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Design of supply chain risk mitigation system using house of risk and Fuzzy AHP methods in precast concrete

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Abstract
Today's global supply chain has many risk factors. These risks include supply disruptions, supply delays, demand fluctuations, price fluctuations, and exchange rate fluctuations. Risks that arise and cannot be mitigated properly in the supply chain can disrupt the company's business processes in various sectors. Companies in the construction sector when working on construction projects face many risks during the project cycle, especially risks in the supply chain process. Partial risk management, namely only on construction projects and not specifically on the supply chain process, causes potential risks in the supply chain process not to be identified in detail, and mitigation strategies cannot be determined effectively for risks in the supply chain. This research was conducted to identify risks and determine appropriate mitigation strategies using the house of risk as a framework and a fuzzy analytical hierarchy process weighting method to select the best mitigation strategy. The research results showed that there were 26 risk events and 21 risk agents identified, and the 5 best mitigation strategies were chosen from the 10 formulated strategies for a mitigation monitoring system. Based on research results, the best risk mitigation strategy can be used as a reference for risk mitigation actions in the company's supply chain as outlined in the form of a dashboard monitoring system.

Keywords:
Fuzzy AHP;
HOR;
Monitoring System;
Risk Mitigation;
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INTRODUCTION

A country's national economic growth is influenced by various sectors such as the level of national and international trade, the level of public consumption, and the rate of development of a region [1][2]. One of the previously mentioned sectors, namely the regional development level, also plays a role in increasing the national economy [1][3]. Regional development is closely related to infrastructure development to support the development of a region, where this sector is usually handled by parties related to the construction sector [1][3].

The construction sector is a sector or industry that is engaged in infrastructure development activities in an area whose activities consist of various supply chain processes such as the production of construction materials, material delivery, purchasing of raw materials, and planning of supply chain processes carried out to support the projects being carried out [1]. Several construction companies face various constraints and the impact of risks that cannot be mitigated in business processes which result in construction projects not being realized [1]. One of the common business processes found in the construction sector and which has a high potential for risk is supply chain activity [1].

The current supply chain has many risk factors. These risks include supply disruptions, supply delays, demand fluctuations, price fluctuations, and exchange rate fluctuations [2]. Some things cause the supply chain to face a lot of risk, namely due to the increasingly complex level of supply chain activity and changes in one supply chain process sometimes have a negative effect on other processes [3]. The company's supply chain activities, especially on a global scale, will always be affected by an event that cannot be identified beforehand so that considerations for conducting risk management in the supply chain continue to increase and experience renewal [4]. The impact of emerging risks such as supply disruptions, price fluctuations, and demand that cannot be mitigated properly in the supply chain can disrupt the course of the company's business processes in various industrial sectors [2][5]. Companies engaged in the construction sector in carrying out construction projects face many risks during the project cycle. This is due to the various complex needs of various parties, especially the logistics and supply chain departments. The absence of an effective risk analysis tool for project managers means the increased potential risks that arise cannot be effectively mitigated [1].

PT XYZ is a company engaged in the construction sector in the Province of Bali. The company's main business lines are projected contractor service providers and providers of construction materials and products. Construction projects handled by the company are in the form of infrastructure projects and public works such as the construction of asphalt roads and bridges. One of the company business units is the Batching Plant which oversees the production of ready-mix and precast concrete. The supply chain process at the Batching Plant which is a sub-business at the company carries out supply chain activities in the form of procuring raw materials in the form of sand, crushed stone, and cement, then production of precast and ready-mix concrete products, and delivery of concrete products to the project site.

Regarding risk management, risk management carried out by the company is generally used for projects that are carried out, but it does not cover the details of the supply chain process. Details of production activities, especially in the batching plant and stone crusher plant, are not included in the project risk analysis that has been made. These potential risks that have not been identified also do not have mitigation actions, and if these potential risks arise, supply chain failure or disruption may occur. In addition, the company'ssupply chain does not have a specific risk management tool that is used as an assessment tool for supply chain risk analysis. Construction companies that have concrete production business units need risk analysis and risk impact to determine mitigation actions to minimize losses that can be caused by product defects and other production disruptions.

Meanwhile, there is a distinct potential risk in supply chain activities at the company which can cause a loss both in time and financially and indirectly also impact construction projects. Potential risks such as machine breakdown, lack of production materials, operator negligence, delivery delays, and other potential risks related to the supply chain that have not been assessed and mitigated, can disrupt future projects [6].

The novelty in this research is in the form of risk assessment results and mitigation strategies with a combined method, namely HOR and Fuzzy AHP which are implemented into an information system in the form of a monitoring dashboard that can be used as a monitoring tool for mitigation actions being carried out. The limitation of this research is that the risk analysis was carried out specifically in the precast concrete supply chain process at the company and the selected mitigation strategy was not further investigated until the implementation stage by the company.

METHOD

There are three main methods used in conducting this research, namely the house of risk method, risk mitigation strategy with FAHP, and system design [6, 9, 16].

House of Risk

The House of Risk (HOR) assessment model provides an assessment of risk factors a model that can be used to address risk causes or risk agents [6]. This model consists of two stages, namely HOR 1 and HOR 2, where HOR 1 functions to determine the level of each risk cause or risk agent through the Aggregate Risk Potential (ARP) value [6].

The HOR 2 model is used to provide a priority assessment of risks that arise in the supply chain [8]. The application of the HOR 1 model aims to determine the priority of risk agents to take proactive action according to the significance of the risk [8]. In the first stage of the HOR 1 model, namely identifying risk events, we use the Supply-Chain Operations Reference (SCOR) model as a mapping of business processes specifically for supply chain activities which consist of several parts, namely plan, make, source, deliver, and return [8].

Fuzzy AHP

The Analytical Hierarchy Process (AHP) is a decision-making method where in the decision-making process the problems faced are broken down into sub-problems so that the criteria to be processed are obtained by providing an assessment and ranking of each criterion where the initial value determination for each criterion is subjective. based on the scale of the level of importance [6].

The AHP method combined with fuzzy logic aims to anticipate subjective judgments on the criteria obtained from the AHP importance level scale. The scale value on the results of the PCJM questionnaire was replaced with a fuzzy number which aims to tolerate the subjectivity of the assessment on the criteria [9]. The fuzzy-AHP method is used to determine the best risk mitigation strategy.

One of the ways that can be used for the formulation of risk mitigation strategies in the supply chain is benchmarking with the previous relevant research and discussion with company stakeholders. This way is used to formulate specific mitigation strategies for supply chain activities where the formulation of mitigation strategies focuses on increasing the organization's ability to continue to grow and survive business process disruptions [13].

Design of Monitoring System

The System Development Life Cycle (SDLC) waterfall is a method of developing software or information systems with several stages such as analysis of system requirements, design of activities on the system, system implementation, and system testing [16].

System requirements analysis in this study is described by components in the form of risk assessment and risk mitigation results. The design of system activities is illustrated with use case diagrams and data flow diagrams to see what activities can be carried out on the system. System implementation in the form of a monitoring dashboard interface for monitoring the risk mitigation process. Finally, for system testing using user validation.

Respondent Characteristics

This research uses a questionnaire as an assessment tool for risk mitigation strategies with the AHP method which involves the respondent as an assessor. The following are the characteristics of the respondents used as a condition for evaluating the questionnaire, namely, the respondent is part of the company's top-level management with a minimum position of department manager, the respondent understands risk management and the company's supply chain flow, and the respondent's work experience in the company for at least 10 years.

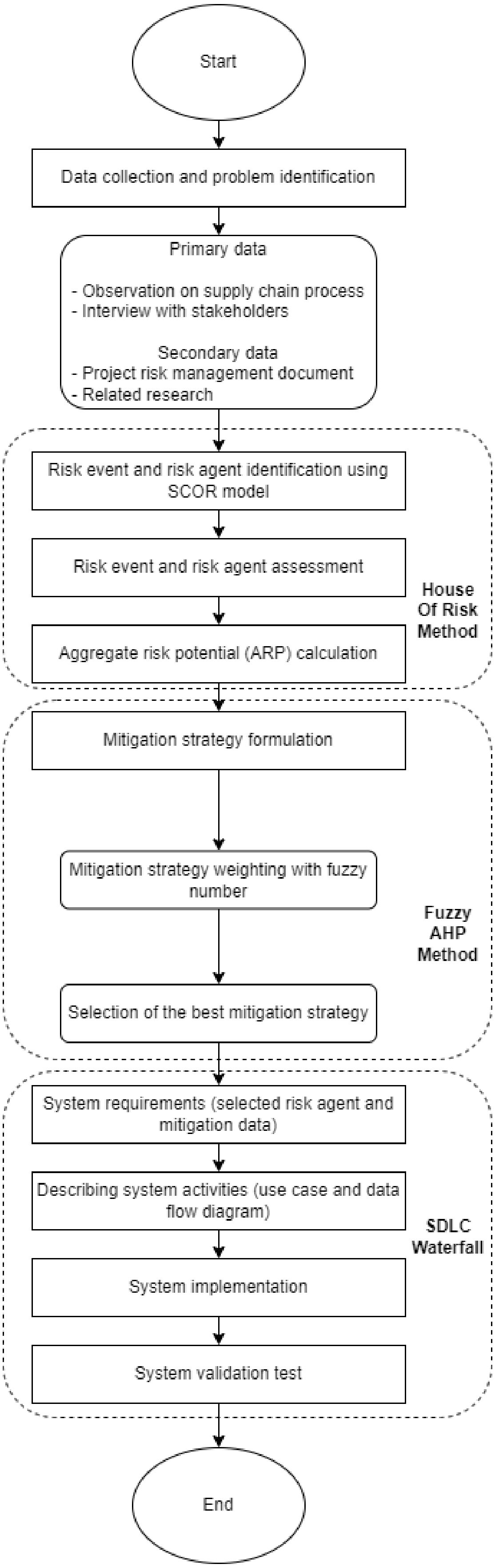

Figure 1. Research Methodology

Research Methodology

Figure 1 shows the stages carried out during the research. The initial stage is data collection and problem definition of risks from the supply chain process in the company. The second stage is risk identification to obtain risk events and risk agents using the SCOR model with each process namely plan, source, make, deliver, and return.

The next step is to evaluate the risk event and agent and calculate the ARP value using HOR. Next is the formulation of a risk mitigation strategy based on a risk agent with high-risk potential. Next is an assessment of risk mitigation strategies to obtain the best strategy for each risk agent using the fuzzy-AHP method. The final stage is designing a risk mitigation monitoring system using the SDLC waterfall method.

RESULTS AND DISCUSSION

Risk Event and Risk Agent Identification

The first stage in efforts to achieve supply chain risk mitigation is to identify risks in the supply chain process. Identification results are obtained by mapping business processes or supply chain processes for precast concrete products using the SCOR model [9].

Identification of risks in the sourcing process relates to several risks that may arise or have the potential to cause losses in the material procurement process. The supply chain process is carried out in material procurement, namely the purchase of excavation areas for sand and stone, the purchase of cement materials for concrete mixtures, as well as the preparation of documents or letters of purchase of materials.

The manufacturing activities in the supply chain of precast concrete products at the company are divided into two manufacturing processes. The first is a manufacturing process to produce sand and crushed stone materials and the second is a precast concrete manufacturing process.

The fourth stage in SCOR in mapping and identifying risks is the delivery process. This process is related to the activity of shipping excavated materials and shipping precast concrete to the construction project site.

The final stage in mapping the supply chain process with the SCOR model is the return process. This process is related to the process of returning defective products or those that do not meet consumer specifications and requests. The return process that occurs in the supply chain of concrete products is that there are precast concrete products that are not by the quality so they cannot be used and sent to the project location.

Risk Event and Risk Agent Assessment

Risk grouping is carried out based on five risk categories using process categories in the SCOR model: plan-process risk, source-process risk, make-process risk, deliver-process risk, and return-process risk. Risk grouping is carried out to determine the types of risks that have the potential to arise in the concrete product supply chain process [8].

Table 1. Identification of Risk Event

Code	Risk Event	Severity
E1	The error rate of forecasting the demand for precast concrete is high	2.29
E2	Production material data does not match actual conditions	2.52
E3	The available fleet data does not match the actual number	1.26
E4	Sudden changes in procurement planning, production, and fleet allocation	3.00
E5	Procurement planning changes	2.62
E6	The supplier is unable to fulfill the material request	1.26
E7	Cancellation of material purchases at suppliers	2.52
E8	Incorrect purchase amount data with procurement planning data	2.00
E9	Material payments to suppliers are delayed	7.32
E10	Production planning changes	2.00
E11	Delay in unloading material from the transport fleet	2.00
E12	Postponement of material production of sand and crushed stone	1.26
E13	There are scattered production materials	7.23
E14	The dust of crushed stone becomes a pollutant in the STC area	7.61
E15	Incorrect crushed stone size	2.00
E16	Concrete products do not meet the quality and specifications	1.59
E17	The concrete mixture is not evenly distributed in the mold	2.00
E18	Cracks on the surface of precast concrete	2.52
E19	Concrete molding tools are not ready for use	3.11
E20	The size and dimensions of the concrete frame are out of specification	2.00
E21	An incorrect concrete mix ratio	2.00
E22	Lack of production materials	2.29
E23	Material excavation delay	1.59
E24	Delays in material delivery to STC	2.00
E25	Delay in delivery of materials to the batching plant	7.61
E26	The high amount of defective concrete	2.29

Table 2. Identification of Risk Agent

Code	Risk Agent	Occurrence
A1	Significant increase in demand for precast concrete	8.96
A2	Error measurement and data recording	1.44
A3	Changes in material and fuel prices	9.32
A4	Material suppliers do not meet the criteria	1.26
A5	Failure to negotiate the purchase price of materials	8.32
A6	Inadequate material storage locations	7.32
A7	Power supply interruption	1.82
A8	Soil material that is still attached to the rock	1.82
A9	Damage to the tool when screening the size of crushed stone	8.32
A10	Operator negligence	6.65
A11	The material load exceeds the carrying capacity	1.44
A12	The concrete press is not clean and there is residual concrete	8.96
A13	Iron frame design error	1.26
A14	Data errors and concrete mix specifications	1.82
A15	Poor concrete vibration process	1.44
A16	The drying temperature of the concrete is too high	1.59
A17	The number of requests for batching plant materials is not fulfilled	1.44
A18	Transport fleet engine damage during delivery	1.59
A19	The number of transport fleets does not meet shipping needs	2.52
A20	Traffic disruption during delivery	5.65
A21	The demand for precast concrete sent is insufficient	1.44

The results of risk identification obtained as many as twenty-six risk events which are divided into five risk categories. The Plan risk category includes risk events E1, E2, E3 and E4, the Source risk category includes risk events E5, E6, E7, E8, E9, the Make risk category includes risk events E10, E11, E12, E13, E14, E15, E16, E17, E18, E19, E20, E21, the Deliver risk category includes risk events E23, E24, E25 and the Return risk category includes risk event E26.

Furthermore, all the results of the risk identification will be assessed on the severity risk event scale or how big the negative impact will be if the risk occurs in the concrete product supply chain. Assessment or assessment of risks that have been identified for both risk events and risk agents have the same scale range, namely 1-10, but have differences in usage [6]. For the risk event, the severity value is used to determine the level of negative impact on the supply chain, while for the risk agent, the occurrence value is used to see how likely the cause of the risk is to occur.

Table 1 and Table 2 show the severity and occurrence assessment results. This value consists of 10 values that have a low to high impact on the supply chain if the risk appears in the supply chain process. The assessment was carried out by respondents, namely precast concrete stakeholders of the company. Based on the assessment of 3 respondents, to obtain a single severity or occurrence value, the Geomean formula is used.

$$G = \sqrt[k]{Ai \; x \; Bi \; x \ldots x \; Mi} \qquad (1)$$

Ai: The i-th severity/occurrence value of the first respondent
Bi: The i-th severity/occurrence value of the second respondent
Mi: The i-th severity/occurrence value of the k-th respondent
k: Number of respondents
G: Geomean value

ARP Calculation

The ARP value is used to determine the ranking of the risk agent obtained by determining the relationship between each risk event and each risk agent [8]. The calculation of the ARP value is done by multiplying the value of the occurrence *j* risk agent by the total multiplication of each *i-risk* event which is mutually related to the *j* risk agent for each severity value of each related risk.

$$ARPj = Oj \left(\sum Si \; x \; Rij\right) \qquad (2)$$

Oj: Occurrence value for risk agent – *j*
Si: Severity value for risk event – *i*
Rij: Correlation value for each risk event – *i* to risk agent – *j.*
ARPj: Aggregate risk potential value for risk agent - *j*

The relationship value used to assess the relationship between each risk event and the risk agent, namely a value of 0 for no relationship, a value of 1 for a weak relationship, a value of 3 for a moderate relationship, and a value of 9 for a strong relationship [8].

Table 3 shows all the results of calculating ARP values performed using Microsoft Excel software. There are eleven ARP values obtained based on the number of identified risk agents. The calculation results also show the ranking of each risk agent with the highest rating based on the largest ARP value.

After all ARP values are obtained, then each ARP value rating and the cumulative percentage of ARP values are determined. This percentage is used to determine the level of contribution of the risk agent to the total ARP which is depicted on the Pareto diagram in Figure 2. The level of contribution to the total ARP is used to determine the priority risk agent for the formulation of risk mitigation strategies.

Based on the visualization of the cumulative value in the Pareto diagram of Figure 2, risk agents are selected that contribute to the total ARP value of 80%, which includes risk agents A6, A3, A12, A5, A9, A1, A20, A10, A19, and A14. According to [6], the cumulative ARP value that is included in 75% of the ARP value is a risk agent that is prioritized for mitigation, while according to [8], the cumulative ARP value used for mitigation that is equal to 80% of the total ARP.

Mitigation Strategy Formulation

The formulation of a risk mitigation strategy is used to determine proactive actions against risk agents who have a high level of risk based on the calculation of the ARP value and cumulative percentage [13]. The formulation of a supply chain risk mitigation strategy for precast concrete products at the company was formulated through a literature review relevant to the risk agent being mitigated, as well as the selection of strategies carried out with the company 's supply chain stakeholders.

Several risk mitigation strategies can be formulated for each selected risk agent. The following is a risk mitigation strategy that can be used as a supply chain risk mitigation action in Table 3

Strategy Weighting with Fuzzy AHP

Assessment and ranking of each risk mitigation strategy that has been formulated aim to determine the best strategy that can be used as a mitigation measure and can minimize the impact of risks in the supply chain process of precast concrete products.

Assessment and ranking use the fuzzy-AHP method where a risk agent that has several mitigation actions will determine the value of each mitigation action by comparing one mitigation action with another using a pairwise comparison matrix.

The consistency test on the AHP method aims to find out if a criterion assessment carried out by respondents is consistent or inconsistent. The results of the assessment criteria can be called consistent if they meet the requirements of the consistency test with the results of the consistency ratio value obtained from dividing the consistency index divided by the random index, namely ≤ 0.1.

$$CR = \frac{CI}{RI} = \frac{\frac{\lambda \max - n}{n-1}}{RI} \quad (3)$$

CR: Consistency ratio
CI: Consistency index
RI: Random index of *n*-criteria
n: Number of criteria

The defuzzification stage aims to form a value based on the fuzzy numbers in the normalization matrix. The results of this defuzzification are used to determine the rank of each strategy.

Based on Table 4, it can be seen that each strategy weighs in each risk agent. Furthermore, the strategy that has the best weight is used as a risk mitigation action that is selected, and its level of effectiveness is assessed.

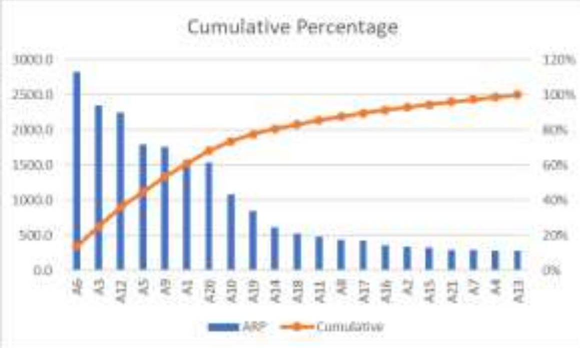

Figure 2. Percent Cumulative Risk Agent

Table 3. Mitigation Strategy

Strategy Formulation	Code
Application of 5S in material and concrete production	S1
Determination of strategic stocks in precast concrete warehouses	S2
Using third-party logistics services for the delivery of materials and concrete	S3
Make purchase contracts with consideration of fluctuations in material or fuel prices	S4
Ensure that the production department understands the SOP and concrete production flow	S5
Periodic checks and repairs on production machines or fleet machines	S6
Planning on alternative material suppliers	S7
Audit every result of recording data on sales, materials, fleet, and production	S8
Determine SOP for evaluation of material suppliers	S9
Tracking each delivery fleet to monitor the real-time location	S10

Table 4. Weight of Each Strategy

Crisp Value	Code	Rank
0.13	**S1**	5
0.06	**S2**	6
0.01	**S3**	10
0.04	**S4**	8
0.17	**S5**	2
0.13	**S6**	4
0.05	**S7**	7
0.22	**S8**	1
0.04	**S9**	9
0.14	**S10**	3

Table 5. Fuzzy Number

AHP Scale	Fuzzy Number
1	(1,1,1)
2	(1,2,3)
3	(2,3,4)
4	(3,4,5)
5	(4,5,6)
6	(5,6,7)
7	(6,7,8)
8	(7,8,9)
9	(8,9,10)

Table 6. Consistency Test

Assessment	CI	RI	CR
Matrix 1	0.11	1.49	0.072
Matrix 2	0.13	1.49	0.090
Matrix 3	0.12	1.49	0.083

Table 7. Normalization of Fuzzy Number

Crisp Value	L	M	U
S1	0.11	0.13	0.15
S2	0.06	0.06	0.06
S3	0.02	0.01	0.01
S4	0.05	0.04	0.04
S5	0.14	0.17	0.20
S6	0.11	0.13	0.16
S7	0.05	0.05	0.04
S8	0.18	0.22	0.27
S9	0.05	0.04	0.04
S10	0.12	0.14	0.17

$$F = \left(\frac{1}{2}\right)(\alpha U + M + (1-\alpha)L) \qquad (4)$$

F: The crisp value
U: The upper value of normalization fuzzy number
M: The middle value of normalization fuzzy number
L: The lower value of normalization fuzzy number
α: Confidence level (0 – 1)

Selection of The Best Mitigation Strategy

Table 5 shows the fuzzy number that is paired in each AHP scale from 1 to 9. From (3), all the consistency tests for each matrix are consistent. Table 6 listed the consistency results. Table 7 shows the normalization result for each fuzzy number on the mitigation strategy.

The best risk mitigation strategy was selected from as many as 5 of the 10 best risk mitigation strategies assessed. Mitigation strategies with the five highest values based on (4) as shown in Table 4 are, S8, S5, S10, S6, and S1.

Mitigation Monitoring System Design

The design of the monitoring system is intended to monitor the risks and mitigation actions carried out on the supply chain process to monitor the running conditions of the supply chain of precast concrete products.

Describing System Activities

A use case diagram is a diagram that functions to describe activities that can be carried out by system users. In this diagram, system users are the company supply chain stakeholders who can enter and manage risk and assessment data.

Based on Figure 3, several activities that can be carried out by users in interaction with the monitoring system consist of inputting risk event data and risk agents, inputting the results of severity and occurrence assessments, inputting correlation values and difficulty levels, inputting data on mitigation strategies and performing mitigation strategy monitoring, and the flow is depicted in Figure 4.

All these flows of activities are shown in Figure 4 below. The flow of activities diagram shows how the User interacts with the System. There are two main parts namely the User, which gives input, and the System will show the output of feedback.

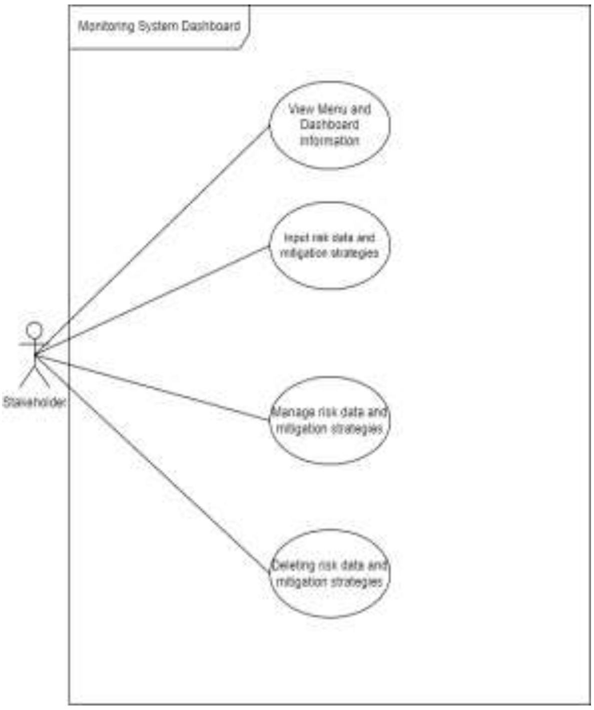

Figure 3. Use Case Diagram Monitoring System

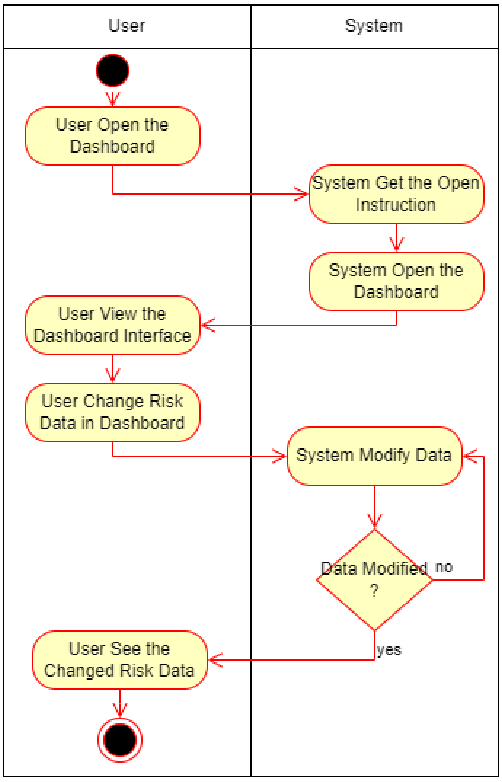

Figure 4. Activity Diagram (BPMN)

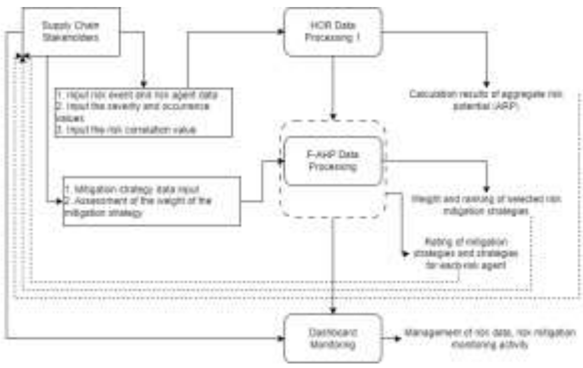

Figure 5. Data Flow Diagram

Figure 6. Dashboard Monitoring Interface

The data flow diagram in Figure 5, shows the flow of information and data used to carry out risk assessments and risk mitigation strategies so that the calculated data on House of Risk 1 can be displayed on the monitoring dashboard and all activities carried out by stakeholders can be carried out on the precast concrete product risk mitigation monitoring system.

Table 4. Validation Testing

Scenario	Testing Case	Expected Result	Testing Result
View Dashboard	The sees risk information and mitigation strategies	The dashboard page successfully opened	Succeed
Input risk and mitigation data	The user inputs risk data and mitigation data	Risk and mitigation data entered successfully	Succeed
Manage risk and mitigation data	the user changes The risk data and mitigation data	Risk and mitigation data changed successfully	Succeed
Delete risk and mitigation data	The user deletes risk data and mitigation data	Risk and mitigation data were deleted successfully	Succeed

System Implementation

Figure 6 shows risk monitoring and assessment system is made in the form of a dashboard that is useful for supply chain stakeholders to carry out risk monitoring and assessment and risk mitigation strategies that have been made. This dashboard includes two main sections, namely the risk assessment and the risk mitigation strategy assessment page.

System Validation

Table 8 shows the validation testing of the risk mitigation system. There are four testing scenarios based on activities that are described in the use case diagram. All results of system validation testing were successfully carried out.

CONCLUSION

Partial risk management is carried out by the company, namely only on project risk management, but has not been carried out in the supply chain process causing disruption to the supply chain which cannot be mitigated. House of risk was chosen as a method for identification and risk assessment with the identification results in the form of 26 risk events and 21 risk agents, with 10 risk agents selected as risks that contributed 80% to the ARP value. The 10 selected risk agents were mitigated using the fuzzy-AHP method as a strategic assessment to choose the best risk mitigation strategy as outlined in the monitoring system.

Based on research results, identification and assessment of risks and risk mitigation strategies can be carried out on the system, with proposed best five mitigation actions that can be carried out sequentially, namely S8, S5, S10, S6, and S1.

Suggestions for academic research in the form of further research that needs to pay attention to the study of supply chain processes up to the concept of sustainability and the environment with the consideration of experts in the field.

ACKNOWLEDGMENT

This research was supported by the company in data collection and discussion on research. The difficulty experienced in this research is detailing all complex precast concrete supply chain activities starting from the stages of planning, material procurement, delivery, concrete production, and storage. It requires an in-depth understanding of the application of the SCOR model as a tool for mapping supply chain activities which will later be used to carry out more detailed risk identification.

In addition, we thank our colleagues from the company and Telkom University who provided insight and expertise that greatly assisted the research, although they may not agree with all the interpretations/conclusions of this paper.

Recommendations that can be proposed for further research are to be able to carry out more specific risk identification by involving green aspects and supply chain sustainability and to be able to monitor the implementation of risk mitigation strategies in one period.

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