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Differences in Supply Chain Material Risk Weight Using the Severity Index Method and Monte Carlo Simulation

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ABSTRACT

Material delays are a significant challenge in completing construction projects, closely tied to the understanding of material supply flow. As a result, a risk weight analysis is essential, considering both internal factors (such as supply, control, processes, and demand) and external factors (such as disasters). This study began with a literature review to compile a list of potential risks, followed by data collection through a questionnaire administered to 50 experts in construction material procurement. The risk analysis was then conducted using both the Severity Index and Monte Carlo methods. The results showed average risk differences between the two methods: supply side (16.40% vs. 16.76%), control risk (16.28% vs. 11.53%), process risk (11% vs. 11.20%), demand risk (16.10% vs. 13.87%), and disaster risk (13.78% vs. 13.41%). The highest risk identified was in the supply side, specifically the extended waiting times due to staggered material deliveries, while the lowest risk was related to the process of ordering materials, where issues arise from the need for reordering based on inaccurate quantity information.

1. Introduction

The construction industry must actively promote more effective, efficient, and productive development to enhance the added value of construction products. Project delays are a common issue that frequently occur and can harm various stakeholders. Such delays prevent the owner or end user from promptly utilizing the completed facilities. Additionally, the contractor faces penalties for the delay, resulting in unnecessary extra costs and potential harm to the company's reputation. Delays in projects can stem from the contractor, the project owner, or other external factors.

Kaliba [1] identified that factors such as delayed payments, financial difficulties faced by contractors and clients, contract modifications, economic challenges, material procurement issues, design alterations, staffing shortages, equipment availability, inadequate supervision, construction errors, poor on-site coordination, changes in specifications, and labor disputes or strikes are the primary causes of delays in road construction projects. On the other hand, factors that cause project delays in the construction industry include [2] The inefficiency of contractor management, issues faced by subcontractors, poor design quality, contract-related problems, and disruptions in the supply chain that affect the availability of labor and construction materials are key challenges. An integrated supply chain system oversees the flow of goods, money, and information from the source to the destination, with an emphasis on procurement, production, and distribution to ensure timely product delivery. In the context of construction, the supply chain transforms raw materials into completed products, such as roads or buildings, and involves collaboration among general contractors, subcontractors, planners, and suppliers. [3].

Supply chain management in construction projects faces challenges due to the temporary nature of organizations, short-term relationships, and the complexity of managing intricate networks. As a result, material management becomes critical; shortages can halt work and lead to significant losses. It is essential to understand procurement, storage, distribution, and risk analysis techniques for material delays. Failing to manage these risks effectively can result in construction costs exceeding the initial budget.[4], [5]

Given the background outlined above, the aim of this study is to analyze both internal risks (supply, control, process, demand) and external risks (disaster factors) using the Severity Index and Monte Carlo simulations. The study seeks to identify the most dominant risk category for material delays in Medan City and propose risk mitigation strategies to reduce the impact of these dominant risks.

2. Literature Study

2.1 Risk identification

Risk identification is the process of discovering, describing, and documenting risks that could hinder a goal, serving as the foundation for further analysis to assess the level of threats and opportunities. According to Ghasemi [6], risk identification involves actions aimed at detecting the uncertainty of an event that, if it occurs, could have either a positive or negative impact on the established objectives [7]. It is not just about listing risks, but also reviewing relevant factors to gain a comprehensive understanding of the risks. The risk identification process requires high-quality information.

The first step in this process is to gather historical information related to risks from past projects. If such data is unavailable, information from other companies with similar work can be utilized and refined through discussions with stakeholders, incorporating historical, current, and evolving data [8]. Sources of this information may include structured interviews, local and international experiences, expert insights, long-term company plans, work plans and budgets, risk management reports, audits, self-assessments, historical data, incident databases, and failure analysis. Various methods can assist in identifying risks, such as compiling a risk list, conducting expert interviews, brainstorming sessions with knowledgeable parties, and collecting data through project meeting minutes or reports [9], [10].

Risk identification includes risks in supply, process, control, demand, and disaster factors. Supply risks arise from various sources such as suppliers, manufacturers, and distributors, and are important to ensure the availability of goods or raw materials on time and in sufficient quantities. Control risks relate to operational management, including inventory management, production scheduling, and efficient flow of goods. This includes the use of technology and management processes to ensure the smoothness and coordination of each stage in the supply chain. Process risks relate to the steps taken to transform raw materials into finished products or provide services to customers. This process includes production, packaging, distribution, and shipping, where efficiency and coordination are essential to optimize supply chain performance. Demand risks relate to the amount of products or services desired by the company as a customer. Demand management is important to predict and anticipate market needs so that the supply chain can respond appropriately and efficiently.

2.2 Risk Analysis with Likert Scale

After obtaining a list of risks in the data collection process, the next stage is to process and analyze the data using the severity index method using Likert scales. To determine the scale of possibility/probability this research refers to the Table 1 below:

Table 1. Probability criteria

Scale	Frequency	Description
1	Material delay (0.5 days or 4 hours)	Almost impossible
2	1-2 times in one period	Less likely to happen
3	3-4 times in one period	Equal chance of happening and not happening
4	4-5 times in one period	Most likely to happen
5	>5 times in one period	Almost certain to happen

Source : Guide Book Risk Management [6]

The scale of impact based on the table below:

Table 2. Impact criteria

Scale	Frequency	Description of delay
1	Not Significant	0.5 days / 4 hours
2	Small	1 day
3	Medium	2 days
4	Large	4 days
5	Catastrophe	>6 days

After the data are collected, data analysis will be carried out using Skala liker simulation to obtain risk weight. Calculating the magnitude of the Risk value, the risk factor equation is as follows:

$$Risk(R) = Probability\ Value(P)_{(e)}\ x\ Impact\ Value(I)_{(e)} \quad (1)$$

The next step is to create a risk categorization. Risk categories are grouped based on color codes from very low, low, medium, high and very high levels. Each risk category grouping depends on the risk treatment to be given. The form of this risk level can be illustrated in the table below :

Table 3. Risk Matrix and Risk Category

Probability					
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
	1	2	3	4	5
	Impact				

Scale	Level	Priority	Response
1-3	Very Low	5	Acceptance
4-6	Low	4	Mitigate
8-10	Medium	3	Transfer
12-16	High	2	Allocation
20-25	Very High	1	Avoidance

Each risk category is obtained from very low to very high risk which will then be treated based on the level of risk. Based on Susilo and Kaho, risk tolerance based on risk level is explained as follows: Very low risk level, risk that can be accepted without special treatment, but only needs to be monitored by the risk owner. Maintain existing controls and monitor whether the risk increases to be given special treatment. Low risk level, risk is unacceptable but tolerable, control treatment (preventive) is given if the benefits outweigh the costs. Medium risk level, risk is unacceptable and requires preventive control treatment. High risk level, risk is unacceptable and requires preventive and responsive control. Very high risk level, risk is unacceptable and requires responsive control

3. Research Method

The stages of this research are described as follows:

3.1 Risk Identification

The first step is to identify the risks and create a risk register based on literature and previous research. This includes identifying risks related to supply, process, control, demand, and disaster factors. The study specifically targets contractors in the Medan construction industry. The primary data for this research was obtained through a questionnaire utilizing a five-point Likert scale, where responses ranged from 1 (very low) to 5 (very high). The survey was distributed via Google Forms to experienced engineers, project managers, contractors, and team members involved in construction projects in Indonesia. One month after the initial distribution, follow-up emails and messages were sent to respondents who had not yet completed the questionnaire.

3.2 Data Collection

Once the risk list is compiled, data will be gathered through interviews and questionnaires to assess the probability and impact of each risk. The questionnaires will be distributed to contractors involved in construction projects in Medan City, including site managers, site engineers, technical staff, quality control personnel, and logistics managers. A simple random sampling method was used within a probability sampling framework. The data collected was analyzed using the Statistical Package for Social Science (SPSS) version 23.0 for Windows.

3.3 Data Analysis

After collecting the data, analysis will be conducted using the severity index to determine risk weights.

Risk analysis is used to determine the level of probability and impact of risk on cost, quality, and time. The processing of this risk analysis data first uses the severity index which will then be categorized based on impact and probability. Calculations using the Severity index are calculated based on the following equation;

$$SI = \frac{\sum_{i=0}^{4} ai\ xi}{4\sum_{i=0}^{4}\ xi} x\ (100\%) \quad (2)$$

Where :
ai = constant assessor
xi = frequency of respondents
I = 0,1,2,3,4,... n
x0, x1, x2,x3, x4 = frequency value of respondents
a0 = 0 , a1 = 1, a2 = 3, a4 = 4
x0 = frequency of "very small/low" then a0 = 0
x1 = frequency of "small/low" then a1 = 1
x2 = frequency of "medium" then a1 = 2
x3 = frequency of "large" then a1 = 3
x4 = frequency of "very large" then a1 = 4

The criteria for determining the scale of possibility and impact are determined by the researcher himself based on discussions and agreements with the respondents, where the agreement states that the level of possibility of risk and impact due to very large risks is 100%, this is considered based on time, quality, and cost. After obtaining the results of the risk category based on the scale above, the probability and impact categories are converted into numbers as follows: very small is worth 1, small is worth 2, medium is worth 3, large is worth 4, and very large risk is worth 5.

Table 4. Severity index value categories for probability frequency and impact

No	Category	SI	Value
1	Very small/low	0% < SI < 20%	1
2	Small/low	20% < SI < 40%	2
3	Medium	40% < SI < 60%	3
4	Large	60% < SI < 80%	4
5	Very large	80% < SI < 100%	5

Monte Carlo simulation technique is a technique for analyzing risk by calculating the final probability of the possibility of a risk occurring [11] This simulation involves random variables that are adjusted to the characteristics of the input data distribution being analyzed [12]. The stages in conducting a Monte Carlo analysis [13] are as follows:

1. Determine the variables to be simulated
2. Determine the type of probability distribution for each variable (normal distribution, uniform distribution, triangular distribution
3. Calculate random values for each activity, at this stage a spreadsheet will be used to determine the maximum and minimum random values of the specified probability distribution
4. Determining the number of iterations in the simulation, iterations are carried out because variable simulations can use repetitions that can be thousands or even hundreds of thousands, determining iterations is done by
   a) Calculate the error formula

   $$\in = \frac{3\sigma}{\sqrt{N}}$$

   Where $\in$ = Errorvalue

   σ = Standard Deviation

   N = Number of iterations

   b) Calculate the standard deviation

   $$\sigma = \sqrt{\frac{\sum(X_{1,2} - \mu)^2}{N}}$$

   where $X_{1,2}$ = Each value from population i and 2

   μ = Population average

   N = Number of population

   c) Calculate the absolute error value

   $$\in = \frac{\mu}{\left(\frac{1}{0.01}\right)}$$

   Where 0.01 is the absolute error value of 1%,

5. Repeat the calculation of random values as many iterations as possible, in this study, the iterative calculation process will be carried out using crystal ball software.

6. Next, a simulation model analysis will be carried out with a forecast value graph (time forecast value) and a risk sensitivity graph.

3.4 Output

Following the analysis, the research findings will be presented in the form of dominant risk weights and recommendations for risk mitigation strategies.

4. Results And Discussion

After compiling a risk identification list through literature review and interviews, the next step was data collection using a questionnaire method. The data obtained came from the impact and probability assessments provided by 50 respondents, holding positions such as project manager, site engineer, site manager, technical staff, quality control, and logistics. The respondents were grouped based on their years of experience: less than 3 years, 3-5 years, and more than 5 years, and were distributed across 10 building projects in Medan. The results of the risk analysis that affect the supply chain can be seen in the following table:

Table 5. Material supply chain risk weight analysis

Risk code	Occurrence / Risk	Severity Index Risk Weight	Monte Carlo Risk Sensitivity Weights	Average Risk Severity Index Weight	Monte Carlo Risk Sensitivity Weighted Average
S1	Materials are sent repeatedly because the material is damaged / does not meet the quality of the specified specifications	15,40%	14,53%	16,40%	16,76%
S2	Material delays due to obstacles in the factory process to material limitations at the supplier	24,90%	21,67%		
S3	Cancellation of shipments due to transportation problems / lack of transportation equipment	9,10%	3,80%		
S4	For each material, only focus on 1 supplier	12,40%	15,85%		
S5	Long waiting time because material delivery is carried out in stages	20,20%	27,97%		
C1	Inefficient inventory management system so that materials are reduced or piled up in the warehouse	10,70%	0,00%	16,28%	11,53%
C2	Changes in material needs due to changes in the material usage schedule and project implementation schedule from the contractor	15,50%	7,00%		
C3	Lack of material storage capacity by the contractor resulting in re-supply	8,90%	6,50%		
C4	Late payment from the main contractor to the subcontractor resulting in late material orders	27,70%	25,53%		
C5	Delayed orders due to lack of information related to the work to be carried out	18,60%	18,60%		
P1	Delay in material arrival due to traffic problems	11,40%	14,30%	11,00%	11,20%
P2	Inability to fulfill orders	12,80%	12,80%		
P3	Lack of detailed information about the quantity of materials ordered, requiring reordering of materials	9,50%	9,50%		

P4	Damage and loss of materials in the storage warehouse	11,50%	9,60%		
P5	Delay in material delivery due to inadequate storage warehouse	9,80%	9,80%		
D1	Difficulty in finding materials	14,80%	14,80%	16,10%	13,87%
D2	Changes in material orders due to sudden changes in specifications or designs from the owner	16,40%	16,40%		
D3	Additional materials due to changes in room function	15,10%	8,90%		
D4	Delays in material delivery due to financial problems that are not running smoothly	18,10%	15,37%		
E1	Bad Weather during delivery	18,90%	15,46%	13,78%	13,41%
E2	Country conditions (inflation, politics, culture)	9,80%	13,10%		
E3	Geographical characteristics of the location	12,20%	10,90%		
E4	Unexpected disaster / Disaster [Social and cultural factors]	14,20%	14,20%		

Based on Table 5, the average weights of risk can describe below :

Table 6.Average Weights Risk

Category	Code of Risk Severity Index	Code of Risk Monte Carlo
Supply	16,40%	16,76%
Controll	16,28%	11,53%
Process	11,00%	11,20%
Demand	16,10%	13,87%
External	13,78%	13,41%

The very high risk based on the table above is supply category, Supply risks come from various sources of suppliers, manufacturers, and distributors. It is important to ensure that supplies of goods or raw materials are available on time and in sufficient quantities. The very high risk in supply is S2 and S5 risk, Material delays due to obstacles in the factory process to material limitations at the supplier and Long waiting time because material delivery is carried out in stages. The recommendations from respondent to mitigate the risk are needing a good commitment to supplier partners and subcontractors in carrying out each work contract, a careful planning and preparation regarding material suppliers and a contract agreement must be made with the supplier to ensure the availability of materials in the field, and have ordered materials before work begins so that the supplier can arrange the materials to be sent.

The second prioritize risk based on the table above is demand category, Demand risk refers to the demand for the amount of products or services desired by the company as customers. Demand management is important to predict and anticipate market needs so that the supply chain can respond in a timely and efficient manner. The very high risk in supply is D2 and D4 risk. Changes in material orders due to sudden changes in specifications or designs from the owner and Delays in material delivery due to financial problems that are not running smoothly. The recommendations from respondent to mitigate the risk is sufficient project funds

The low risk in severity index method and monte carlo method is process subcategory 11% and 11,2%. Process risk refers to a series of steps or activities performed to transform raw materials into finished products or provide services to a company/customer. This process includes production, packaging, distribution, and shipping. Efficient and coordinated processes are essential to optimize overall supply chain performance. Eventhough this risk classified as low risk, the mitigating risks are needed such as Order by reviewing the distance between the project location and the supplier, accordance with the contract requirements, check the materials to be purchased from several suppliers, to ensure that the materials to be purchased are available and in accordance with the required volume and ensure that transportation is also available and have a material time schedule that can be used as a reference for suppliers in supplying materials.

5. Conclusion

The risk analysis was then conducted using both the Severity Index and Monte Carlo methods. The results showed average risk differences between the two methods: supply side (16.40% vs. 16.76%), control risk (16.28% vs. 11.53%), process risk (11% vs. 11.20%), demand risk (16.10% vs. 13.87%), and disaster risk (13.78% vs. 13.41%). The highest risk identified was in the supply side, specifically the extended waiting times due to staggered material deliveries, while the lowest risk was related to the process of ordering materials, where issues arise from the need for reordering based on inaccurate quantity information.

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