:

1. Companies can be aware of risks that may re-emerge.
2. This research is expected to provide useful information for the company.
3. Companies get alternative for risk mitigation
4. The company has priority risk mitigation alternatives

C. Benefits for other researcher

1. This research is expected to be used as a useful reference. Especially regarding supply chain management and methods in it.

1.6 Systematical Writing

Study writing is based on the rules of scientific writing in accordance with the systematics as follows:

1. **CHAPTER I INTRODUCTION**

This chapter consists of background problem, formulation of the problem, research question, problem limitation of the research, the objectives or purpose research, the benefits of research, and systematic writing.

2. **CHAPTER II LITERATURE**

   In this chapter, there will be an elaboration on the theories of reference books and journals as well as the results of previous study related to the research problem which are used as a reference for problem-solving.

3. **CHAPTER III RESEARCH METHODOLOGY**

   This chapter consists of the description of the framework or concept, the line schedule of research, and the methodology in conducting the research.

4. **CHAPTER IV COLLECTION AND PROCESSING DATA**

   This chapter contains the data obtained during the research and how to analyse the data. Data processing result is displayed either in the form of tables, or graphs. What is meant by processing the data also includes analysis of the results obtained. This section is a reference to the discussion of the results to be written in Chapter V.

5. **CHAPTER V DISCUSSION**

   This chapter presents a discussion of the data processing results that have been done in research, compatibility with the objectives of research to produce a recommendation.

6. **CHAPTER VI CONCLUSION AND RECOMMENDATION**

   This chapter consists of the conclusion of the research and is completed with recommendations for future research.

REFERENCES

APPENDIX

CHAPTER II

LITERATURE REVIEW

This chapter elaborates the literature review studies which are divided into two, preliminary study and Fundamental theory. The preliminary study is a study derived from reputable previous research. Besides, the fundamental theory is a study that explains about the basic theory derived from the textbooks that correlated with the recent research. Preliminary and fundamental studies need to be done to reveal the gap between the previous study and the recent research as well as to avoid plagiarism. This literature review will be divided into several sub-chapters.

2.1 Preliminary Study

Several studies employ House of Risk method to mitigate risk. One of the research was conducted by Aini et al. (2019) who conducted its research in the women's clothing industry. The research aims to recognize the risks that might occur in the supply chain so that they can be minimized. From the observing and interviewing results, it is found that there are seven risk events and ten risk agents that occurred in the clothing industry X. Two of the risk agents are sudden demand and human error. To mitigate the risk, the researcher suggest making agreements with suppliers regarding the immediate orders and also conducting training for workers. Ahmad et al. (2020) conducted similar research for different industries, which is the women's handbag industry. This research also uses two phases of the House of Risk (HOR) method, which aims to identify and mitigate risk in its supply chain activities.

There is also Ratnasari et al. (2018) who examined the risk in the newspaper industry to formulate the risk mitigation alternative. The research is using SCOR (Supply Chain Operation Reference) to identify the risk, which is plan, source, deliver, make, and return process in the newspaper industry's supply chain. HOR method identified 24 risk events and 20 risk agents. Maulidah (2020) also analyzed and mitigated the risk of tobacco's supply chain using SCOR and HOR, respectively. The research suggested several mitigation strategies. Handayani et al. (2019) conducted similar research for a different industry, which is a dairy company. It is stated that the HOR model is used to analyze risks using the SCOR approach as well. This research implemented Failure Mode and Effect Analysis (FMEA) to obtain the value of risk level in the HOR phase 1. Then followed by Quality Function Deployment (QFD) to reduce the identified risk causes. The study found 15 risk events and 11 risk agents. 7 out of 11 risk agents contributed 79.55% to the company's total risk.

Wahyudin and Santoso (2016) also mitigated risk in one of the company, which sells mozzarella cheese and yogurt as the products. It is slightly different from the previous research discussed because it is focused on the product development phase for the yogurt drink. This phase is needed by the company to achieve the company's goal to expand the market. HOR is the method that was used to identify the risk. The research obtained 20 risks with 27 identified risk agents. Then, by using Aggregate Risk Potential (ARP) value and Pareto principle, this research formulates a guideline to mitigate top-three risk agents. Similar research was conducted by Siregar and Suparno (2020) in one of the mining companies in Sulawesi, which aims to analyze operational risk using the HOR method. After identifying the risks using the SCOR approach, HOR is being executed. The result shows that 17 preventive actions are obtained. Then, those inputted to the HOR phase 2 to rank the most effective prevention, based on cost and resources. Not only mining but there is also a study in the marine industry which conducted by Amelia et al. (2017). This research aims to analyze risks in PT PAL Indonesia's business process. Then, the HOR model was executed to measure the severity and occurrence. Then, seven risk agents are selected based on Pareto Diagram 80/20 which later will become the suggestions for the management of PT PAL Indonesia.

Santoso and Wafi (2019) conducted research in PT XYZ which runs cocoa commodities in East Java. The company has not implemented supply chain risk management to identify and mitigate the risk. After interviewing the experts, the researcher calculate the data using the Fuzzy HOR method. The result shows 17 mitigation strategies for farmer's and 30 mitigation strategy for company's that suggested by the researcher.

Some studies also analyze and mitigate risk not only using HOR but also using the additional method. Several methods can be combined with HOR which is Analytical

Network Process (ANP). These methods applied to make the research especially in prioritizing the risk is more accurate.

Kurniawan et al. (2021) studied PT XYZ, which is one of the palm oil companies. The research aims to determine the priority of the risk agents using SCOR, HOR phase 1 and followed with ANP. The SCOR method is applied to map the supply chain activity. HOR phase 1 is addressed to determine the priority of the risk agent, while the ANP is designated to determine the priority of mitigation actions as suggested. This research concludes the existence of 36 risk events and 35 risk agents. 19 from 35 risks are being prioritized and 11 preventive actions are proposed to be implemented in the palm oil company, PT XYZ. Another research also has the same objective, which is to identify supply chain risk and suggest mitigation strategies to be implemented in the case study. This research is also using SCOR to analyze the risk and mitigate it (Afifa and Santoso, 2018). Later, the researcher could conduct the risk assessment using a fuzzy-FMEA method, to analyze the risk weight. To formulate the mitigation strategies, the researcher use the Fuzzy ANP method. From this research, it can be concluded that fuzzy FMEA can be used to analyze the risk supply, while fuzzy ANP can formulate the risk mitigation to support supply performance.

Puji et al. (2019) investigated the risks in the supply chain activity of CV. Multiguna which located in Yogyakarta. First, the risks are identified using the SCOR approach. Then, fuzzy logic, HOR, and AHP to know the risk mitigation and rank the priority. Actually, from the HOR method, it can be seen the mitigation option, but to make sure, AHP was conducted. From the AHP process, it obtained the consistency value which is equal to 0.09 or considered valid for $CR < 0.1$.

Different from previous research, Wang et al. (2018) conducted research that aims to get a solution to the shortcomings of traditional FMEA. The research uses a transmission system to demonstrate the proposed approach for the risk evaluation. The method used in this research is the HoR-based rough VIKOR (*VIsekriterijumska optimizacija i KOmpromisno Resenje*) approach. The result shows that the proposed model can aggregate the diversity evaluation of experts better. Besides, it also can minimize the information loss in the FMEA process using the rough number from the VIKOR method.

Not only in the supply chain sector but there is also research about risk which is related to health. Fariza et al. (2020) conducted research about tuberculosis (TB) in Surabaya.

The researcher map the risk using the fuzzy method. The result shows that from 31 sub-districts, using four factors influence TB, in the last three years, there are 4 sub-districts that the risk is decreasing (12.9%). Another research also uses Fuzzy logic as the method to assess the risk (Santos et al. 2020). The research aims to evaluate the risk level of system development in the open innovation environment. Table 2.1 shows the research map from previous researcher related to this research.

Table 2.1 Research gap

No	Author	Year	Problem Identification	Method						Main Result
			Data, Questionnaire & Interview	FMEA	SCOR	HOR	ANP	Fuzzy	Other	
1	Aini et al.	2019	v			v				Interactive decision support system for increasing inventory control.
2	Ahmad et al.	2020	v			v				Developing the critical factors on the risk production process into mitigation strategy.
3	Ratnasari et al.	2018			v	v				Optimization to determine the optimal process of the suitable flow process supply chain of the UMKM in Jakarta.
4	Handayani et al.	2021			v	v				Supply chain optimization in order to increase the capacity planning for the next years by assessments in risks.
5	Wahyudin and Santoso	2016	v			v				Mitigation action focused on the production due to a lot of risks that occur in the supply chain based on the production process.

No	Author	Year	Problem Identification	Method						Main Result
			Data, Questionnaire & Interview	**FMEA**	**SCOR**	**HOR**	**ANP**	**Fuzzy**	**Other**	
6	Kurniawan et al.	2021			v	v	v			Dynamic mitigation action by increasing the capacity of the stocks up to 1.4%.
7	Maulidah	2020			v	v				Implementation of the mitigation in order to reduce the production process risk.
8	Wang et al.	2018		v					v	The risk was occur based on the procurement and designing the supplier management.
9	Fariza et al.	2020	v					v		The decrease of the performance was based on the potential risk that happens in the production – delivery.
10	Afifa and Santoso	2018			v		v	v		Most of the problems came from production and in order to decrease that, capacity calculation and scheduled downtime are required.
11	Santoso and Wafi	2019	v			v		v		The machine was the main problem and create more than 12 high levels of risk.

No	Author	Year	Problem Identification				Method			Main Result
			Data, Questionnaire & Interview	FMEA	SCOR	HOR	ANP	Fuzzy	Other	
										To develop it need daily maintenance and good machine management.
12	Puji et al.	2019			v	v		v		The performance of the SC decreased due to a lot of problems that happen in Make and Source. The design mitigation used experts discussion.
13	Siregar and Suparno	2020			v	v				The FGD and interview will create the credibility of the mitigation action in the production supply chain in PT. XYZ.
14	Amelia et al.	2017	v			v				11 wastes were eliminated in order to decrease unnecessary processes.
15	Santos et al.	2020	V					V		Fuzzy of empirical approaches for better management production determination.
16	Prazakova et al	2016	V		V					
17	Chin et al.	2018				V			V	The changing of the mitigation action will affect the lead time of the
18	Kozarevic et al.	2018	V					V		

No	Author	Year	Problem Identification		Method					Main Result
			Data, Questionnaire & Interview	FMEA	SCOR	HOR	ANP	Fuzzy	Other	
19	Breen et	2021							V	production process and reorder point of
	al.									the company.
20	Aryal et al.	2018			V				V	
	Zailani et									The probability risk might happen due
21	al.	2017			V				V	to the internal SC than the external
	Haleem									problem.
22	and Jami	2021			v	V				More than 11% reduction of back order
	Khan et al.									quantities.
23	Azaeil	2020						V	V	There are more than 10 risks that might
24	Hadeed et	2019	V		v					become potential risks, based on the
25	al.	2017	V		v					halal critical point.
	Liu et al.									The U.S exports create many risks since
26	Jena	2016	V	V						a lot of repercussions for U.S exporters.
27	Costa et al	2019				V				The external risk such as recessing or
28	Wiengarte	2018							V	work stoppage should be mitigated by
29	et al	2016	V		v					developing key manufacturing
	Wang et al									partners.
30	Ghage	2018	V					V	V	In order to decrease the external risk,
31		2016	V	V						the sector of specialization has to be

No	Author	Year	Problem Identification	Method						Main Result
			Data, Questionnaire & Interview	FMEA	SCOR	HOR	ANP	Fuzzy	Other	
										conducted by the level of trade, fiscal policy, and monetary. Defining postpones as the delay of the movement formulation of a product until purchase orders are received to reduce the risk of inventory

2.2 Fundamental Theory

2.2.1 Risk Management

Risk is defined as a type of unpredictable event that will arise in the future, with decisions being made at this time based on various factors. Risk is split into pure and speculative risk. Pure risk is the risk that exists, such as the risk of physical assets, employee risk, and risks that might arise, with the probability of loss. Speculative risk is the risk of loss and gain, for example, risk and operational risk (Fahmi, 2010). Based on ISO 310000:2009, risk management is an essential business activity for the enterprise of all sizes. Enterprises that manage risk effectively will thrive and produce high-quality services or standards where these are organizational objectives.

2.2.2 SCOR

The SCOR (Supply Chain Operation Reference) model is endorsed by the SCC (Supply Chain Council). This model was created by SCC in order to provide an independent research method and comparison of supply activities and performance as a chain management standard in the industry (Paul, 2018). The SCOR model consists of five components: plan analysis, sources analysis, make analysis, delivery analysis, and return analysis (Salazar F, Caro M, & Cavazos J, 2012). Each of these components is considered both an important intra-organizational function and a critical inter-organization process. This framework can be viewed as a strategic tool for describing, communicating, implementing, controlling, and measuring the complex or flexible supply chain process to support communication and collaboration processes between supply chains so as to increase supply chain effectiveness and supply chain improvement effectiveness (Seifbarghy, 2010).

SCOR structure consists of 5 parts, such as plan, source, make, deliver, and return. The five sections will be explained in Table 2.2 (Salazar, Caro, & Cavazos, 2012).

Table 2.1 SCOR structure

Category	Description
Plan	Processes related to planning, scheduling, supply chain coordinator.
Source	Processes related to the procurement of raw materials, receipt, and storage of raw materials.
Make	Processes associated with converting raw materials into finished products.
Deliver	Processes associated with the storage, packaging, and delivery of finished products to customers.
Return	Return of goods from business unit customers.

2.2.3 Fuzzy Logic

2.2.3.1 Fuzzy Logic

Fuzzy is a theory that has the ability to represent/manipulate data and information that has uncertainty based on independent statistics. In addition, the fuzzy theory has been systematically designed to represent uncertainty and ambiguity and provides formal tools to deal with the inherent imprecision of decision-making problems. According to (Roghanian & Mojibian, 2015) fuzzy theory is a theory used to overcome uncertainty and imprecision. The big contribution of a fuzzy theory is the ability to present fuzzy data. The fuzzy theory has been applied to many cases that require the ability to manage uncertainty and vague values such as risk management. The degree of membership of a data and uncertain conditions that require an answer that cannot be determined absolutely "yes" or "no" can be calculated using fuzzy logic. Several things need to be recognized in understanding fuzzy systems, namely:

a. Fuzzy Variable

Fuzzy variables are variables that will be discussed in a fuzzy system. Example: age, temperature, demand, etc.

b. Fuzzy Set

A fuzzy set is a group that represents a certain condition or situation in a fuzzy variable.

c. Universe of Conversation

The universe of speech is the entire value that is allowed to operate in a fuzzy variable. The universe of speech is a set of real numbers that always increase (increase) monotonically from left to right. The value of the universe of speech can be a positive or negative number. Sometimes the value of the universe of this conversation is not limited to its final limit.

d. Domain

The domain of the fuzzy set is the total allowable value in the universe of discourse and may be operated in a fuzzy set.

2.2.3.2 Fuzzy Set

Fuzzy logic is a logic that has a value of ambiguity between true or false. In fuzzy logic, a value can be true or false at the same time. But how much truth and error on something depends on the weight of its membership. The degree of membership of fuzzy logic is in the range of 0 to 1. In contrast to classical logic which only has two values, namely 0 or 1. Fuzzy logic is used to translate a quantity expressed in the language as below.

a. One (1), which means that an item belongs to a set.

b. Zero (0), which means that an item is not a member in a set

Fuzzy sets are based on the idea of extending the range of characteristic functions such that the function will include real numbers in the interval [0,1]. The membership value indicates that an item in the universe of conversation is not only at 0 or 1 but also values that lie between them. In other words, the truth value of an item is not only true or false. A value of 0 indicates false, a value of 1 indicates true, and there are still values that lie between true and false. The fuzzy set is based on the idea of extending the range of characteristic functions such that the function will include real numbers in the interval [0,1]. The membership value indicates that an item in the universe of conversation is not only at 0 or 1 but also values that lie between them. In other words, the truth value of an item is not only true or false. A value of 0 indicates false, a value indicates true, and there are still values that lie between true and false (Mahderavi et al., 2016).

2.2.3.3 Fuzzy Process

There are 3 main stages in fuzzy, including:

1. Fuzzification is the process of using linguistic variables to convert three risk factors severity, occurrence, and detection into fuzzy. Using linguistic variables and definitions, then ranking the three factors on a basic scale, to obtain the degree of membership in each class.
2. Rule evaluation contains knowledge from experts regarding the interaction of error modes and their effects in the form of "if-then" fuzzy rules. These rules are easier to formulate in linguistic rules than numerical ones.
3. Defuzzification is the process of creating a ranking of fuzzy Risk Priority Number (RPN) to give priority level of error mode. The defuzzification process uses the centroid method. The input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules, while the resulting output is a number in the domain of the fuzzy set. So if given a fuzzy set within a certain range, it must be able to take a certain crisp value.

2.2.4 House of Risk (HOR)

Adapting the modification of the Failure Mode and Effect Analysis (FMEA) model to determine risk agents should be given priority as a precautionary measure. A rating is given for each risk agent based on the amount of the ARP_j value for each risk agent j. This two-spread model is called the House of Risk (HOR) which is a modification of the FMEA model (Pujawan & Geraldin, 2009). HOR is used to manage supply chain risk proactively with a focus on prevention efforts, such as minimizing risk agents that appear in the supply chain. The House of Risk aims to identify risks and design risk mitigation to reduce the probability of a risk agent occurring through prevention efforts in accordance with the priority level of the risk agent. (Achmandi & Mansur,2018). There are 2 phases to conduct the HOR model as below.

1. HOR phase 1

   This phase is used to determine which risk agents are given priority for preventive actions.

2. HOR phase 2

   This phase is used to give priority to those actions considered effective but with reasonable aspects.

The first step is to identify risk events and risk agents. The output of the House of Risk phase 1 is in the form of risk agent levels based on priority groups resulting from the calculation of the ARP (Aggregate Risk Potential) value. The stages of calculating the Aggregate Risk Potential in HOR phase 1 are as follows:

1. Identified risk events that happen or obstructs the business process (Ei)
2. Assess the impact and probability occurrence (Si)
3. Identify risk agents and assess the likelihood of occurrence of each risk agent (Oj)
4. Develop matrix between each risk (Rj)
5. Calculate Aggregate Risk Potential (ARP_j)
6. Rank the risk based on the result of aggregate risk potential

The example of House of Risk Model phase 1 is illustrated in Table 2.3, which consists of a risk event, risk agents, occurrence score, severity score, relation matrix score risks agents towards events, and aggregate risk potential score.

Table 2.2 House of risk calculation

Risk Events	***Risk Agent***					***Si***
	A1	**A2**	**A3**	**A4**	**A5**	
E1	R11	R12	R13	...	...	S1
E2	R21	R22	...	...	...	S2
E3	R31	...	...	...	...	S3
E4	...	...	...	...	...	S4
E5	...	...	...	...	...	S5
O*j*	O1	O2	O3	O4	O5	O6
ARP*j*	ARP1	ARP2	ARP3	ARP4	ARP5	ARP6
P*j*	P1	P2	P3	P4	P5	P6

Where:

E1, E2, ... E_k	=	Risk event	P1, P2, ... P_k	=	Rank
A1, A2, ... A_k	=	Risk agent	O1, O2, ..., O_j	=	Occurrence of Risk agent
R11, R21, ... R_{ij}	=	Risk agent towards Risk event	ARP_j	=	Aggregate risk potential
			S1, S2, ... S_i	=	Severity of Risk event

Based on the explanation above, Equation 2.1 shows the calculation of the House of Risk.

$$ARP_j = O_j \sum S_i R_{ij} \quad \text{.............................2.1}$$

In HOR phase 2, a mitigation design strategy is carried out which is categorized according to the priority of the risk agent. The output from phase 1 will then be used as input in phase 2 to calculate the total effectiveness value and effectiveness to difficulty ratio (ETD). The following are the steps to calculate the Aggregate Risk Potential in phase 2: Select the high-risk agents score is based on priority rank.

1. Determine actions to prevent the risk agents
2. Develop matrix relationship between each preventive action and risk agents
3. Calculate the total effectiveness score (TEk)
4. Assess the degree of difficulties on each preventive action (Dk)
5. Calculate the final score of total effectiveness (ETDk)
6. Rank the final score (Rk)

The example of House Of Risk Model phase 2 is illustrated in Table 2.4. The figure below consists of preventive action difficult performance score, a relation matrix score between risk agent and preventive action, and risk agent aggregate risk potential score from HOR phase 1, and the effectiveness ratio score.

Table 2.3 HOR preventive action toward risk

To be treated risk agent (Aj)	Preventive Action (P Ak)					Aggregate Risk Potential (ARPj)
	PA1	**PA2**	**PA3**	**PA4**	**PA5**	
A1	E11	E12	E13	...	...	ARP1
A2	E21	E22	...	...	...	ARP2
A3	E31		...	...	...	ARP3
A4	...		...	...	...	ARP4
A5	...		...	...	Ejk	ARP5
Total effectiveness of action -k		TE1	TE2	TE3	TE4	
Degree of difficulty performing action -k		D1	D2	D3	D4	
Effectiveness to difficulty ratio		ETD1	ETD2	ETD3	ETD4	
Rank priority		R1	R2	R3	R4	

Where:

$A1, A2, \ldots, A_k$	=	Risk agent	$P1, P2, \ldots, P_k$	=	Rank of mitigation
$E11, E21, \ldots E_{jk}$	=	Risk agent towards preventive action	$O1, O2, \ldots, O_k$	=	Occurrence of Risk agent
$TE1, TE2, \ldots, TE_k$	=	Severity of Risk event	ARP_j	=	Aggregate risk potential
$D1, D2, \ldots, D_k$	=	Rank of difficulties of preventive action	$ETD1, ETD2, \ldots ETD_k$	=	Effective comparison

After creating the matrix, it can be seen the preventive action ranking shown in Equation 2.2.

$$TE_k = \sum_j ARP_j E_{jk}$$
$$ETD_k = \frac{TE_k}{D_k} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research Object

3.1.1 Research Location

This research was conducted in PT. XYZ in East Java. This company was a subsidiary of Europe environmental consultant and services. This company was founded around 1860 as a waste treatment company. From a waste treatment company, this company did many innovations to develop their services so they can be a well-known company and provide a wide range of environmental treatment services for people in Europe. In 2017, the branch company was opened in Indonesia which focused on polyethylene terephthalate (PET) collaborated with the biggest food and beverages company as partner, and became the biggest recycled Polyethylene Terephthalate (rPET) manufacturing in Asia.

3.1.2 The Focus of The Research

This research will focus on assessing and analyzing the supply chain risk in PET manufacturingThe method that will be used is modified Fuzzy Logic in HOR (House of Risk).

3.2 Research Tools and Device

This research was carried out by utilizing MATLAB R2020a programming. MATLAB is a multi-mathematical figuring climate and fourth-age programming language. A restrictive programming language created by Math Works, MATLAB permits framework controls, plotting of capacities and information, execution of calculations, production of UIs, and interfacing with programs written in different dialects, including C, C++, C#, Java, Fortran, and Python. This product comprises the application Fuzzy that is utilized to help in ascertaining questionable or ambiguous information.

3.3 Research Flowchart

This research flow chart explains the stages that will be carried out during the research process. The research flow is made to establish a more focused and directed research. So that, it can simplify the work and the process of analyzing the problems that might occur. The following is a flow chart of the research to be carried out as shown in Figure 3.1 below:

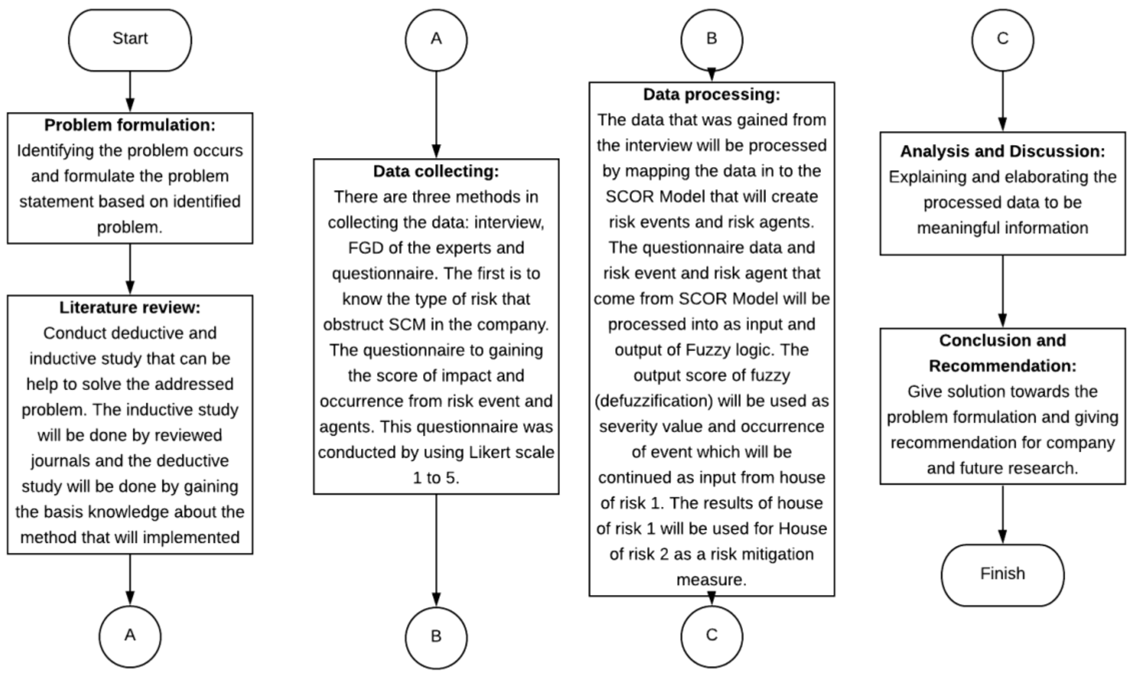

Figure 3.1 Research flowchart

1. Problem formulation

The problem formulation is the first step in this research. Before determining the problem formulation, problem identification should be done. Problem identification is obtained after a literature review study. It defines a problem that will be used and solved in this research. The problem identification is served in a question form that will be answered in the conclusion section.

2. Literature review

The literature review is the basic support of the research. There are two kinds of literature reviews. Which are:

a. Preliminary study

The preliminary study consists of several past studies related to the research, which can be accessed from journals.

b. Fundamental theory

The fundamental theory, which is derived from several sources and guides of the methods that will be used for this theoretical basis of the research

3. Data collection

Data collection is used to collect all the data and information needed that is related to the problems that exist. The data and information will be proceeded to achieve the objective of the research. Two types of data will be collected, which are:

a. Primary data

Primary data is information collected through original or first-hand research. The primary data that collected, will become the input of the calculation for this research. The list below is the primary data that will be used for this research:

1) Business process flow
2) Risk event in the operation management department
3) Risk severity level of impact (by using a questionnaire)
4) Sub risk (risk agent) in the operation management department
5) Risk occurrence level (by using a questionnaire)
6) Correlation between risk

7) Management mitigation action
8) Correlation level between risk with a mitigation strategy.

b. Secondary data

Secondary data is information that has been collected in the past by someone else. It could be from books, journals, online portals, etc. Then, the researcher will use this secondary data and information as supporting references to accomplish this research

4. Data processing

The data processing step is designed to convert the data into meaningful information that can be used to solve the research problem. The steps that are taken to accomplish the data processing are as below:

a. Determination of supply chain activities

At this stage, the identification of activities in the company's supply chain is carried out using the Supply Chain Operation Reference (SCOR) model. Then mapping activities on plan, source, make, deliver, and return

b. Risk Identification

This stage is carried out to identify risks that may occur and have the potential to occur in the company's supply chain activities. One of the important aspects to identify risk is to list the risks that are likely to occur as much as possible through field surveys, interviews, and filling out questionnaires, the results of which will be mapped for the fuzzy model.

c. Calculation Process

1) Fuzzy risk house of risk phase 1 (mapping and range calculation)

The first activity is to perform fuzzy risk calculations by classifying into the fuzzy model. In this research, the mapping is based on the questionnaire as the input and output. This step is also designated to calculate the range parameter to be used in the fuzzy (0-5).

2) Questionnaire data input process

The next step is to carry out a risk assessment that aims to determine the severity and occurrence level of each questionnaire. The results of this process will be used as the core input in fuzzy processing which will produce a valid severity and occurrence score. In this research, there are 5 parameters score of severity and occurrence value:

a. Severity (Risk Event)

According to Rakaditya (2019), the score will divide into scores 1 to 5 by severity classification. As shown in Table 3.1 parameters of risk severity in this research are divided into 5 ranks, i.e. catastrophic, severe, moderate or significant, and minor risk. The determination of parameters is based on the company policy and standards.

Table 3.1 Risk Severity Parameter

Effect	Criteria	Ranking
Minor	A risk that does not affect the system performance, the operator probably will not notice	1
Significant	A risk that would cause slight annoyance to the operator, but that would cause no deterioration to the system	2
Moderate	A risk that would cause a high degree of operator dissatisfaction or that causes noticeable but slight deterioration in system performance	3
Severe	A risk that causes significant deterioration in system performance and/or leads to minor injuries	4
Catastrophic	A risk that would seriously affect the ability to complete the task or cause damage, serious injury, or death, took long delay time and took several weeks in repairing	5

b. Occurrence (Risk Agent)

The score occurrence will also be divided into 1 to 5 depending on the probability of the risk happening in 6 months. As shown in Table 3.1,the parameter of occurrence is divided into 5 ranks based on the probability the risk occurs.

Table 3.2 Risk Occurrence Parameter

Effect	Criteria	Ranking
Not present/ rarely happen	Occurs < 1 times in a 6 month	1
Probably happen	Occurs 2-3 times in a 6 month	2
Moderate	Occurs 4-6 times in a 6 month	3
Frequent to happen	Occurs 7-8 times in a 6 month	4
Almost certain to happen	Occurs >9 times in a 6 month	5

3) Fuzzy rule-based

After determining the mapping and the range parameter the next step is to create rules-based on Matlab. In this research, the rule-based will be focused on by using IF-THEN laws which is the basis of the Mamdani Fuzzification.

4) Defuzzification

Defuzzification is the output of the proses from fuzzy logic. Afer filling the fuzzy rules and the range parameter input and output, the last step is defuzzification or finding the truth values of the score severity and occurrence using the house of risk.

5) Correlation Assessment (House of Risk Phase 1)

The next stage, after determining the severity value and the occurrence score from fuzzy logic, is to calculate the value of the relationship between risk events by giving a score of 1.3, or 9 where 1 This means that there is a low level of association between risk events and risk agents. While 3 means that there is a moderate level of correlation between risk events and risk agents. Then 9 refers to the existence of high degree of association between risk events and risk agents. The output of this process is ARP (Aggregate Risk Potential) or the level of risk.

6) Aggregate Risk Priority

At this stage, an assessment or ranking of risk is carried out from the highest ARP to the lowest. In this step, the data visualization will be using Pareto diagrams with 80-20% theory. This step has focused to prioritized the risk that has to be mitigated as soon as possible or the risk that has a high level of severity and occurrence.

d. Determination Mitigation Action

After identifying the risk that has to be prioritized, the next step isthe identification of the mitigation action, based on the results of the risk rank as shown in the Pareto chart. The main focus of this step is mapping the suitable mitigation action referring to a discussion with experts.

e. Calculation process fuzzy mitigation action (for house of risk phase 2)

1. Fuzzy Mitigation Action

   At this stage, the fuzzy process has a similar process with the previous fuzzy logic for house of risk phase 1 which are: mapping input and output, range calculation, and defuzzification, the calculation process of this fuzzy logic 2 (for mitigation action) is to determine the score of degree difficulties or the level of difficulties based on mitigation action. This step is using Fuzzy logic with using cost and human resources as the parameter. The main focus of this step is to obtain a validity score of mitigation action.

2. House of Risk 2 (Mitigation Action)

   This step has similarity method from the House of Risk 1 (between risk event and risk agent). The main difference of this step is the assigning value that will be used, namely Aggregate Risk Potential (ARPj) and Degree of difficulties (Dk) that are obtained from fuzzy values. The output of this method is the mitigation rank that should be done first.

5. Analysis and discussion

In this step, the analysis of the result of HOR 1 and HOR 2 consists of the analysis of risk events that are used to sort the highest risk to the lowest and provide a visualization of the risk in the supply chain while the mitigation strategy analysis will provide an analysis of proposed improvements as an effort to carry out mitigating risks that occur in the company's supply chain.

6. Conclusion and recommendation

The final stage after obtaining the results of the analysis and discussion will be used as the closing of this research. Conclusions are drawn to describe the results of the research as a whole to answer the predetermined problem formulation. Then the suggestions proposed by the researcher are expected to be input for the company in making improvements to existing problems as an effort to mitigate risk.

CHAPTER IV

DATA COLLECTING AND PROCESSING

4.1 Data Collection

4.1.1 Production System of PT. XYZ

PT. XYZ production flow system starts from procurement material by making purchase order (PO) list to the supplier. Material that is usually ordered by the company is a waste plastic drinking bottle or can be called polyethylene terephthalate (PET). The procurement department makes the PO, and for receiving material, it will be managed by the operation department. After a supplier sends the material, the material will be kept in the warehouse as an inventory. In the production process, the material will be through three primary machines. Namely, the washing line to wash the material, the cutting machine to cut the material into flakes, and the last are SSP or polymerization of flakes. The finished product will be sent to the customer directly with the truck. A summary of the flow production process in PT. XYZ has shown in Figure 4.1.

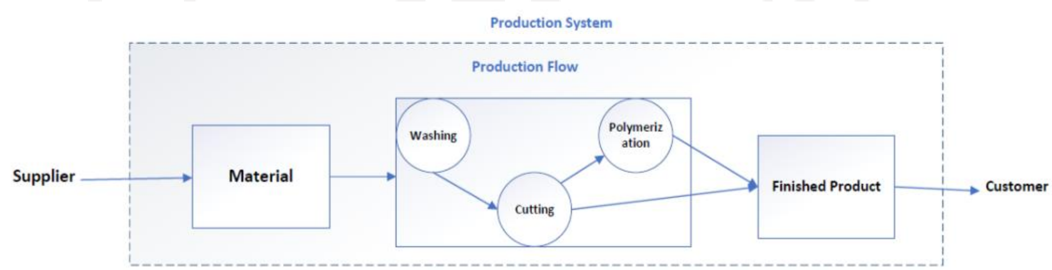

Figure 4.1 Production Process of PT. XYZ

4.2 Data Processing

4.2.1 Supply Chain Operation Reference Model

The data collection process starts by identifying activities in the supply chain using the Supply Chain Operation Reference (SCOR) model. Next is identifying supply chain activities to determine the risks that occur in the company's activities that can potentially happen and affect the company's supply chain activities (Table 4.1). This identification is assisted by SCOR, which consists of a plan, source, make, delivery, and return. The results of determining activities in the supply chain at PT. XYZ is as shown in Table 4.1.

Table 4.1 Supply Chain Activities of PT. XYZ

SCOR	Process	Activity
Planning	Plan - Source	Production Planning
		Raw Material Planning
Source	Source (make to order)	Raw material procurement
		Receiving material (PET)
		Material (PET) placement in warehouse (open warehouse)
Make	Make to order	Washing process
		Cutting process
		Extrusion process
		SSP process
		Quality control process
		Packaging (jumbo bag)
		Finished goods placement in the warehouse (closed warehouse)
Delivery	Deliver department to order product	Updating the availability of stock (finished goods)
		Document preparation
		Delivery to customer
Return	Return products	Return product (customer)
		Return raw material (supplier)

4.2.2 Identification Risk

This model (House of Risk phase 1) tests the correlation between risk agent and risk event to a supply chain process. The House of Risk (HOR) model underlies risk management, focusing on prevention by reducing risk agents' likelihood. So the earliest stage is to identify risk events and risk agents. Usually, one agent can cause more than one risk event. Adapting from the Failure Mode and Effect Analysis (FMEA) method, the risk assessment applied is the Risk Priority Number (RPN) which consists of 3 (three) factors, namely the probability of occurrence, the severity of the impact that appears, and detection. The House of Risk (HOR) method only establishes the probability for the risk agent and the severity of the risk event. Because one risk agent can cause more than one risk event, it is necessary to quantify the aggregate risk potential of the risk agent. The house of risk method is as follows:

1. Risk Event

   Based on the results of interviews and Focus Group Discussion (FGD) that have already been collected in the data collection stage, mapping and identification of risk events can be carried out from each activity in the supply chain. Risk identification is carried out to determine the risks that occur in the company's activities that can potentially happen and affect the company's supply chain activities. Based on the supply chain activities in Table 4.2, it is known that the process carried out by the company will be followed by identifying risk events by collecting data through interviews by experts (head department of procurement, operation, and warehouse). After the supply chain activities have been identified, the next step is to discuss risk events for the entire company's operational processes. Here, the fuzzy logic method is used to find the range of the vague actual values. The following table 4.2 explains the results of risk events based on interviews with informants/ experts.

Table 4.2 Risk Event

Code	Risk Event	SCOR Model Process
E1	High cost of raw material	Source

Code	Risk Event	SCOR Model Process
E2	A bad condition of raw material (when material arrived)	Source
E3	Planning the amount of material is a missed target	Source
E4	Late arrival of suppliers.	Source
E5	Raw material specifications do not match the orders.	Source
E6	Product targets are not achieved (losses)	Make
E7	PET bottle washing process is not perfect (In Washing line)	Make
E8	The cutting sensor is not working properly	Make
E9	Finished goods coloring issues (In SSP machine)	Make
E10	The decreasing quality of finished goods	Make
E11	High contaminant in finished goods.	Make
E12	Machine stopped (production line)	Make
E13	Overheating machine	Make
E14	Data lost	Make
E15	Color result issues (yellowish/ greyish)	Make
E16	Leaked water (in washing line)	Make
E17	High emission energy	Make
E18	Set – up machine too long	Make
E19	Human error	Make
E20	Data production error	Make
E21	Incorrect labelling the jumbo bag (packaging)	Make
E22	Incompatibility of products received by the customer	Delivery
E23	Delay in delivery to customers	Delivery
E24	Tax rules policies changing frequently	Delivery

Code	Risk Event	SCOR Model Process
E25	Return of raw materials that do not match the request	Return
E26	Return of goods by customer	Return

Detailing disruptions from business process sources into sub-processes that can cause disruption or possible risks from each sub-process is used to identify risk events. Table 4.2 shows that the business process sources follow the five criteria/sources of the SCOR dimension. The number of risk events identified obtained 26 risks (5 risks from the source, 16 from the make/production process, three from the delivery process, and two from return activity). After the risk event is classified, the next step is to discuss the risk agent shown in Table 4.3 or risk source for the entire company's operational processes.

2. Risk Agent

Table 4.3 Risk Agent

Risk Agent	Code
Rare raw material	A1
No monitoring towards the supplier	A2
Lead time/ schedule of production changing	A3
Forecasting error	A4
Human error	A5
Tired workers	A6
Limited maintenance analysis	A7
Lack of work supervision	A8
Material price fluctuation	A9
The decreasing volume of production	A10
Limit on the number of workers (pandemic occasion)	A11
Unstable engine (overload)	A12
Overheat machine	A13

Risk Agent	Code
The lack of negotiation	A14
Sudden request by the customer	A15
Missed scheduling	A16
The lack of quality control	A17
Damage of production machine	A18
Delivery error (address)	A19
Incomplete purchase and sale documents	A20

After obtaining the risk agent and event, the next step is to create a questionnaire as the input value for the fuzzy logic method, processed using MATLAB R2020a. The next step, shows the design of the risk event questionnaire.

3. Risk Event and Risk Agent Questionnaire

Rakadhitya (2019) stated that after the first stage of mapping supply chain activities using the SCOR model and equalizing risk events and agents, the next step is to search for input and output for the fuzzy model.

In making a fuzzy model, what is needed is in the form of input and output. In the case of Risk Analysis, the input can be cause and effect from the output (Risk Agent and Risk Event) taken from the questionnaire. The risk event questionnaire will describe the impact that a Risk Event will have on other supply chain components or processes, while for risk agents, it will be described by searching for cause and effect or why this risk agent occurs.

The relation between risk event and risk agent is the search for risk and risk triggers. So that by making a risk questionnaire, the results will be more valid by recognizing the resulting impact and the causes of the risk. The final result of using fuzzy logic based on this questionnaire (Risk Event questionnaire and Risk Agent questionnaire) is to determine Severity (Risk Event) and Occurrence (Risk Agent) to eliminate ambiguity. The following is a risk questionnaire as below:

A. Risk Event Questionnaire

No	Question	Answer		
1	The decline in the quality of finished goods has an impact on:	• Price changing	• Customer complaint	• Operational cost losses
2	A bad condition of raw material (when material arrived) has an impact on:	• Decreasing the quality	• Lead time/schedule production changing	• Financial loss (return)
3	Planning the wrong amount of product so that it does not match the target with the indicator has an impact on:	• Market demand filled by other competitors	• Financial losses	• Increased working hours of employees
4	The delay in the arrival of suppliers has an impact on:	• Become bottleneck in the production process	• Increased working hours of employees	• The market will be fulfilled by responsive competitors
5	Raw material specifications do not match with the	• Additional fees for returns	• Product quality may change	• Changed production schedule/Lead-time

No	Question	Answer		
	request, which has an impact on:			
6	The reduced product target after leaving the washing line (high reject material) has an impact on:	• Reducing production volume	• Financial loss	• The market is likely to be filled by competitors.
7	PET bottle washing process is not perfect (contaminant) has an impact on:	• Reducing production volume due to many reject materials	• Financial loss due to rejected goods	• There is a bottleneck in production
8	The cutting sensor not working properly has an impact on:	• Engine overheating/engine breakdown	• Decrease in production capacity (cutting line)	• There is a bottleneck in the production process
9	Finished goods colouring issues (In SSP Machine) has an impact on:	• Machine breakdown	• Excessive working hours of employees because it is	• There is a bottleneck in the production process

No	Question	Answer		
			• considered a failed product	
10	The increase in raw materials has an impact on:	• Reducing production volume	• Lead time/production schedule changed	• Disrupted production process
11	High contaminant in finished goods (Metal contaminant) has an impact on:	• Financial loss	• Machine damage (due to high contaminant emission in machines)	• Operational loss
12	The engine stops indicator has an impact on:	• Production schedule changed/production lead time changed	• There is a bottleneck in production	• Financial loss
13	Overheating machine indicator has an impact on:	• Machine breakdown	• High-value heat emission	• The bottleneck in the production process
14	Data lost indicator has an impact on:	• Incomplete project documents	• Human error	• Bottleneck in warehousing

No	Question	Answer		
15	Colour result issues (grey/yellowish) indicator have an impact on:	• Lower cost of goods sold	• Financial loss	• Chances are the market will be filled by a faster market
16	Leaking water in washing line machine indicator has an impact on:	• Machine breakdown	• The bottleneck in the production process	• Financial loss
17	High emission energy indicators have an impact on:	• Damage to the machine	• A penalty by Industry and Environment Institute (financial loss)	• Company image is declining
18	Set-up machine took a long-time impact on:	• Overload capacity	• Machine breakdown	• Bottleneck in production
19	Human error indicators have an impact on:	• Damage to the machine	• Data loss	• Bottleneck production
20	Data production error indicators have an impact on:	• Missed planning	• Financial loss	• A bottleneck in the production process
21	Incorrect labeling of the	• Financial loss	• The bottleneck in	• Human error

No	Question	Answer		
	packaging has an impact on:		the packaging to warehousing process	
22	Non-conformance of product specifications received by the customer has an impact on:	• Complaint from customer	• Financial loss (additional for retransmission)	• Company image is declining
23	Delays in delivery to customers have an impact on:	• Financial loss (penalty)	• Complaint from customer	• The request will likely be filled by other competitors
24	Tax rules policies changing frequently have an impact on:	• Financial loss	• Delays in delivery	• Delivery schedule
25	The return of unsuitable raw materials has an impact on:	• Financial loss (additional fee for return)	• Lead time/production schedule changed	• The working relationship (Supplier Relationship) is stretched
26	The return of goods by the customer has an impact on:	• Financial loss (penalty)	• Possible requests will be filled by competitors	• Decreased customer trust in the company

This questionnaire is created and modified based on the reference concept from Rakadhitya (2019). Next is the risk agent section questionnaire. The following is the design of the Risk Agent questionnaire to be filled out by experts/people who understand the company's operational cycle.

B. Risk Agent Questionnaires

No	**Question**	**Answer**	
1	Rare materials are caused by:	• Fewer collectors are working	• PPKM government policy
2	Lead time/schedule of production changing caused by:	• The engine that exceeds capacity, causing engine downside (damage from within)	• The expertise of each employee is still considered less fast
3	No monitoring towards supplier caused by:	• The absence of supervisors or departments that focus on Supplier relationship management (SRM)	• Information that is not transparent (supplier – procurement department)
4	Forecasting errors are caused by:	• Lack of coordination and information flow from the sales department	• Lack of information about popular products
5	Human error is caused by:	• New employee	• Lack of management skills from employees
6	Additional working hours are caused by:	• Not fulfilled the production targets that are not met	• The number of products rejected / not worth selling
7	Limited maintenance analysis due to:	• No predictive analysis	• Lack of monitoring

No	Question	Answer	
8	The lack of work supervision is caused by:	• Lack of adequate standard operating procedures	• Employees prefer to work alone
9	Fluctuations in material prices are caused by:	• The number of export and import activities	• Fulfillment of sudden demand
10	Reduced capacity is caused by:	• Broken machine	• The machine has been overloaded before, so it needs to reduce the capacity for the next batch
11	Limitation on the number of workers (pandemic occasion) is caused by:	• Adjusted labour budget	• Market down
12	Unstable engine (overload) caused by:	• Missed calculation	• Poor engine performance
13	Machine overheating is caused by:	• The machine is running too long	• There is no analysis of maintenance
14	Lack of negotiation is caused by:	• Lack of skills in negotiation	• New employees
15	Sudden requests by customers are caused by:	• Fluctuations in demand because of the specific period	• Fulfillment of markets outside Asia
16	Missed scheduling is caused by:	• Error receiving information	• Delay in the arrival of raw materials by suppliers
17	The lack of quality control is caused by:	• No department handle it	• The number of items that must be produced per day

No	Question	Answer	
18	Damage to the production machine is caused by:	• Lack of predictive maintenance analysis	• Lack of Standard Operational Procedure (SOP)
19	Delivery error is caused by:	• High employee load	• The complexity of ID in product labels
20	Incomplete purchase and sale documents are caused by:	• Poor communication	• Lack of information transparency

4.3 Fuzzy Logic Process

4.3.1 Determine Fuzzy Severity Score (Risk Event)

Based on the questionnaire risk event that was already studied, fuzzy membership functions were determined. Table 4.4 shows the detail of the fuzzy membership map.

A. Risk Event Membership Model

Table 4.4 Risk Event Membership Map

Function	Variable	Range	Explanation
INPUT	Decreasing the volume of production	0 - 5	Severity/impact that happens from the output
	Lead time or the schedule of production changing	0 - 5	Severity/impact that happens from the output
	Production operations are disrupted	0 – 5	Severity/impact that happens from the output

OUTPUT	High cost of raw material	0 – 5	Possible level of impact

B. Range Parameter

After mapping the membership function, the next step is to calculate the membership function parameter based on the fuzzy indicator as follows:

$$\mu Very\ low\ (x) = \begin{cases} 0, & x \geq 2 \\ \dfrac{2-x}{0.5}, & 0 \leq x \leq 2 \\ 1, & x \leq 1 \end{cases}$$

$$\mu Low(x) = \begin{cases} 0, & x \leq 1\ or\ x \geq 3 \\ \dfrac{x-1}{1}, & 1 < x \leq 3 \\ \dfrac{3-x}{1}, & 2 \leq x < 3 \end{cases}$$

$$\mu Normal(x) = \begin{cases} 0, & x \leq 2\ or\ x \geq 4 \\ \dfrac{x-2}{1}, & 2 < x \leq 3 \\ \dfrac{4-x}{1}, & 3 \leq x < 4 \end{cases}$$

$$\mu High(x) = \begin{cases} 0, & x \leq 3\ or\ x \geq 4 \\ \dfrac{x-3}{1}, & 3 < x \leq 4 \\ \dfrac{4-x}{1}, & 4 < x < 5 \end{cases}$$

$$\mu Very\ high(x) = \begin{cases} 0, & x \leq 4 \\ \dfrac{x-4}{1}, & 4 < x \leq 5 \\ 1, & x > 5 \end{cases}$$

The range parameter from 0 until 5 is based on the probability density. The score of probability has the meaning as follows:

Table 4.5 Probability score meaning

Category	Probability density	Explanation
Very High	$x > 5$	Continuously experienced and has a huge impact on systems.
High	$4 < x < 5$	Occurs regularly and major systems damage
Normal	$3 \leq x < 4$	Occurs several times in the process of supply chain and has minor system damage
Low	$2 \leq x < 3$	Can be expected in the process of supply chain and has minor system damage
Very low	$x \leq 1$	So unlikely to happen, this risk can assume will not occur in a process supply chain and has minor systems damage on the systems

Thus, the formula's calculation shows the unit of range for membership function (Rakadhitya, 2019). Table 4.6 shows the result after calculation, which is the range of membership functions.

Table 4.6 Fuzzy Parameter Risk Event

Function	**Variable**	**Fuzzy indicators (impact)**	**Range**	**Unit of Range**
Input	Interrupted schedule of production	Very low	0-5	[0,5 1 1,5]
		Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,25]

		High		[2,5 3 3,5 4]
		Very high		[3,5 4,5 5]
	High cost of operational management	Very low	0-5	[0,5 0,1 1,5]
		Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,25]
		High		[2,5 3 3,5 4]
		Very high		[3,5 4,5 5]
	Disrupted market demand/ customer loyalties	Very low	0-5	[0,5 0,1 1,5]
		Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,25]
		High		[2,5 3 3,5 4]
		Very high		[3,5 4,5 5]
Output	High raw material cost	Minor	0-5	[0 0.1 1 2]
		Significant		[1 2 3]
		Severe		[2 3 4]
		Major		[3 3.5 4]
		Catastrophic		[3.5 4 5]

Figure 4.2 to Figure 4.6 shows the Input and Output result from MATLAB2020a based on the range of Table 4.6.

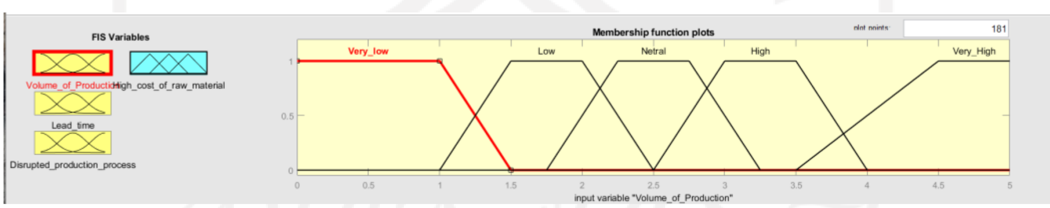

Figure 4.2 Input Membership Function 1 (Decreasing volume of production)

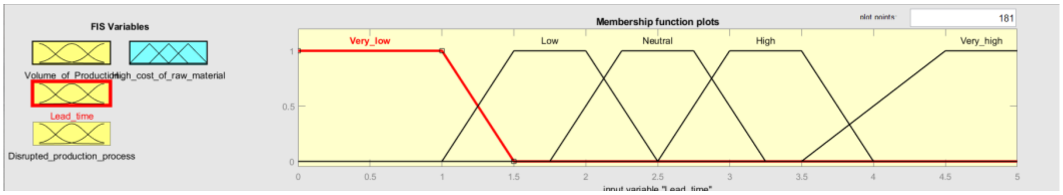

Figure 4.3 Input Membership Function 2 (Lead time or schedule time changing)

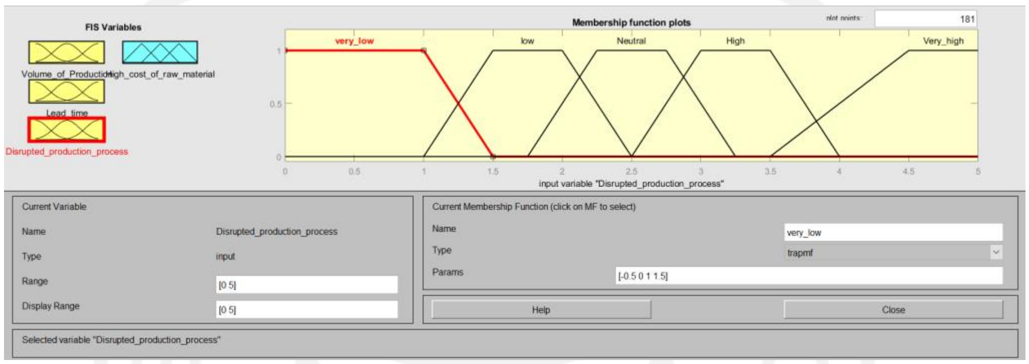

Figure 4.4 Input Membership Function 3 (Disrupted production process)

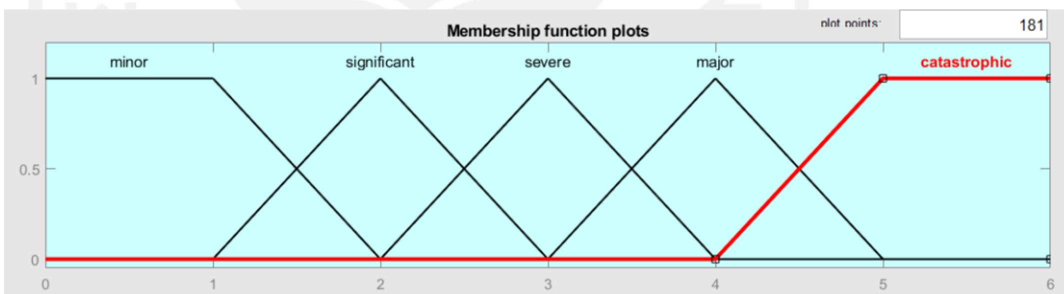

Figure 4.5 Output Membership Function (High raw material cost)

C. Define the Fuzzy Rule

Before calculating defuzzification, the last step is defining the rule of each input and output. According to Roghanian (2015), the experts' judgment in a linguistic variable will generate IF-THEN rules. In this research, the fuzzy rule consists of three variables that represent the risk event. There are 125 rules generated.

1. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
2. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
3. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Minor severity)
4. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is significant severity)
5. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Severe severity)
6. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very low) THEN (The fluctuation of the raw material coat is Minor severity)
7. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
8. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
9. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is significant severity)
10. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Severe severity)

11. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
12. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
13. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
14. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Severe severity)
15. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Severe severity)
16. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
17. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity)
18. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity)
19. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
20. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)

21. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Severe severity)
22. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Severe severity)
23. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity)
24. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity)
25. IF (Interrupted schedule of production is Very low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)
26. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
27. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
28. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
29. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Severe severity)
30. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Severe severity)

31. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
32. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
33. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
34. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Severe severity)
35. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Major severity)
36. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
37. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
38. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
39. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Severe severity)
40. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Major severity)

41. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
42. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
43. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity)
44. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
45. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)
46. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Severe severity)
47. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Severe severity)
48. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity)
49. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity)
50. IF (Interrupted schedule of production is Low) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)

51. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
52. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
53. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
54. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Severe severity)
55. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Severe severity)
56. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
57. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Minor severity)
58. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is significant severity)
59. IF (Interrupted schedule of production is Moderate and (the fluctuating cost of operational is Low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Severe severity)
60. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Major severity)

61. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
62. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity)
63. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity)
64. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
65. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)
66. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is significant severity)
67. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Severe severity)
68. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity)
69. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
70. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)

71. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Severe severity)
72. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Severe severity)
73. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity)
74. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity)
75. IF (Interrupted schedule of production is Moderate) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)
76. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is significant severity)
77. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity)
78. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity)
79. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
80. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)

81. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Minor severity)
82. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity)
83. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity)
84. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
85. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)
86. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is significant severity)
87. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity)
88. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity)
89. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity)
90. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity)

91. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is significant severity)
92. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Severe severity)
93. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Major severity)
94. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Major severity)
95. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Catastrophic severity)
96. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Major severity)
97. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Major severity)
98. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity)
99. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity)
100. IF (Interrupted schedule of production is High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity).

101. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is significant severity).
102. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity).
103. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity).
104. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity).
105. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity).
106. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is significant severity).
107. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is significant severity).
108. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Severe severity).
109. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Low) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Major severity).
110. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Low) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity).

111. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Severe severity).
112. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Severe severity).
113. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity).
114. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity).
115. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Moderate) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity).
116. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Major severity).
117. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Major severity).
118. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Major severity).
119. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity).
120. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity).

121. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very low) THEN (The fluctuation of raw material cost is Major severity).
122. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Low) THEN (The fluctuation of raw material cost is Catastrophic severity).
123. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Moderate) THEN (The fluctuation of raw material cost is Catastrophic severity).
124. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is High) THEN (The fluctuation of raw material cost is Catastrophic severity).
125. IF (Interrupted schedule of production is Very High) and (the fluctuating cost of operational is Very High) and (the demand disruptive is Very High) THEN (The fluctuation of raw material cost is Catastrophic severity).

D. Defuzzification of Risk Event

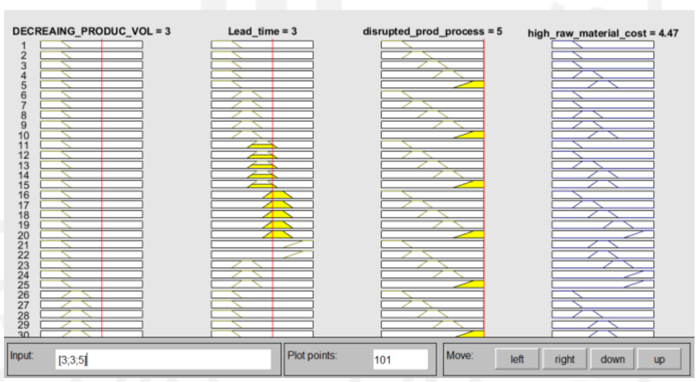

Figure 4.6 Defuzzification Risk Event

Defuzzification is the last step in calculating fuzzy logic risk. An expert will assist the determination to fill in the input score. For example, Figure 4.6 shows that the impact score output is 3 for the decreasing volume and lead time, classified as moderate. As for disrupted production, it gets a very high score. The final output of the defuzzification process is 4.47, so, in risk event 1 (E1), it gets a severity score of 4.47

or can be classified as catastrophic impacted. House of Risk Phase 1 will obtain the result from the severity score.

For the record, the determination of variables, membership function, and parameter calculation in this study has the same rules as the other 26 risk events. The researcher only writes one model and fuzzy rule to speed up and simplify the fuzzy processing process. The final value generated is not much different, even if it is differentiated.

4.3.2 Determining Fuzzy Occurrence Score (Risk Agent)

After identifying the severity of the risk agent, the next step is to determine the risk agent occurrence score. The perception of the fuzzy membership function is based on the questionnaire risk agent that has been studied. Table 4.6 shows the detail of the risk agent membership map.

A. Risk Agent Membership Model

Table 4.5 Risk Agent Membership Map

Function	Variable	Range	Explanation
Input	Fewer scavenger/ collectors that working so, delivery is minimal	0-5	The causes of output
	PPKM policy that prohibits leaving the house/some places cannot be visited	0-5	The causes of output
Output	Limited Material/ The material become rare	0-5	Possible impacts that occur due to input

B. Range Parameter

The membership function parameter calculation has the same calculation for the risk event range parameter which is based on the table on 4.5 the meaning of the range calculation has a similar meaning. The results of the calculations are shown in Table 4.7.

Table 4.6 Fuzzy Parameter Risk Agent

Function	**Variable**	**Fuzzy Indicators**	**Range**	**Unit of Range**
Input	Fewer collectors are working	Very low	0-5	[0,5 1 1,5]
		Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,5]
		High		[2,5 3 3,5 4]
		Very high		[3,5 4,5 5]
	PPKM Rules	Very low	0-5	[0,5 1 1,5]
		Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,25]
		High		[2,5 3 3,5 4]
		Very high		[3,5 4,5 5]
Output	Rare Material	Not present	0-5	[0 0.1 1 2]
		Rare		[1 2 3]
		Possible		[2 3 4]
		Likely		[3 3.5 4]
		Almost certain to certain		[3.5 4 5]

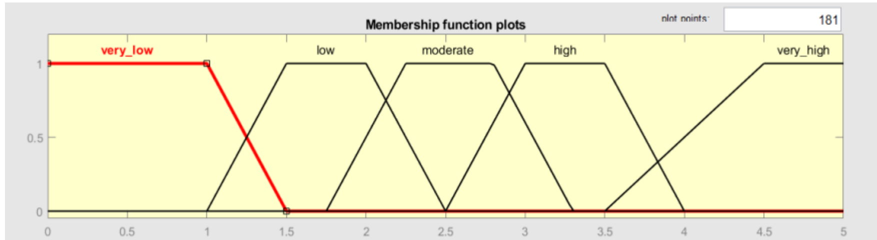

Figure 4.7 Input Membership Function 1

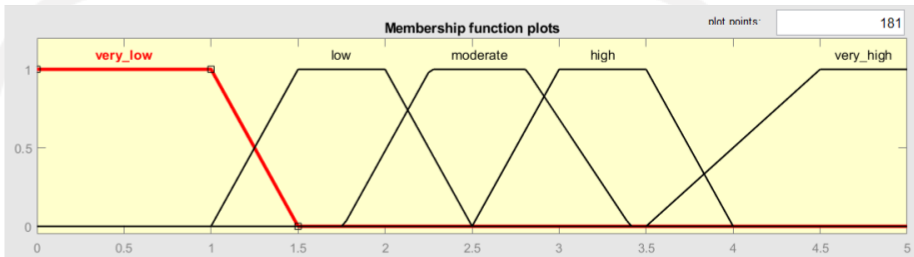

Figure 4.8 Input Membership Function 2

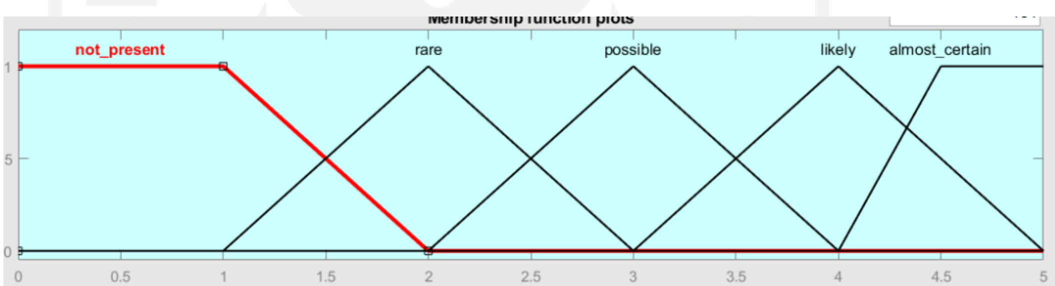

Figure 4.9 Output Membership Function

C. Rule-Based Model

1) IF (Broken machine is Very low) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Not present)
2) IF (Broken machine is Very low) and (Machine overload is Low) THEN (Decreasing production volume (per batch) is Not present)
3) IF (Broken machine is Very low) and (Machine overload is Moderate) THEN (Decreasing production volume (per batch) is Rare)
4) IF (Broken machine is Very low) and (Machine overload is High) THEN (Decreasing production volume (per batch) is Possible)

5) IF (Broken machine is Very low) and (Machine overload is Very high) THEN (Decreasing production volume (per batch) is Possible)
6) IF (Broken machine is Low) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Not present)
7) IF (Broken machine is Low) and (Machine overload is Low) THEN (Decreasing production volume (per batch) is Not present)
8) IF (Broken machine is Low) and (Machine overload Moderate) THEN (Decreasing production volume (per batch) is Rare)
9) IF (Broken machine is Low) and (Machine overload is High) THEN (Decreasing production volume (per batch) is Possible)
10) IF (Broken machine is Low) and (Machine overload is Very high) THEN (Decreasing production volume (per batch) is Likely)
11) IF (Broken machine is Moderate) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Not present)
12) IF (Broken machine is Moderate) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Rare)
13) IF (Broken machine is Moderate) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Possible)
14) IF (Broken machine is Moderate) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Likely)
15) IF (Broken machine is Moderate) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Likely)
16) IF (Broken machine is High) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Rare)
17) IF (Broken machine is High) and (Machine overload is Low) THEN (Decreasing production volume (per batch) is Possible)
18) IF (Broken machine is High) and (Machine overload Moderate) THEN (Decreasing production volume (per batch) is Likely)
19) IF (Broken machine is High) and (Machine overload is High) THEN (Decreasing production volume (per batch) is Likely)

20) IF (Broken machine is High) and (Machine overload is Very high) THEN (Decreasing production volume (per batch) is Almost certain to certain)
21) IF (Broken machine is Very high) and (Machine overload is Very low) THEN (Decreasing production volume (per batch) is Possible)
22) IF (Broken machine is Very high) and (Machine overload is Low) THEN (Decreasing production volume (per batch) is Possible)
23) IF (Broken machine is Very high) and (Machine overload Moderate) THEN (Decreasing production volume (per batch) is Likely)
24) IF (Broken machine is Very high) and (Machine overload is High) THEN (Decreasing production volume (per batch) is Likely)
25) IF (Broken machine is Very high) and (Machine overload is Very high) THEN (Decreasing production volume (per batch) is Almost certain to certain)

D. Result of Defuzzification of Risk Agent

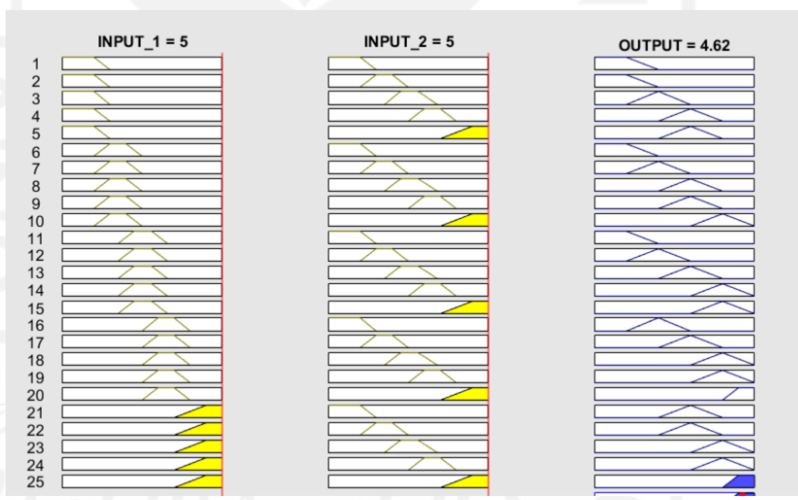

Figure 4.10 Defuzzification Risk Agent

The expert fills in the input score and generates defuzzification risk agent 1 (A1). From the result of input 1, which is fewer collectors are working, they get a score of 5 because the most significant cause of rare material is the lack of supplier labor. The second input also received a score of 5, namely PPKM government policy, which can reduce the supply of raw materials in this new policy. The result of the output that is rare material (A1) gets an occurrence score of 4.62. So, it can be seen the probability of this event is very often. This occurrence score will be used for House of Risk 1.

For the record, this study's determination of variables, membership function, and parameter calculation has the same rules as the other 20 risk agents. The researcher only writes one model and fuzzy rule to speed up and simplify the fuzzy processing process. Even if it is differentiated, the final value generated is not much different.

4.4 Severity and Occurrence Score

After assessing the risk using fuzzy logic, which aims to determine the severity and occurrence of each risk event, Table 4.8 is obtained based on defuzzification.

Table 4.7 Risk event (severity) score

Code	Risk Event	SCOR Model Process	Severity Score
E1	High cost of raw material	Source	4.47
E2	A bad condition of raw material (when material arrived)	Source	4.38
E3	Missed forecasting for material amount	Source	4.38
E4	Late arrival of suppliers.	Source	4.38
E5	Raw material specifications do not match the orders.	Source	4.74
E6	Product targets are not achieved (losses)	Make	4.38
E7	PET bottle washing process is not perfect/ left residue (In Washing line)	Make	2.98
E8	The cutting sensor is not working properly	Make	4.38
E9	Finished goods coloring issues (In SSP machine)	Make	4.78

Code	Risk Event	SCOR Model Process	Severity Score
E10	The decreasing size of finished goods	Make	4.78
E11	High contaminant in finished goods.	Make	4.78
E12	Machine stopped (production line)	Make	4.38
E13	Overheating machine	Make	4.38
E14	Data lost (sales and finished goods)	Make	4.38
E15	Color result issues (yellowish/ greyish)	Make	4.38
E16	Leaked water (in washing line)	Make	4.38
E17	High emission energy	Make	4.47
E18	Set – up machine too long	Make	4.47
E19	Human error	Make	4.47
E20	Data production error	Make	4.38
E21	Incorrect labeling of the jumbo bag (packaging)	Make	4.47
E22	Incompatibility of products received by the customer	Delivery	4.47
E23	Delay in delivery to customers	Delivery	3.29
E24	Tax rules policies changing frequently	Delivery	3.82
E25	Return of raw materials that do not match the request	Return	4.47
E26	Return of goods by customer	Return	4.47

Table 4.8 Risk agent (occurrence) score

Code	Risk Agent	Probability Score
A1	Rare raw material	4.62
A2	No monitoring towards supplier	4.02
A3	Lead time/ schedule of production changing	3.55
A4	Missed forecasting	4.62
A5	Human error	4.57
A6	Tired workers	4.57
A7	Limited maintenance analysis	4.13
A8	Lack of work supervision	3.55
A9	Material price fluctuation	4.62
A10	Decreasing volume of production	4.62
A11	Limit on the number of workers (pandemic occasion)	3.41
A12	Unstable engine (overload)	4.62
A13	Overheat machine	4.57
A14	The lack of negotiation	2.95
A15	Sudden request by customer	3.49
A16	Missed scheduling	4.57
A17	The lack of quality control	4.57
A18	Damage of production machine	3.55
A19	Delivery error (address)	3.55
A20	Incomplete purchase and sale documents	4.57

4.5 House of Risk Phase 1

4.5.1 Aggregate Risk Potential Calculation

After the identification, assess the severity and occurrence level, from the fuzzy logic process. Then the next step is, to assess the relationship based on the value of the relationship between the risk event and the risk agent. 1, 3, and 9 matches the level of correlation between each, then calculated by the ARP_j.

Value of Aggregate Risk Potential (ARP) calculates the level or sequence of risk sources to be mitigated first. The results of this ARP will be analyzed in a Pareto diagram with the 80:20 principle so that risk mitigation actions in the ARP ranking can focus on being succeeded. Below is the formula and explanation of Aggregate Risk Potential (ARP).

$$ARP = O_j \sum S_i R_j$$

Oj	=	Occurrence
Si	=	Severity
Rj	=	Risk Correlation

The formula shows that Oj is the occurrence value derived from the questionnaire or defuzzification of the risk agent. At the same time, Si is the result of severity that comes from defuzzification in risk events. Rij is the correlation between the risk agent to a risk event. Table 4.8 shows the more detailed calculation of the Aggregate Risk Potential.

Table 4.9 House of Risk Phase 1

Severity	Code	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
4,47	E1	9								9											
4,38	E2		9	9																	
4,38	E3	9	3	9	3																
4,38	E4		9	3	9																
4,74	E5	1	9	9						9					9						
4,38	E6					9	9		9		9										
2,98	E7							9					3	9							
4,38	E8					3								9							
4,78	E9							9					9	3				9			
4,78	E10	9		3		3					9	9		9		9		3	9		
4,78	E11									3								9	9		
4,38	E12							9					9	9							
4,38	E13							9	9				3	3							
4,38	E14					3	3		9												
4,38	E15					9												9	9		
4,38	E16							9	9					3					9		
4,47	E17							9											9		
4,47	E18							3	9										9		
4,47	E19				9				9					9	9		3	3		3	3
4,38	E20					9	9														
4,47	E21								3									9			
4,47	E22					9			9									9			
3,29	E23	9		9													9			9	9
3,82	E24																9				9

Severity	Code	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
4,47	E25																	9		9	
4,47	E26					9			9												
Occurrence		4,62	4	3,55	4,62	4,57	4,57	4,13	3,55	4,62	4,62	3,41	4,62	4,57	2,95	3,49	4,57	4,57	3,55	3,55	4,57

Code	Severity	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
E1	4,47	40,2								40,2											
E2	4,38		39,4	39,4																	
E3	4,38	40,2	13,1	39,4																	
E4	4,38		39,4	13,1																	
E5	4,74	4,5	42,7							42,7					42,7						
E6	4,38					39,4	39,4		39,4		39,4										
E7	2,98							26,8					8,9	26,8	9		9	9			
E8	4,38					13,1								39,4							
E9	4,78							43					43	14,3				43			
E10	4,78	40,2				14,3					43	43		43		43		14,3	43		
E11	4,78									14,3								43	43		
E12	4,38							39,4					39,4	39,4							
E13	4,38							39,4	39,4				13,1	13,1							
E14	4,38					13,1	13,1		39,4												
E15	4,38					39,4												39,4	39,4		
E16	4,38							39,4	39,4					13,1					39,4		
E17	4,47							40,2											40,2		
E18	4,47							13,4	40,2										40,2		
E19	4,47				40,2				40,2					40,2	40,2		13,4	13,4		13,4	13,4
E20	4,38					39,4	39,4														
E21	4,47								13,4									40,2			
E22	4,47					40,2			40,2									40,2			
E23	3,29	40,2															29,6			29,6	29,6
E24	3,82																34,4				34,4
E25	4,47																	40,2		40,2	
E26	4,47					40,2			40,2												
TOTAL		165,4	134,6	92	40,2	239,3	92	241,7	332	97,2	82,4	43	104,5	229,5	91,9	43	86,4	282,9	245,3	83,3	77,4
ARPJ		764,1	538,6	326,5	185,9	1094	420,3	998,4	1179	449,2	380,9	146,7	482,9	1049	271,1	150,1	394,8	1293	871	295,5	353,7

4.5.2 Risk Rank

The result of the House of Risk Phase 1 is ARP_j value, which is the multiplication result of the occurrence of the risk agent and the severity value of each risk event. The ARP_j of the f will show a risk rank from the biggest to the smallest. This rank aims to reveal which risk has a high-risk potential and needs preventive action, whereas the minor risk only needs several corrections. Table 4.11 shows more detail of the rank risk.

Table 4.10 Risk Rank

Risk variable	Risk Agent	ARPJ
Lack of quality control	A17	1292,853
Lack of supervision	A8	1178,636
Human error	A5	1093,784
Overheat machine	A13	1048,952
Limited maintenance analysis	A7	998,3862
Damage of production machine	A18	870,957
Rare raw material	A1	764,1018
No monitoring towards the supplier	A2	538,56
Unstable engine (suddenly off)	A12	482,8824
Material price fluctuation	A9	449,2026
Tired worker /overtime	A6	420,3486
Missed scheduling	A16	394,848
The decreasing volume of production	A10	380,8728
Incomplete purchase and sales documents	A20	353,718
Lead time/ schedule of production changing	A3	326,529
Wrong delivery	A19	295,5375
Lack of negotiation	A14	271,0755
Forecasting error	A4	185,8626
Sudden request by the customer	A15	150,1398
Limited worker	A11	146,6982

4.5.3 Pareto Diagram

The next step of the result of HOR phase 1, which is risk rank is to be prioritized by using Pareto chart that is one of the tools to determine the most dominant factors or causes for a problem. The Pareto chart provides the facts needed to set the risks' priority and then do the mitigation. In the Pareto chart, determine the dominant factor by using 80-20 rules. 80% of the accumulated factor means the dominant factor. Those factors are the priority to mitigate first. Table 4.12 shows the calculation of the cumulative percentage and then presented in Pareto chart as shown in Figure 4.11.

Table 4.11 Cumulative Risk Rank

Rank	**Risk Agent**	**ARPJ**	**Total Percentage**	**Cumulative percentage**	**Status**
1	A17	1292,853	0,11103221	0,11103221	Prioritized
2	A8	1178,636	0,10122308	0,2122553	
3	A5	1093,784	0,09393586	0,30619116	
4	A13	1048,952	0,09008562	0,39627678	
5	A7	998,3862	0,08574295	0,48201973	
6	A18	870,957	0,07479913	0,55681886	
7	A1	764,1018	0,06562224	0,62244111	
8	A2	538,56	0,04625237	0,66869347	
9	A12	482,8824	0,04147069	0,71016416	
10	A9	449,2026	0,03857821	0,74874237	
11	A6	420,3486	0,03610019	0,78484256	
12	A16	394,848	0,03391016	0,81875272	Non Prioritized
13	A10	380,8728	0,03270994	0,85146266	
14	A20	353,718	0,03037785	0,88184051	
15	A3	326,529	0,02804282	0,90988333	
16	A19	295,5375	0,02538122	0,93526454	
17	A14	271,0755	0,02328038	0,95854493	
18	A4	185,8626	0,01596217	0,97450709	

Rank	Risk Agent	ARPJ	Total Percentage	Cumulative percentage	Status
19	A15	150,1398	0,01289424	0,98740133	
20	A11	146,6982	0,01259867	1	

Figure 4.11 shows that 11 risks are included prioritizing risk and nine risks are included as non-prioritized risk.

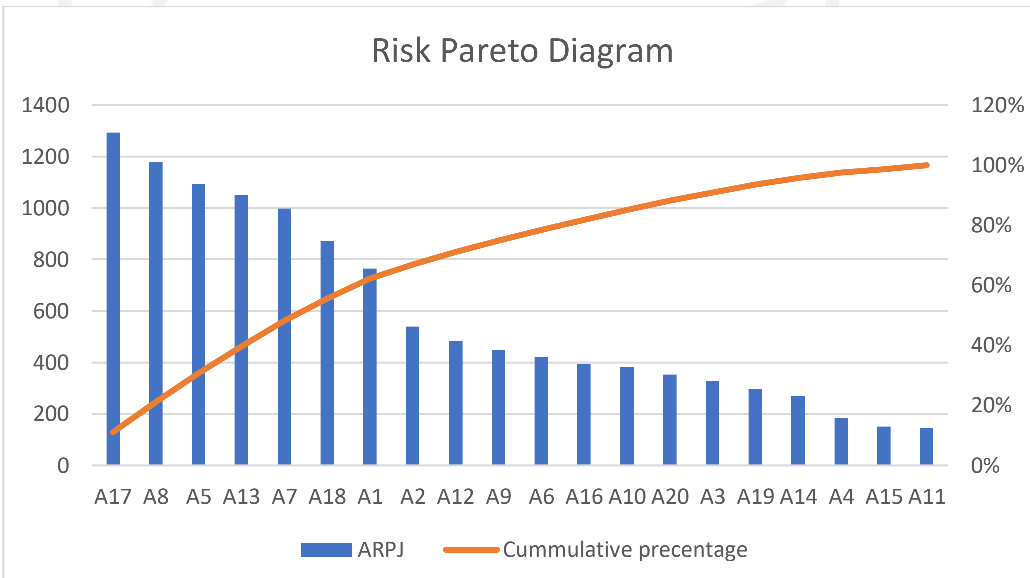

Figure 4.11 Risk Pareto Chart

The Pareto chart shows that the level of importance in reducing the probability of occurrence of each risk agent varies greatly. Figure 4.11 concludes that 11 risk agents contribute to the existing risks that hinder the supply chain process in the company. In the rules of the house of risk method. to choose the source of risk to be treated is in a ratio of 80:20. The result shows the rank aggregate risk potential of 11 risk agents that have already been filtered based on the 80% of occurring risk as follows:

1. Lack of quality control

   The lack of checking for finished goods or quality control (A17) causes this risk agent to have the highest ARP value with a score of 1292.8. This risk agent is the highest priority for mitigation. The lack of finished goods checking often causes many defective goods to be mixed with the good finished goods. So that, it is often to suffer from a return goods by the client to a penalty because it does not match the specifications or amount. Therefore, this risk deserves to be handled

2. Lack of supervision

   The lack of work supervision (A8). This risk agent has the second-highest ARP value with a score of 1178.7 This risk agent is included as the second priority to be exposed with mitigation. The lack of work supervision sometimes arises because of the dense production and busy business owners. Errors in production or the delivery process sometimes occur due to a lack of work supervision. Therefore, this risk deserves to be handled

3. Human error (A5)

   Human error (A5) this risk agent has the second-highest ARP value of 1093.8. So, this risk agent will be the second priority to be treated. Human error is a risk that may arise and even has a high chance because the production process requires human labor. In PT.XYZ, human error, in fact, often occurs, this can be due to a high workload. Wrong input data and failed operating machine errors are one of the human errors that exist in PT. XYZ. Therefore, this kind of risk deserves mitigation action.

4. Overheat machine due to overwork

   Overheating machines due to overwork machines (A13) is positioned as the fourth-highest ARP value with a score of 1048.2. This risk happens due tothe machine's working hours that are often not commensurate with the machine's workload, so the machine repeatedly heats up and even dies before the machine downtime. Therefore, this kind of risk deserves mitigation action.

5. Limited maintenance analysis

   Lack of maintenance analysis (A7) is the fifth highest risk agent with a score of 998.4. The lack of analysis by the department regarding the causes or abnormal behaviours shown by the machine causes frequent machine breakdowns or even sudden stops (A12), it is due to poor maintenance. There are 3 main machines at PT. XYZ namely washing line, cutting line, and SSP or polymerization. According to an expert from the operations department, the lack of machine analysis during maintenance occurred due to the difficulty of obtaining certain spare parts in Indonesia, so replacement parts must be ordered from abroad, besides, it was difficult to recognize machine behaviours so it took a long time to find out machine habits. Therefore, this kind of risk deserves mitigation action.

6. Internal damage of production machine (spare part)

   Internal damage on a production machine (A18) is the sixth risk with an ARP score of 870.9. This risk occurs due to the difficulty of purchasing machine spare parts from abroad in large amounts. The machines at PT.XYZ is manufactured in Germany and Hong Kong, so to get suitable spare parts for maintenance, the company is required to make the orders from abroad, in which based on Indonesian Law, it is not allowed the purchase the parts in large quantities and at certain times. Therefore, this kind of risk deserves mitigation action.

7. Material risk

   The scarcity of raw material PET (A1) is the seventh rank risk with an ARP score of 764.1. The difficulty of finding raw materials due to the reduced volume of raw materials and also the high demand for materials is also the cause of material scarcity. The number of competitors who also require large quantities of raw materials causes the price of materials to rise suddenly (A9). Therefore, this kind of risk deserves mitigation action.

8. No monitoring towards the supplier

   The lack of supervision of suppliers is the eighth risk with an ARP score of 538.5. This risk occurs due to a lack of communication with suppliers, often materials and inappropriate specifications make it an obstacle to the production process. Therefore, this kind of risk deserves mitigation action.

9. Tired worker (A6)

   The frequent occurrence of work accidents due to worker fatigue causes many production processes to be hampered. According to experts from the department of occupational safety and health, the lack of airflow and the intensity of engine heat causes workers to often feel tired. In addition, long shifts of 5 – 6 hours work often cause many workers to lose focus due to fatigue. Therefore, this kind of risk deserves mitigation action.

Pareto chart is the visualization of House of Risk (HOR) 1. Then, the risk agents on the prioritized line will proceed to the next step, House of Risk Phase 2. To make the mitigation process effective it needs to calculate the risk. Regularly, mitigation action is in strategic or tactical means. Tang (2019) stated that planning must focus on increasing flexibility, avoidance, corporation internal and external, and control risk in providing mitigation. The calculation process in HOR 2 is mostly the same as HOR 1, but the difference calculation is on both variable inputs. Previously the input used risk event and agent data, but in HOR 2, the inputs are the risk agents with high ARP numbers and data from mitigation action.

4.6 House of Risk Phase 2

4.6.1 Mitigation Action Identification

After obtaining the priority of the risk agent from the Pareto chart, the new stage can be initiated, which is constructing HOR model phase 2 to propose mitigation actions. To obtain the best alternative on mitigation actions, it requires brainstorming and analysis of suitable mitigation actions based on the root cause of the problem. This research uses a fishbone diagram to analyse the cause and effect risk analysis. This method aims to obtain the suitable proposed mitigation action for optimizing the flow of the supply chain in PT XYZ that is shown in Figure 4.12.

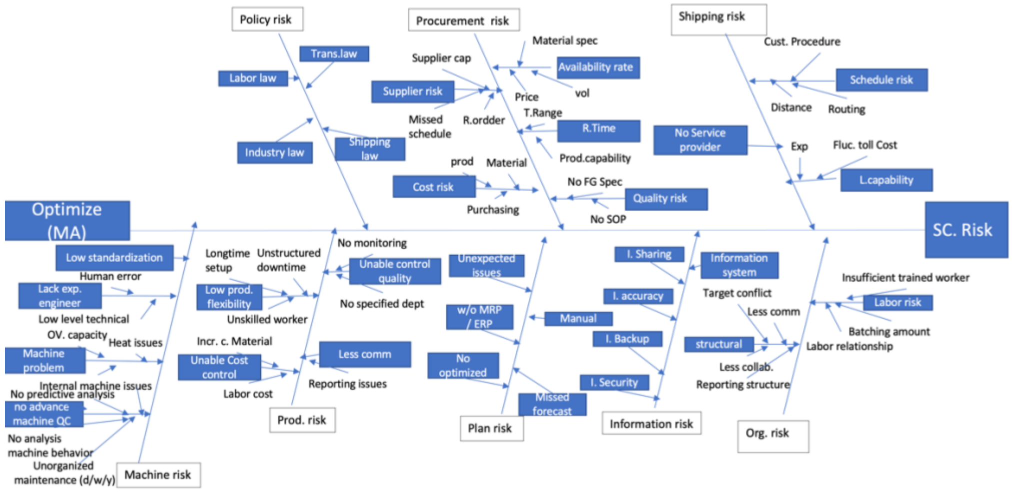

Figure 4.12 Fishbone Diagram

From figure 4.12, it can be seen the main problem (root cause) of risk is highlighted in the blue box. Based on that, it needs to map the prevention risk based on the root cause of the problem. Therefore in the future, the occurrence of the risk could decrease. The next step is to identify mitigation action which can be seen in Table 4.13 based on the root cause of the problem.

Table 4.12 Risk Mitigation Action Mapping

Risk Agent	Risk title	Preventive action	Code
A17	Lack of quality control	Understand and develop guidance regarding products specification and quality standards	P1
		Do quality checklist / rechecking	P2
		Increasing communication internal and external	P3
A8	Lack of supervision	Increasing communication internal and external	P3
		Make integrate information system	P4
		Make reporting schedule (effectiveness)	P5
A5	Human error	Create reward, punishment and manage motivation of the staff	P6
		Make proper work environment	P7
		Provide regular training to workers	P8

Risk Agent	Risk title	Preventive action	Code
		Increasing communication on the department	P3
A13	Overheat machine (SSP Machine)	Make schedule exact downtime of the machine	P9
		Make a predictive analysis of maintenance per machine	P10
		Do control of the input capacity of a machine	P11
		Do periodic checks	P12
A7	Limited maintenance analysis	Do periodic checks	P12
		Improve the quality of machine maintenance	P13
		Make a predictive analysis of maintenance per machine	P10
A18	Damage of production machine (internal)	Do periodic checking	P12
A1	Rare raw material	Create buffer material/safety stock	P14
		Develop control stock management	P15
A2	No monitoring towards the supplier	Increasing communication on the department	P3
		Make reporting schedule (effectiveness)	P5
A12	Unstable engine	Do control of the input capacity of machine	P11
A9	Material price fluctuation	Add mark-up cost by adding contingency	P16
		Create buffer material/safety stock	P14
A6	Tired worker/overtime	Fatigue management	P17
		Work analysis	P18

After determining the mitigation strategy, the next step is defining the degree of difficulty (Dk). In order to determine the degree of difficulties, this research uses fuzzy logic to obtain a valid degree of difficulties based on cost and human resource engagement. Later after determining the degree of difficulty score the next step will be shown in the house of risk in

Table 4.10 and measuring the correlation value between mitigation and the selected risk agent, after determining the correlation value between the mitigation strategy and the risk agent, then calculating the Total Effectiveness (TEK) value by multiplying the correlation value between the risk agent (j) and preventive action (k). It aims to find out the effectiveness of the mitigation strategy implementation. Table 4.14 and Table 4.15 show the calculation of HOR phase 2.

4.6.2 Fuzzy Mitigation Action

For this calculation, the researcher uses fuzzy logic to determine the number of degrees of difficulties (Dk). The input needed is a cost value and resource commitment that from experts' opinion score. Both of the inputs will be processed using fuzzy to gain the output as a degree of difficulties for mitigation action for the next calculation in HOR phase 2. The calculation will be:

1. Define The Rule of The Fuzzy
   A. IF the cost is very low and the resource commitment is very low Then the degree of difficulties mitigation action is very low.
   B. IF the cost is very low and the resource commitment is low Then the degree of difficulties mitigation action is low
   C. IF the cost is very low and the resource commitment is medium Then the degree of difficulties mitigation action is low.
   D. IF the cost is very low and the resource commitment is high Then the degree of difficulties mitigation action is low.
   E. IF the cost is very low and the resource commitment is very High Then the degree of difficulties mitigation action is medium.
   F. IF the cost is low and the resource commitment is very low Then the degree of difficulties mitigation action is low.
   G. IF the cost is low and the resource commitment is low Then the degree of difficulties mitigation action is low.
   H. IF the cost is low and the resource commitment is medium Then the degree of difficulties mitigation action is medium.

I. IF the cost is low and the resource commitment is high Then the degree of difficulties mitigation action is medium.
J. IF the cost is low and the resource commitment is very high Then the degree of difficulties mitigation action is high.
K. IF the cost is medium and the resource commitment is very low Then the degree of difficulties mitigation action is low.
L. IF the cost is medium and the resource commitment is low Then the degree of difficulties mitigation action is medium.
M. IF the cost is medium and the resource commitment is medium Then the degree of difficulties mitigation action is medium.
N. IF the cost is medium and the resource commitment is high Then the degree of difficulties mitigation action is high.
O. IF the cost is medium and the resource commitment is very high Then the degree of difficulties mitigation action is high.
P. IF the cost is high and the resource commitment is very low Then the degree of difficulties mitigation action is low.
Q. IF the cost is high and the resource commitment is low Then the degree of difficulties mitigation action is medium.
R. IF the cost is high and the resource commitment is medium Then the degree of difficulties mitigation action is high.
S. IF the cost is high and the resource commitment is high Then the degree of difficulties mitigation action is high.
T. IF the cost is high and the resource commitment is very high Then the degree of difficulties mitigation action is very high.
U. IF the cost is very high and the resource commitment is very low Then the degree of difficulties mitigation action is medium.
V. IF the cost is very high and the resource commitment is low Then the degree of difficulties mitigation action is high.
W. IF the cost is very high and the resource commitment is medium Then the degree of difficulties mitigation action is high.

X. IF the cost is very high and the resource commitment is high Then the degree of difficulties mitigation action is very high.

Y. IF the cost is very high and the resource commitment is very high Then the degree of difficulties mitigation action is very high

2. Define Fuzzy Input

The inputs of fuzzy calculation are cost and human resource commitment engagement that was defined based on experts' opinions. In the calculation process of both inputs, the parameter of the membership function variable should be declared in Matlab software because this parameter will measure the membership function of each cost and resource commitment.

$$\mu Very\ low\ (x) = \begin{cases} 0, & x \geq 2 \\ \frac{2-x}{0.5}, & 0 \leq x \leq 2 \\ 1, & x \leq 1 \end{cases}$$

$$\mu Low(x) = \begin{cases} 0, & x \leq 1\ or\ x \geq 3 \\ \frac{x-1}{1}, & 1 < x \leq 3 \\ \frac{3-x}{1}, & 2 \leq x < 3 \end{cases}$$

$$\mu Normal(x) = \begin{cases} 0, & x \leq 2\ or\ x \geq 4 \\ \frac{x-2}{1}, & 2 < x \leq 2.8 \\ \frac{4-x}{1}, & 3 \leq x < 4 \end{cases}$$

$$\mu High(x) = \begin{cases} 0, & x \leq 3\ or\ x \geq 4 \\ \frac{x-3}{1}, & 3 < x \leq 4 \\ \frac{4-x}{1}, & 3 < x < 5 \end{cases}$$

$$\mu Very\ high(x) = \begin{cases} 0, & x \leq 4 \\ \frac{x-4}{1}, & 4 < x \leq 5 \\ 1, & x > 5 \end{cases}$$

From the result, the range parameter from 0 until 5 are based on probability/ range density that has meaning as follows: very low is 0 to 2 and low is 1 to 3 has similar interpretation which the cost and the human resources that needed for conducting the mitigation action is low, for the medium score of 2 to 4, in order to conduct mitigation action, it needs medium cost and needs human resource more than the low parameter, the last is the high score that has a range of 3 to 5 and very high, which is 4 to 5. Both of the parameters have the same interpretation which is in order to create the mitigation action is needed the high cost and a lot of the human resources to construct and conduct mitigation action.

The result of membership parameter number will be made into a curve for fuzzy calculation. As shown in Table 4.14, the summary of input membership function parameter. The illustration of the input membership function parameter number that was inputted in Matlab, illustrated in Figure 4.13 and Figure 4.14.

Table 4.13 Membership Function Parameter of Input

Function	**Variable**	**Fuzzy indicators (impact)**	**Range**	**Unit of Range**
Input	Operational Cost	Very low	0-5	[0,5 0 1 1,5]
		Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,25]
		High		[2,5 3 3,5 4]
		Very high		[3,5 4,5 5]
		Very low	0-5	[0,5 0,1 1,5]

Function	Variable	Fuzzy indicators (impact)	Range	Unit of Range
	Resources commitment engagement	Low		[1 1,5 2 2,5]
		Moderate		[1,75 2,25 2,75 3,25]
		High		[2,5 3 3,5 4]
		Very High		[3,5 4,5 5]

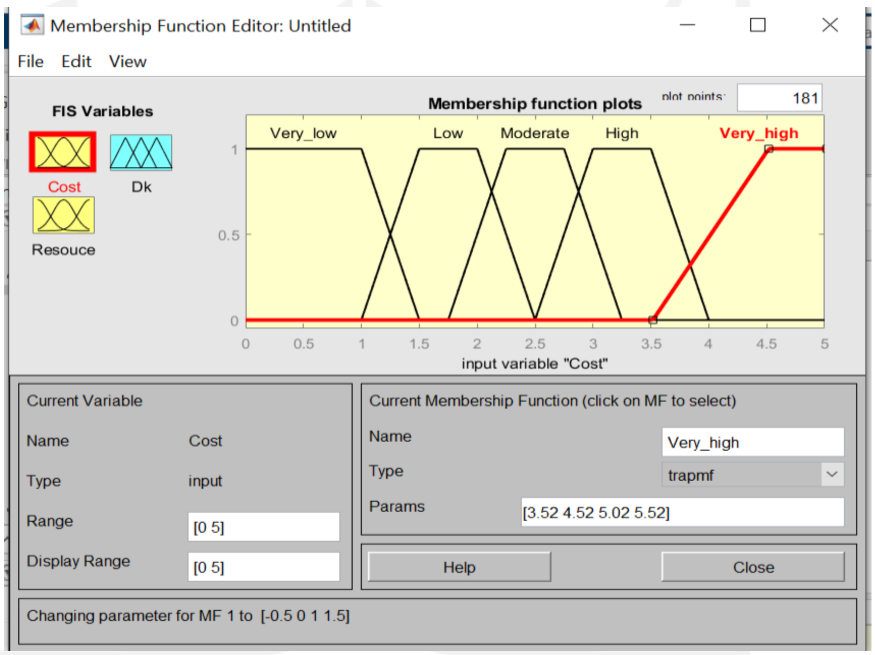

Figure 4.13 Membership function input parameter of cost curve

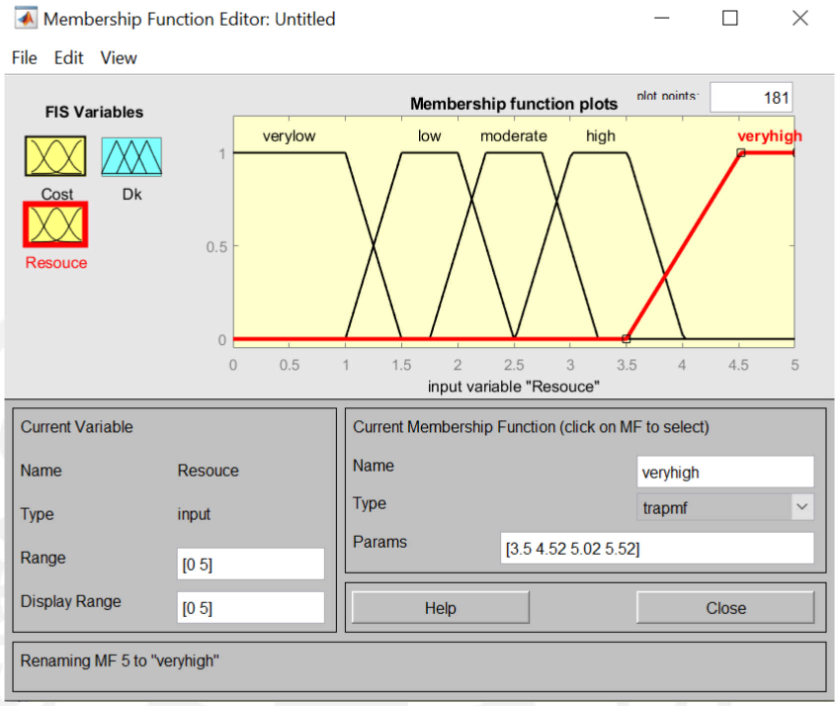

Figure 4.14 Membership function input parameter of the cost curve

3. Define Fuzzy Output

As explained above, the output of the fuzzy calculation is the degree of difficulties (Dk). The number is obtained from the fuzzy calculation of cost and human resource commitment, in which the score is based on the experts' opinion. Similar to the input, the parameter of the output membership function variable should be declared in MATLAB software. Table 4.15 shows the variable output membership function parameter of degree difficulties.

$$\mu Very\ low\ (x) = \begin{cases} 0, & x \geq 2 \\ \dfrac{2-x}{0.5}, & 0 \leq x \leq 2 \\ 1, & x \leq 1 \end{cases}$$

$$\mu Low(x) = \begin{cases} 0, & x \leq 1 \; or \; x \geq 3 \\ \frac{x-1}{1}, & 1 < x \leq 3 \\ \frac{3-x}{1}, & 2 \leq x < 3 \end{cases}$$

$$\mu Normal(x) = \begin{cases} 0, & x \leq 2 \; or \; x \geq 4 \\ \frac{x-2}{1}, & 2 < x \leq 2.8 \\ \frac{4-x}{1}, & 3 \leq x < 4 \end{cases}$$

$$\mu High(x) = \begin{cases} 0, & x \leq 3 \; or \; x \geq 4 \\ \frac{x-3}{1}, & 3 < x \leq 4 \\ \frac{4-x}{1}, & 3 < x < 5 \end{cases}$$

$$\mu Very\ high(x) = \begin{cases} 0, & x \leq 4 \\ \frac{x-4}{1}, & 4 < x \leq 5 \\ 1, & x > 5 \end{cases}$$

The result of the range parameter has a similar meaning with the input fuzzy 2 interpretation. The result membership parameter number will be made into a curve for fuzzy calculation. As shown in Table 4.15, the summary of the degree of difficulties mitigation action membership function parameter is revealed. The illustration of the degree of difficulties membership function parameter number that was inputted in Matlab, illustrated in Figure 4.15.

Table 4.14 Membership Function Parameter of Input

Function	**Variable**	**Fuzzy indicators (impact)**	**Range**	**Unit of Range**
Output		Very low	0-5	[0 0.1 1 2]

The degree of difficulties mitigation action	Low	[1 2 3]
	Moderate	[2 3 4]
	High	[3 3.5 4]
	Very high	[3.5 4 5]

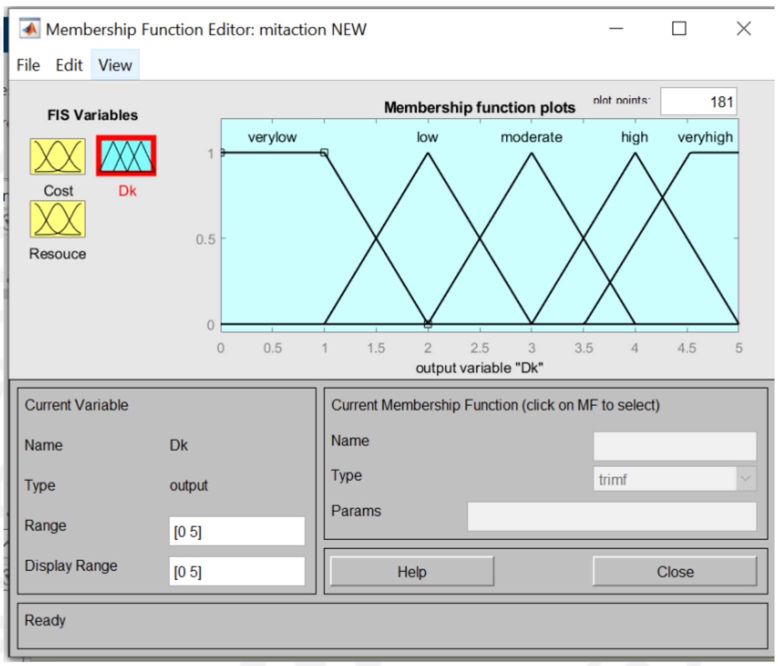

Figure 4.15 Membership function output parameter of Dk curve

4. Calculation Result (Defuzzification)

After arranging the curve of variable input and output as shown in Figure 4.16, the calculation can be conducted by inputting the score number of cost and resource. The result of fuzzy the degree of difficulties calculation was shown in Table 4.16.

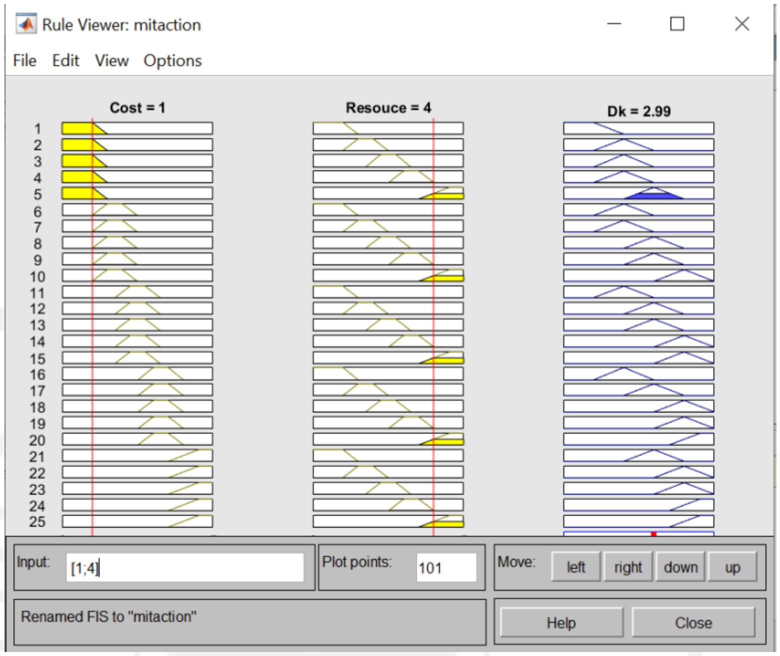

Figure 4.16 Defuzzification Calculation Process

Table 4.15 Calculation Fuzzy Result (Defuzzification)

Prevention Action	Code	Cost	H. Resource	Degree Difficulties
Understand and develop guidance regarding products specification and quality standards	P1	1	4	2.99
Do quality checklist / rechecking	P2	3	3	3.58
Increasing communication internal and external	P3	1	4	2.99
Make integrate information system	P4	4	4	4.36
Make reporting schedule (effectiveness)	P5	1	2	2.03

Prevention Action	Code	Cost	H. Resource	Degree Difficulties
Create reward, punishment and manage motivation of the staff	P6	3	2	3.42
Make good work environment	P7	1	3	2.03
Provide regular training to employees	P8	3	3	3.58
Make schedule exact downtime of the machine	P9	1	3	2.03
Make a predictive analysis of maintenance per machine	P10	3	3	3.58
Do control of the input capacity of the machine	P11	2	3	3.42
Do periodic checking	P12	1	2	2.03
Improve the quality of machine maintenance	P13	1	2	2.03
Create buffer material / safety stock	P14	3	3	3.58
Develop control stock management	P15	3	3	3.58
Add markup cost by adding contingency	P16	4	2	3.93
Impose length of time restriction/ human endurance limits	P17	3	3	3.58

Prevention Action	Code	Cost	H. Resource	Degree Difficulties
Add new batch of worker	P18	4	4	4.36

After determining the degree of difficulties or the level of difficulties based on cost and human resource commitment, the next step is measuring the correlation value between mitigation and the selected risk agent, after determining the correlation value between the mitigation strategy and the risk agent, then calculating the Total Effectiveness (TEK) value by multiplying the correlation value between the risk agent (j) and preventive action (k). It aims to find out the effectiveness of the mitigation strategy implementation as shown in Table 4.17 below.

Table 4.16 Calculation of House of Risk Phase 2

ARPJ	Risk Agent	Preventive Action																	
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**
1292,853	A17	9	9	9															
1178,636	A8			9	9	3													
1093,784	A5						9	3	9										
1048,952	A13									9	9	9	9						
998,3862	A7										3		9	9					
870,957	A18												9						
764,1018	A1														9	9			
538,56	A2			9		9													
482,8824	A12											9							
449,2026	A9														9		9		
420,3486	A6																	1	9
394,848	A16			9	9	9													
380,8728	A10		9								9								
353,718	A20				9		9												
326,529	A3			1	9										9				
295,5375	A19		9																
271,0755	A14			9															
185,8626	A4				9														
150,1398	A15														9				

Table 4.17 Relationship of Risk Agent and Preventive Action

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18
A17	11636	11636	11636															
A8			10608	10608	3536													
A5						9844	3281	9844										
A13									9441	9441	9441	9441						
A7										2995		8985	8985					
A18												7839						
A1														6877	6877			
A2			4847		4847													
A12											4346							
A9														4043		4043		
A6																	420	3783
A16			3554	3554	3554													
A10		3428								3428								
A20				3183		3183												
A3			327	2939										2939				
A19		2660																
A14			2440															
A4				1673														
A15														1351				
A11																	440	
Tk	11636	17723	33410	21956	11937	13028	3281	9844	9441	15864	13787	26265	8985	15210	6877	4043	860	3783
Dk	2,99	3,58	2,99	4,36	2,03	3,42	2,03	3,58	2,03	3,58	3,42	2,03	2,03	3,58	3,58	3,93	3,58	4,36
ETD	3891,5	4950,7	11174	5035,9	5880,1	3809,2	1616,4	2749,7	4650,5	4431,2	4031,1	12938,3	4426,3	4248,5	1920,9	1028,7	240,3	867,7

4.6.3 Mitigation Action Rank

From the result of Table 4.15, the next step is ranking the mitigation action, the ranking based on HOR phase 2 is based onthe correlations score of risk agent and preventive action that is shown in the ETD. The risk with score 1 means the risk event and agent have a shallow relationship. While a score of 3 means that the risk event and agent have a low relationship. The risk with a score of 9 means that the risk event and agent have a high relationship. The difference in the relationship may happen in each of the risks. Perhaps it is occurred because of the effect and impact of preventive action that is also implemented differently. Table 4.18 shows the sequence of mitigation strategies from the highest to the lowest that are resulted from the calculation of House of Risk phase 2.

Table 4.18 Preventive Action Rank

Code	Mitigation Action
P12	Do periodic checking
P3	Increasing communication internal and external
P5	Make reporting schedule (effectiveness)
P4	Make integrate information system
P2	Do quality checklist / rechecking
P9	Make schedule exact downtime of the machine
P10	Make a predictive analysis of maintenance per machine
P13	Improve the quality of machine maintenance
P14	Create buffer material/safety stock
P11	Do control of the input capacity of the machine
P1	Understand and develop guidance regarding products specification and quality standards
P6	Create reward, punishment and manage motivation of the staff
P8	Provide regular training to employees
P15	Develop control stock management
P7	Make the good work environment
P16	Add markup cost by adding contingency
P18	Add new batch of worker
P17	Fatigue management

House of Risk in phase 2 aims to determine risk mitigation strategies for each dominant risk agent. The output of the second phase of House of Risk is a sequence of risk mitigation strategies generated from interviews and discussions with experts. The following are the priority mitigation strategies for each selected risk agent.

1. Do periodic checking

   The mitigation action with the highest ranking is periodic checking of machines with a degree of difficulties (Dk) 2,99 and the total of effectiveness and difficulties (ETDk) of 12938.3. This mitigation action intentionally makes a schedule to do periodic checking, divided into daily, weekly, and monthly checking. The function of this risk mitigation is to increase efficiency where routine maintenance (inspections, oil changes, and replacement of spare parts) can help the equipment department run more efficiently. Besides, it also prevents high repair costs caused by the need for significant repairs in engine maintenance, so that the company won't lose so much money.

2. Increase communication internal and external

   The second-ranking risk mitigation action is to increase internal and external communication, with a degree of difficulties (Dk) 3.58 and the total of effectiveness and difficulties (ETDk) of 1174. In improving internal and external communication, the company can minimize risk events, such as missed scheduling, human error, and missed communication with suppliers. Increasing the effectiveness of communication between departments and external parties will make the information delivery received appropriately.

3. Make reporting schedule

   The third mitigation action is to make a reporting schedule. This mitigation strategy has a degree of difficulties (Dk) 2,99 and a total of effectiveness and difficulties (ETDk) of 5880.1. By using email media to do reporting schedules, rather than verbal reporting makes each department easier to make decisions when there is an emergency. It also improves the flow of information exchange from subordinates to the managers and vice versa to streamline the process.

4. Make integrate information system

   The fourth mitigation action is to make the integrated information system Mitigation strategy have a degree of difficulties (Dk) 4.36 and the total of effectiveness and difficulties (ETDk) of 5035.9. This mitigation action helps combine several departments or various components into one extensive system. A mitigation action is helpful so that cross-division collaboration increases so that each division no longer works individually or repeats the process due to differences in subsystems. An integrated system will reduce the risk of data usage errors or corrupted data because of real-time data access. Another function of mini-site integration is to optimize teamwork.

5. Do quality checklist or rechecking

   The fifth risk mitigation action is to carry out quality control by implementing a quality checklist that is intended not only in the quality management system but also for rechecking before delivery. This mitigation strategy has a degree of difficulties (Dk) 2.03 and a total of effectiveness and difficulties (ETDk) of 4950.7. The function of this quality control is to ensure that the product that comes out is a product that is by company standards to increase trust in consumers so that there will be different quality for each product.

6. Make schedule and duration exact downtime of the machine

   The sixth mitigation action is to make a scheduling downtime or planned downtime. This mitigation strategy has a degree of difficulties (Dk) of 2,99 and a total of effectiveness and difficulties (ETDk) of 12938.3. Make a schedule for downtime is important so that when production equipment is off, it will allow for planned maintenance. This plan is essential for keeping critical assets healthy, but it can also reduce excessive vital maintenance. Currently, PT.XYZ does not have an exact downtime duration and schedule for moderate maintenance. They prefer machine downtime when the machine has reached peak capacity or often known as system run to failure. So the risk that occurs is the number of internal damage to the machine and high costs in maintenance. Princewill (2018) suggests planning downtime by putting a daily schedule for moderate downtime and exact duration to avoid any vital internal equipment issues. The daily downtime is a systematic tackle to avoid unplanned downtime. So that if there is a schedule, the cost loss will be forecasted.

7. Make a predictive analysis of maintenance per machine

   The seventh mitigation action is to make a predictive maintenance analysis. This mitigation strategy has a degree of difficulties (Dk) 2.03 and a total of effectiveness and difficulties (ETDk) of 4431.2. There are many benefits of using predictive analytics because it can extend the operating time of an asset, prevent unexpected breakdowns, and save costs. According to He (2017), Predictive maintenance makes organizations to experience best practice output maintenance from database setup, schedule monitoring, measurement, and management data, to machine and cost analysis.

8. Improve the quality of machine maintenance

The risk mitigation action with the eighth-highest rank is to improve the quality of machine maintenance which has a degree of difficulties (Dk) of 3.58 and the total of effectiveness and difficulties (ETDk) of 4426.3. Implementing the mitigation actions, aims to improve the quality of machine maintenance. Besides, this mitigation minimizes severe engine damage because it usually only replaces or fills oil. When a machine part is damaged, it cannot be operated for several days while waiting for procuring new machine parts.

9. Create buffer material/safety stock

   The ninth mitigation action is to create a buffer or safety stock. This mitigation strategy has a degree of difficulties (Dk) 2,03 and a total of effectiveness and difficulties (ETDk) of 4248.5. Mitigation actions intentionally aim to reduce rare raw materials and also material fluctuation costs. So that with the existence of a buffer or safety stock, the production system can still apply even though there are risks that hinder it. The use of this buffer system is also to provide material in case there is a sudden order from the customer.

10. Do control of the input capacity of the machine

    The tenth mitigation action is to control the input capacity of production machines. This mitigation strategy has a degree of difficulties (Dk) of 3.58 and a total of effectiveness and difficulties (ETDk) of 4031.1. This mitigation reduces the risk of overloaded engine capacity, which will impact internal engine damage. It makes the resulting product is also not suitable with company standards.

11. Understand and develop guidance regarding products specification and quality standards

    The eleventh mitigation action is to make guidance regarding product specification and quality standards. This mitigation strategy has a degree of difficulties (Dk) 3.42 and a total of effectiveness and difficulties (ETDk) of 3891.5. This mitigation action reduces the risk of products that do not meet specifications proceeding to become finished goods. The existence of quality standards will help workers to know exactly which products that are considered as passed and which products aren't. So that, it helps to speed up the standardization process.

12. Create reward, punishment, and manage motivation of the staff

    The twelfth mitigation action is creating a system of rewards, punishments, and managing staff motivation. This mitigation strategy has a degree of difficulties (Dk) 2.03 and a total of effectiveness and difficulties (ETDk) of 3809.2. This mitigation action aims to provide two sides to the staff: a deterrent effect and increased motivation at work.

Punishment is the threat of discipline that aims to improve the performance of the violating employees, maintain applicable regulations and provide lessons. The effect of punishment is minimizing errors and effective in increasing quality skills. In contrast, rewards is a management concept that intentionally provides rewards as contributions as good work. Shields (2018) suggests that the company's motivation staff have to put indicators such as incentives or benefits to increase the contributions of positive values.

13. Provide regular training to employees

    The thirteenth mitigation action is to provide regular training to employees. This mitigation strategy has a degree of difficulties (Dk) of 2.03 and a total of effectiveness and difficulties (ETDk) of 2749.7. Mitigation action aims to reduce errors made to operators and staff, such as misuse of machines and data loss. Besides, this mitigation action will improve the workers' skills.

14. Develop control stock management

    The fourteenth mitigation action is developing control stock management data. This mitigation strategy has a degree of difficulties (Dk) of 3.58 and a total of effectiveness and difficulties (ETDk) of 1920.9. Stock control is also known as data inventory control, whereas maintaining the appropriate quantity of stock to balance the need for surplus supplies. According to Wijaya (2017), control stock management, such as perpetual stock management, is suitable for a huge company and has extensive stock. This management and electronic tracking records and continually tracks inventory, giving accurate and up-to-date inventory counts. It gives a more accurate and recentindication of stock levels and removes the risk of human error.

15. Increasing contingency cost

    The fifteenth mitigation action is cost estimation for procurement. This mitigation strategy has a degree of difficulties (Dk) of 3.58 and a total of effectiveness and difficulties (ETDk) of 1616.4. Cost contingency is a cost estimation by using risk as an indicator of the cost added range. In PT.XYZ, there are often sudden cost fluctuations when buying raw materials, so it is necessary to calculate this risk. A contingency system provides a range of possible cost results to cost elements and evaluates the likelihood of achieving the overall cost estimate. So that the cost for procurement will be adequate.

16. Develop a good/positive working environment

    The sixteenth mitigation action is to develop and maintain a good working environment. This mitigation strategy has a degree of difficulties (Dk) 3.93 and a total of effectiveness and difficulties (ETDk) of 1028.7. In this mitigation, creating a positive work environment will significantly influence employee attitudes towards their job. This mitigation benefits from strengthening teamwork and protecting employees' mental health or employee well-being. Fridayanti (2019) stated that company culture/environment is one of the most significant indicators in reducing human error. A good environment will increase productivity at work not only but also reduce missed communication.

17. Work Analysis

    The seventeenth mitigation action is work analysis which has a function to measure performance management and workforce planning. This mitigation strategy has total a degree of difficulties (Dk) of 3.58 and a total of effectiveness and difficulties (ETDk) of 867.7. In this mitigation, the manager must plan the number of workers by calculating the work weight needed so that the work done becomes effective. Besides, it can be evaluated later on.

18. Fatigue Management

    The eighteenth mitigation action is fatigue management, where worker fatigue is a significant problem in the industry and can be associated with the safety and health of the worker. This mitigation strategy has a degree of difficulties (Dk) 4.36 and a total of effectiveness and difficulties (ETDk) of 240.3. In PT.XYZ, the fatigue in the workplace relates to the physical load and forceful exertion that happens in the washing line (production process). As the mitigation strategy, we needed to create fatigue management by increasing the rest hours in each batch by measuring workers' endurance. So that it will maintain all the workers’ health and will not disturb any production line later on.

CHAPTER V

DISCUSSION

5.1 Fuzzy Arithmetic

In this research, data validation will use the fuzzy number set method or fuzzy arithmetic. A fuzzy number is a mapping number from the R line to a unit interval that satisfies properties such as normality, unimodality, continuity, and finite support. According to Dubois and Parade (1980) in validating fuzzy numbers using interval analysis, some properties in the set are interpreted as alpha cut. In this fuzzy number validation experiment, triangular fuzzy numbers is employed. There is the simplest model of an indeterminate numerical quantity. The analytical focus in this class introduces us to the most obvious properties of fuzzy arithmetic. In two fuzzy numbers, A = (x; a, m, b) and B= (x; c, n, d). More specifically, the membership functions of these two numbers are defined by the following connected linear function fragment:

$$A(x; a, m, b) = \begin{cases} \frac{x-a}{m-b}, if\ x \in [a, m] \\ \frac{b-x}{b-m}, if\ x \in [m, b] \\ 0\ or\ for\ the\ othes \end{cases}$$

$$A(x; c, n, d) = \begin{cases} \frac{x-c}{n-c}, if\ x \in [c, n] \\ \frac{d-x}{d-n}, if\ x \in [n, d] \\ 0\ or\ for\ the\ othes \end{cases}$$

Capital values (m and n) designate a dominant value (characteristic) of the appropriate quantity, while the lower (a or c) and upper (b or d) limits reflect the expansion of the concept. Therefore, if the above equation is entered in the risk event and agent and the mitigation action validation, in this case, it will be explained as follows.

1. Fuzzy HOR 1 (Risk Agent and Risk Event)

If the risk agent is 4.7 and risk event 4.62 that based on risk event and agent 1 then,

- Risk agent ($\bar{A}$)= 4.7 and Risk Event ($\bar{B}$)= 4.62

- Function $\bar{A}$ & $\bar{B}$ as below:

$\bar{A} = [4\ 5\ 6]$

$\bar{B} = [3\ 4\ 5]$

$$\mu_A = \begin{cases} 0\,, x < 4 \\ \dfrac{x-4}{5-4}, 4 \leq x < 5 \\ \dfrac{6-x}{6-5}, 5 \leq x \leq 6 \\ 0, x > 6 \end{cases}$$

$$\mu_B = \begin{cases} 0\,, y < 3 \\ \dfrac{y-3}{3-4}, 3 \leq y < 4 \\ \dfrac{5-y}{5-4}, 4 \leq y \leq 5 \\ 0, x > 5 \end{cases}$$

- $\bar{A}$X$\bar{B}$ = ? since $\alpha = [\ 0\ 1]$

$\bar{A}\alpha = [(\alpha + 1)(-2\alpha + 4)]$ $\bar{B}\alpha = [(2\alpha + 4)(-\alpha + 5)]$

$\bar{A}_\alpha X\, \bar{B}_\alpha = [\ (\alpha + 1).(2\alpha + 4) \quad (-2\alpha + 4).(-\alpha + 5)]$

$\bar{A}_1 X\, \bar{B}_1 = [(1 + 1)(2.1 + 4) \quad (-2.1 + 4)(-1 + 5)]$

$\bar{A}_1 X\ \bar{B}_1\ = [\ 8\ 8]$

$\bar{A}_0 X\ \bar{B}_0\ = [(0+1)(2.0+4)\ \ (-2.0+4)(-0+5)]$

$\bar{A}_0 X\ \bar{B}_0\ = [\ 4\ \ 20]$

Therefore, approximately function $\bar{A}$ & $\bar{B}$ is $\cong [\ 4\ 8\ 20]$

Based on the results of the parameter calculation, it shows the interval or alpha cut of the multiplication of the two membership sets of risk agent and risk event. The results of the set range will be continued for the process of decreasing the parameters [4 8 20] to obtain a functional approach which will be tested using the center of gravity method to find out whether the results have results close to the parameters or often called linearity.

$$F1 = a.c + \omega.c(m-a) + \omega a(n-c) + \omega^2(m-a)(n-c)$$
$$= 2 + 2\omega(2-1) + \omega(4-2) + \omega^2(2-1)(4-2)$$
$$= 4 + 2\omega + 2\omega^2$$

$$F1 = \sqrt{\frac{2}{\omega} + 1 - 1}$$

$$F2 = m.n + 1 - \omega(b - m + d - n) + (1-\omega^2)(b-m)(d-n)$$
$$= 2.4 + (1-\omega)(4-2+5-4) + (1-\omega^2)(4-2)(5-4)$$
$$= 8 + 3(1-\omega) + 2(1-\omega)^2$$
$$= 8 + 3 - 3W + 2 - 2W$$
$$= \sqrt{\frac{7}{2}} - 2\omega$$

The result of the defuzzification of the Fuzzy arithmetic formula from Risk event 4 and Risk Agent 5 is:

$$c[\ 4\ 8\ 20] = \begin{cases} \sqrt{\frac{2}{\omega}+1}\ -1\ , for\ c\ \in [4\ \ 8\ ] \\ \sqrt{\frac{7}{2}}-2\omega, for\ c\ \in [8\ 20] \\ 0, for\ others \end{cases}$$

Next step as explained before, the final formula value will be calculated by using Centre of Gravity (COG) for validity calculation of the parameters function risk event and risk agent. The detailed formula of COG can be shown below.

$$COG = \frac{\sum_{i=1}^{20} Xt.u(Xi)}{\sum_{i=1}^{20} u(Xt)}$$

From the formula COG, the calculation of the height of the fuzzy number (u) will use the formula for calculating the set parameter validation [4 8 20] as follows.

$$= \frac{\sum_{i=1}^{20} 4.0 + 5.0{,}41 + 6.0{,}58 + 7.0{,}81 + 8.1 + 9.0{,}86 + \cdots \ldots\ldots +19.0{,}21 + 20.0}{\sum_{i=1}^{20} 0 + 0{,}41 + 0{,}58 + 0{,}81 + 1 + 0{,}86 + \cdots \ldots\ldots +10{,}21 + 0}$$

$$= \frac{23.278}{6.579}$$

$$= 4.034 \approx 4$$

Based on the results of the calculation of the center of gravity shows the numbers that are included in the set parameters, namely [4 8 20] so it can be said that fuzzy numbers are valid. The next step isto calculate s to determine the validity of fuzzy mitigation action, In order to prove the decrease the ambiguity values.

2. Fuzzy HOR 2 (Mitigation Action)

This calculation has a similarity with the previous calculation (Risk event and Risk agent). The difference of the calculation was in the formula in order to determine the range of the parameter. The detail will be explained below.

If the risk = 4.04 and the prevention action 1 is 2.99 then,

Risk ($\bar{A}$)= 4.04 and Prevention action 1 ($\bar{B}$)= 2.99

Function $\bar{A}$ & $\bar{B}$ as below:

$\bar{A} = [4\ \ 5\ 6]$

$\bar{B} = [2\ 4\ 6]$

$$\mu_A = \begin{cases} 0\ , x < 4 \\ \dfrac{x-4}{5-4}, 4 \le x < 5 \\ \dfrac{6-x}{6-5}, 5 \le x \le 6 \\ 0, x > 6 \end{cases}$$

$$\mu_B = \begin{cases} 0\ , y < 2 \\ \dfrac{y-2}{4-2}, 2 \le y < 4 \\ \dfrac{6-y}{6-4}, 4 \le y \le 6 \\ 0, x > 6 \end{cases}$$

- $\bar{A}/\bar{B}$ = ? since $\alpha = [\ 0\ 1]$

  $\bar{A}\alpha = [(2\alpha + 4)(\alpha + 5)]$ $\bar{B}\alpha = [(-2\alpha + 4)(4\alpha + 6)]$

  $\bar{A}_\alpha /\ \bar{B}_\alpha\ = [\ (-2\alpha + 4)/(2\alpha + 4)\quad (\alpha + 5)/(4\alpha + 6)]$

  $\bar{A}_1 /\ \bar{B}_1\ = [(-2 + 4)/(2 + 4)\quad (1 + 5)/(-4.1 + 6)]$

$$\bar{A}_1/\ \bar{B}_1\ = [\ 3\ 3]$$

$$\bar{A}_0/\ \bar{B}_0\ = [(0+4)(0+4)\ \ (\ 0+5)(0+6)]$$

$$\bar{A}_0/\bar{B}_0\ = [\ 0\ \ 1]$$

Therefore, approximately function $\bar{A}$ & $\bar{B}$ is $\cong$ [0 1 3]

The results of the set range will be continued for the process of decreasing the parameters [0 1 3] to obtain a functional approach which will be tested using the center of gravity method to find out the linearity and validation of the fuzzy method.

$$F1 = a + \omega.c(m-a) + \omega a(n-c) + \omega^2(m-a)(n-c)$$
$$= 4.2 + 2\omega(5-4) + \omega 4(4-2) + \omega^2(5-4)(4-2)$$
$$F1 = \sqrt{\frac{1}{\omega} - 2} + 1$$
$$F2 = m.n + 1 - \omega(b - m + d - n) + (1-\omega^2)(b-m)(d-n)$$
$$= 5.3 + 1 - \omega(6 - 5 + 6 - 4) + (1-\omega^2)(6-5)(6-4)$$
$$= 1 - \sqrt{\frac{4\omega}{9} - \frac{1}{2}}$$

The result of the Fuzzy arithmetic formula that is already defuzzy from the risk and the prevention action is :

$$c[\ 0\ 1\ 2] = \begin{cases} \sqrt{\frac{1}{\omega} - 2 + 1}\ , for\ c\ \in [0\ \ 1\ ] \\ 1 - \sqrt{\frac{4\omega}{9} - \frac{1}{2}}, for\ c\ \in [1\ 2] \\ 0, for\ others \end{cases}$$

The next step as explained in the previous calculation is to calculate the Centre of Gravity (COG). Here the COG is calculated to determine validity calculation of the parameters function risk event and risk agent. The detailed formula of COG can be shown below.

$$COG = \frac{\sum_{i=1}^{20} Xt.u(Xi)}{\sum_{i=1}^{20} u(Xt)}$$

From the COG formula, the calculation of the height of the fuzzy number (u) will use the formula for calculating the set parameter validation [0 1 3] as follows.

$$COG = \frac{\sum_{i=1}^{3} 0.0 + 1.0{,}87 + 2.1 + 3.0}{\sum_{i=1}^{3} 0 + 0.879 + 1 + 0}$$

$$= \frac{2{,}879}{1{,}8792}$$

$$= 1{,}531 \approx 2$$

Based on the results of the calculation of the center of gravity shows the numbers that are included in the set parameters, namely [0 1 3] so it can be said that fuzzy numbers are valid.

5.2 Fuzzy House of Risk

This research concept calculation of the proposed model is presented to manage the enterprise risk. The concept method is adapted from the House of Risk to prioritize risk with a large aggregate risk potential number. This result of aggregate risk potential will be continued to determine which corrective action should be implemented first. The purpose of this model is mostly the same as the original House of Risk, but with a different framework and calculation process.

In the previous chapter, there were two phases of HOR. The first phase focuses on determining the aggregate risk potential (ARPj). This first phase of HOR focuses on the potential impact of risk determination on supply chain processes. Severity assessment should be based on the worst possible outcome that can reasonably be expected. Using the quantitative risk assessment method, the risk is the probability of the risk and its severity and occurrence are calculated. This method can be used when the factors mentioned in the previous chapter can be determined unequivocally. According to Pokardi (2015), occurrence and severity cannot be identified unequivocally. In this case, we should use the severity and occurrence categories. Therefore, to construct the equivocally or more valid results have to be combined with fuzzy based on human thinking (human experts). In order to create a logical combination of them and the use of fuzzy is to model to avoid any imprecision and uncertainty of human thinking on the severity and occurrence score.

To avoid the ambiguous score, fuzzy is employed to obtain severity and occurrence score as Karimi (2019), mentioned that fuzzy can be used to interpret imprecise data, uncertainty data, and ambiguous data. The score severity and occurrence are obtained from the determined risk agent and risk event in order to assess the correlation between the risk to create the output of HOR 1 which are the Aggregate Risk Potential or (ARPj) to create risk rank. The main result interpretation of House of Risk phase 1 is addressed to identify what risks that could obstruct the supply chain process.

The second phase is focused on finding which preventive action should be implemented. The process has involved the result of aggregate risk potential from phase 1, total effectiveness of preventive action, and degree of difficulties. The calculation process of phase 2 has lots of similarities with the previous phase (phase 1) which is multiplying each score level. The output of this calculation is the scoring effectiveness of preventive action. The preventive action can be said effective or not depending on the effectiveness action ratio that can be seen in the result of the calculation. This second phase of House of Risk also uses Fuzzy logic to edecrease the imprecision data for the degree of difficulties. The degree of difficulties is the parameter to get the result in the House of Risk phase 2. In constructing the degree of difficulties in this research are using two parameters namely, cost and human resource. According to Tang (2019), the degree of difficulties should be measured based on the cost and humans involved to avoid any potential risk from happening in the future. It means, the more human resource leads to more risk that might happens (Human error) and the same goes for the cost, if the mitigation needs a lot of money then it will cause trouble to the company if unable to provide it.

5.3 Mitigation Strategy

5.3.1 Mitigation Strategy Framework

In general, mitigation is also defined as prevention that covers the strategies to respond the current problems and prevent the future risk. In this research, mitigation planning is divided into 4 stages namely, risk identification, assessments, decision, and implementation. Mitigation risk is used to handle the top ranks of the risk agents in this case, there are 11 risks as the top priority to be mitigated immediately. To manage the identified mitigation, actions are needed to conduct discussion and the result can be seen in Table 4.13. The determination of correlation value between risk mitigation strategy and risk agents was aimed to investigate the relation and effect of the mitigation towards the identified risk agents. This measurement aims to decrease the event by assessing the agent or the cause of some event (Risk event). According to Gomez and Espana (2020), stated that the measurement of the risk in order to get deep result have to assess the root cause (Risk agent) of some events in order to propose the best prevention action and decrease the probabilities same events from happening again in the future.

5.3.2 Degree of difficulties towards mitigation action

Based on the previous chapter stated that to solve risk, risk mitigation is needed. The risk mitigation step involves the development of mitigation plans designed to manage, eliminate, or reduce risk to an acceptable level. The once implemented plan is continually monitored to assess its efficiency with the intent of revising for better results. The risk reduction plan includes evolving options and actions to enhance opportunities and reduce threats to company objectives. Reducing risk is the process of executing risk mitigation and risk mitigation is the last to handling risk towards the business process. Based on Table 4.14, it shows mitigation strategy rank based on the degree of difficulty and the degree of effectiveness. However, in the implementation of mitigation strategies, several variables affect the application mitigation strategies process. Therefore, in this chapter, we will focus on variables that affect the mitigation strategy. The following are factors that can hinder the mitigation action as below:

1. Cost

The cost structure at PT.XYZ generally refers to the types of costs that have been incurred by the company, which generally include both fixed costs and variable costs. At PT.XYZ there are three very crucial costs, namely production costs, manufacturing costs and the last is cost allocation. Production costs are costs that reflect the expenses associated with the production or manufacturing process while manufacturing costs only represent the costs involved in a product. At PT.XYZ in the cost of production there is a management or contingency cost that will be used if there is a risk. These two costs are crucial because they can evaluate the total business operating costs which determine the profitability of the company.

According to the finance manager (SR, 2021) stated that most of the mitigation strategies that connect to those costs will take longer than other mitigation strategies. This is due to PT.XYZ is still building a new cost structure. The Operational Manager (JN, 2021) also stated that implementing the mitigation strategy requires permission from cost control so it can take up to 5 months or even more for the cost mitigation strategies that are directly related to production processes such as machine operations, stock management, and material management.

2. Skills (Human resource)

The role of human resources in risk management has high mutual relation. Human resources play important roles in PT.XYZ. Commonly, Human resource has two roles in risk management first, people as the source of the risk such as human error or sloppy works or workers who refuse to take on additional responsibility. Second, skills or how the worker handles the unexpected event as a source of risk. People use their ingenuity to solve unexpected problems but in reality, in the PT.XYZ many workers avoid unnecessary work or didn't want to work out of the orders from the manager. This case is caused by many workers that are unable to solve the problem without any instructions from the manager. This is why this problem related to the skill of the individual. Mitigation strategies involves the use of information technology to integrate the entire supply chain process to facilitate supply chain supervision. This can be said to be difficult since many staffs from PT. XYZ are unfamiliar with high technology. This factor also stated in the risk agent indicated lot of lost or corrupted data due to inadequate skills of staff. These inadequate skills were caused by large number of staffs were recruited with no standard educational criteria, as required by the company. According to (HN,2021) as HR Manager, this is a result of the laws and regulations that foreign companies must be obliged to empower the surrounding workforce so that the recruitment process does not run according to the criteria.

CHAPTER VI

CONCLUSION

6.1 Conclusion

Based on the previous calculation chapter, the conclusion can be drawn to answer the problem identification as follows:

1. The calculation of risk event and risk agent was conducted using the House of Risk (HOR) method as one of the research tools benefiting to identify risks that, which is practical to apply. The HOR method can assist to identify emerging risks, causes of risk and measure the value of those risks. This method becomes one of the alternatives to support decision-making in a short time.

   The risk events in this study, were identified as 26 risk events with 20 risk causes (risk agents) then prioritized based on ARP values and 11 risk reasons that must identify mitigation strategies from HOR 1 processing. The prioritized mitigation or prevention strategies are mostly based on the operation department or in the procurement – production that has the high prioritized risk such as lack of quality control (A17), lack of supervision (A8), Human error (A5) with ARP is 1093.8, overheat machine due to overwork (A13) limited maintenance analysis (A7), and the rest is also still categorized as a priority to be mitigated as soon as possible.
2. Prioritized mitigation or prevention strategies are processed with HOR 2 and also Fuzzy logic as validation measurement score. Here, the HOR 2 produce mitigation strategies with the lowest to greatest difficulties levels. The mitigation strategy was measured based on the degree of difficulties that the parameter-based cost and human resource and found 18 mitigation strategies. In this research, most the mitigation strategies are focused on operation department such as do periodic checking (P12), make predictive analysis (P10) and make a schedule of downtime for the machine (P9). The rest of the mitigation is focused on the management problem such as developing internal communication (P3), Fatigue management (P7) and creating integration information control (P4)

6.2 Recommendation

The recommendation can be provided, as follows.

1. This research is conducted in the production and operation department only. For the next research, risk data can be taken from another department, such as marketing, warehouse, and the project can be added to obtain more detailed mitigation actions.
2. For further research, it is expected that fuzzy logic can be applied to the correlation process of the risk agent and risk event matrix, risk agent, and preventive action as well as determining the severity and occurrence values in the probability impact matrix process.

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