Supply Chain Mitigation for Shipbuilding in Indonesia Shipyard by using Bayesian Network

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The implementation of modular construction in shipbuilding is increasing production by approximately 50%. However, supply chain remains a critical component of the project, particularly in the material inventory system, which significantly affects shipbuilding process. Delays in supply chain are caused by various factors, including a limited number of goods or service providers, changes in material or service specifications, supplier challenges, cash flow limitations, failed negotiations, incomplete documentation, customs clearance, failure to optimize networks and procurement system, redundant or unordered materials, limited storage capacity, insufficient transportation equipment, and high maintenance costs. Therefore, this study aims to introduce a new method for evaluating supply chain performance in Indonesian shipbuilding industry. Using Bayesian Network (BN) method, the evaluation process started by identifying constraint factors, assessing the probability, mapping associated risks, and providing mitigation strategies to enhance supply chain performance in support of new ship construction. The results showed that the procurement of materials, specifically sensors, weapons, communication system, as well as electrical and electronic components, carried the highest risk. These items were difficult to procure because of sudden specification changes and complex technical requirements. Project schedules often deviated from plans, causing an increase in equipment costs and procurement, as well as extended times. Consequently, early coordination between the procurement, planning, and supplier divisions is recommended to confirm and lock in equipment specifications, minimizing disruptions.

KEYWORDS
~ Supply chain performance
~ Bayesian network
~ Modular construction shipbuilding
~ Mitigation

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1. INTRODUCTION

In Indonesia, the application of risk management analysis in various sectors is still limited and mostly found in field of banking and finance. However, its use is gradually extending to the maritime industry in particular, both in shipyard and other construction building fields. A risk in system development process is a measure of the uncertainty of complying with certain requirements (technical or contractual) and the associated consequences of non-compliance. This risk can lead to schedule delays, cost overruns, performance problems, adverse environmental, or other undesirable impacts, etc (Ben, 2008).

The rapid development of shipbuilding system with the latest methods of modular strategy shortens the production process, thereby reducing costs by 5 to 10% and production time by approximately 50% or 75% (CERF, 1996) (Rubesa et al., 2011). To properly adopt this development, there is a need to synergize with supply chain modeling that is able to work by minimizing material procurement obstacles during ship production process with a variety of methods developed. However, there are still triggers for failure of supply chain performance due to limited providers of goods or services, risk of delayed payment of ship owners, the risk of difficulty in obtaining suppliers, the risk of delays in the customs process on imported goods.

Risk management studies have been carried out on operational risk at the Warship Division of PT PAL (Amelia, 2017), shipyard Industry (Basuki et.al, 2014), and maritime sector (Zarei and Wadhwa, 2017; Jager and Theocharis, 2017). In the field of supply chain, Badurdeen (2014) explored shipyard risk (Ben, 2008; Lee, 2009; Geoffreym 2017; Xue, 2020) and the efficiency shipbuilding model. For other fields related to environmental impact, various studies have been carried out by (McDonald, 2015; Tummala, 2011; Ceryno, 2015; Tang, 2011; and Badurdeen, 2014), showing a well-structured method using BN for the assessment of supply chain risk. The results showed that constraints in supply chain integration greatly affected the production process of shipbuilding in the maritime industry. Therefore, there is a need to implement risk management towards the successful implementation of shipbuilding network ability for proper management (Mello et al., 2011). Some risk mitigations have been carried out in various structural fields in previous studies. Basuki et al. (2014), Asdy et al. (2021), and Baroroh et al. (2024) conducted an assessment of shipyard, focusing on improvement to reduce the impact of risk, particularly regarding cost and scheduling. Basuki et al. (2021) also conducted a risk assessment on the new ship-building process related to imported materials using House of Risk (HOR) combination and Critical Chain Project Management (CCPM). To support supply chain performance with the largest financing content, it is necessary to organize strategies to control risk that hamper performance. Other studies have also explored the feasibility of shipyard, the application, and supply chain information technology (Ma'ruf et al., 2024; Centobelli et al., 2023; Sutrisno, et.al, 2024). However, there is no report on mitigation strategies for supply chain in the construction of modular ship.

Based on the background above, this research aimed to introduce supply chain model designed for ship construction in Indonesia. Risk control was applied to the modular ship construction supply chain using Bayesian Network (BN) method. The method was used to identify inhibiting factors in the modular ship construction supply chain, allowing for proactive risk control at the initial stages of project implementation, thereby minimizing the likelihood of project failure. The contribution of this research was to create a new method of assessing the risk of the modular ship construction supply chain, namely Product-Oriented Work Breakdown Structure (PWBS) method or (block and modular) carried out in single or multi yards around Surabaya, Indonesia. The evaluation focused more on the procurement of supply chain of 3-4 hospital auxiliary ship to be built in single or multi-yards. In multi-yards construction, one shipyard served as a leader in building complex modules and integrating other blocks/modules built in several shipyards around Surabaya. The purpose of building the modular ship, both single and multi-yards, was adjusted to the current government program in the form of sustainable maritime industry development. Furthermore, supply chain risk management aimed to determine the feasibility of building modular ship in Indonesian shipyard. The results were expected to provide valuable information supporting shipyard in the construction of the modular ship to reduce the impact of project failure.

2. RESEARCH METHODOLOGY

BN is a powerful probabilistic method that is often used for reasoning, diagnosis, prediction, and decision-making under uncertainty. This method consists of a set of variables (causes and effects) including conditional probabilities representing the strength of the relationship between the causes and their effects.

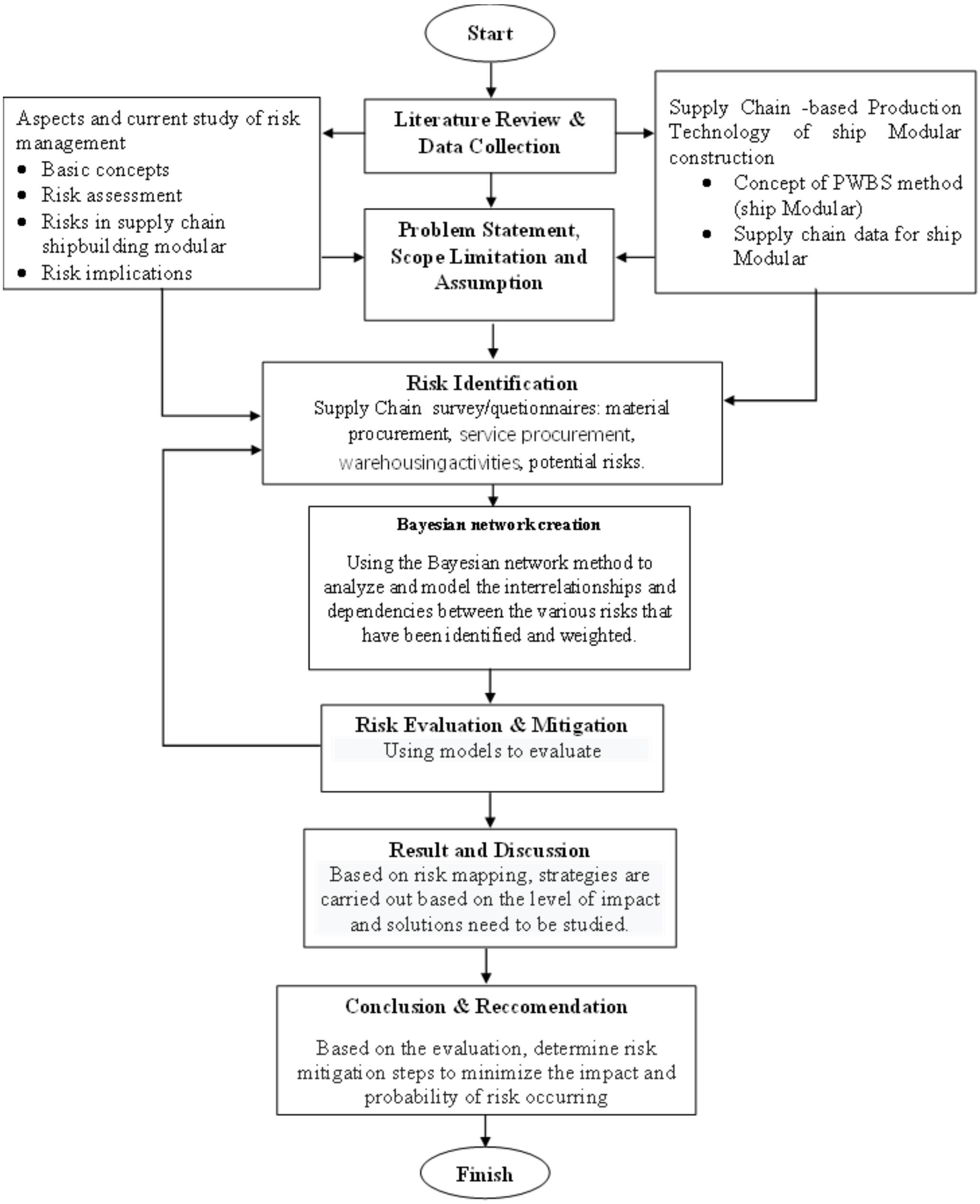

Figure 1. Flow chart of Research Methodology

BN is selected as an alternative to solving risk assessment models due to the effectiveness in several areas. Specifically, BN allows for efficient analysis of probability of risk occurrence for each node to obtain VaR (Value at Risk). In this method, there are conditional opportunities, ensuring a more accurate estimation of probability value at risk in the group of nodes in supply chain according to the following research flowchart (Basuki et.al, 2014).

A primary data study model is used, which includes surveys, interviews, and filling out questionnaires by the head of the work coordinator and some staff. The stages taken are shown in Figure 1:

- Bayesian model on supply chain process activities of modular shipbuilding.
- Determining the weighting factor for each supply chain activity of modular shipbuilding. The basis for compiling the weighting factor for work activities is based on "Proportional Progress Reparations". This suggests that the balance in carrying out production is divided into several stages of work with the term 'Proportional Progress Supply Chain method' emphasizing proper distribution to each supply chain activity of the modular shipbuilding (Baroroh et al., 2024).
- Compiling a questionnaire related to delay factors in supply chain sub-model activities.
- Measuring the delay factor with Bayesian theory.

2.1. Theoretical Considerations

The relationship between supply chain activities is a complex system that mutually affects each other in the division of activities. The complexity of this system can be analyzed with BN method which is a conditional probability on risk of interdependence between activities in supply chain.

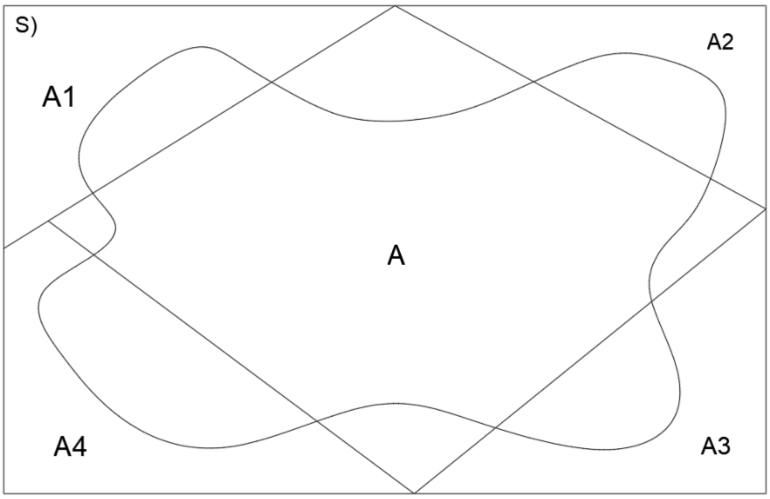

Figure 2. Partition Concept Supply Chain Model in Ship Modular (A = Concept Supply Chain Model in Ship Modular, A1 = Service procurement department, A2= Material procurement department, A3 = Warehousing department, A4 = Other department).

System is described as activities in material procurement, services, and warehousing with the basis of Bayes' theorem as follows:

$$P(Pt|C) = \frac{P(C|Pt)*P(Pt)}{P(C)} \quad \text{...}(1)$$

Conditional probability is the occurrence of a child node C given that a parent node Pt is true and is denoted as P (Pt | C). The child node C is highly dependent on parent node Pt. For risk assessment using BN, each risk event is considered a node and the complex relationships are captured through conditional probabilities (Punyamurthula, 2018). The ability of BN to exploit quantitative and qualitative data to generate posterior probabilities is helpful in the field of risk assessment.

or $p(A_k|A) = \frac{p(A_k).p(A|A_k)}{p(A_1)p(A|A_1)}$, ...(2)

is a conditional probability such that:

$$p(A_k|A) = \frac{p(A_k).p(A|A_k)}{p(A_1).p(A|A_1)+p(A_2).p(A|A_2)+\dots+p(A_n).p(A|A_n)} \quad \text{..............................}(3)$$

K = 1,2 (number of departments) n, j = 1,2 (names of departments one to n)
A = supply chain activity process
A1 = Service procurement department, A2= Material procurement department, A3= Warehousing department

BN model developed in supply chain process, the probability of risk occurrence in the following supply chain network:

$$\frac{Probabilitas\ of\ risk\ accurance\ in\ the\ supply\ chain\ network\ process}{\sum \frac{1}{Number\ of\ supply\ chain\ network\ process}\ x\ the\ weight\ of\ supply\ chain\ network\ process} \dots (4)$$

The probability of risk accuracy of supply chain network process is the number of departments included in the activity process. The number of supply chain network processes shows the number of sub-processes in each department. Meanwhile, the weight of each supply chain activity network process shows the number of influential hazards.

2.2. Implementation of Supply Chain in Shipyard

The material flow of shipyard starts with the design engineering division. Subsequently, the division is tasked with breaking down the required material, planning drawings, as well as the amount needed. After the work done by the design engineering division is completed, the process is continued to Project Management Office (PMO) division which makes material requests, plans project schedules, and job descriptions. The purchasing division will place material orders, request from suppliers, make purchases, ask for purchase budget, and control the material arriving at shipyard. In this context, the purchasing division will be in direct contact with the finance division regarding finances and budgets. After the material arrives at shipyard, the inventory division will identify the material according to specifications, store, distribute to production, manage stock, and classify the project material. When the task performed by supply chain division is completed, material is distributed to each workshop.

The flow of material procurement performance in both local and imported shipyard can be described in more detail. Starting from the planning of a new ship, the use date or application of material according to the schedule is submitted to supply chain section. Supply chain prepares material and service procurement activities consisting of manpower planning requirements and procurement of material requirements. Material procurement consists of domestic and imported materials. Domestic material procurement is delivered directly to the field or warehouse, checked for suitability, sent, and reported to the field. Subsequently, the warehouse receiving team checks the quantity and quality of material. Regarding imported material, several terms define the seller's responsibility to deliver goods to the buyer or Cost Insurance and Freight (CIF). This suggests that the seller is responsible until the port of destination, including shipping and insurance costs. The definition is opposite of free on board, namely the buyer's obligation to take the goods on board or when ship is loading. Since imported material entering through forwarding is risky, there is a need to establish some rules for sending goods. According to Interm 2020 (International Commercial Term 2020), all imported materials must be reported to the Project Management Office (PMO), which creates a list of goods requests.

Warehousing services or delivers the required goods to production. Goods that are not urgent are standardly stored in warehouse, identified in quantity and quality, put on shelves, and determined by place after storing. In comparison, urgent goods for administration are reported in warehouse and immediately placed in the field. Moreover, one factor that requires urgent delivery is the implementation of outfitting, namely the main engine, must be overcome. The main engine that has left the port to the location is close to installing near the graving dock or building dock. This is because the main engine is an extra heavy item and the moving cost is high. Outfitting is serviced in the warehouse, such as supply of values measurement for easy control. Additionally, plate and profile are put into the steel stock house (SSH) workshop by recording by the warehouse. Specially imported goods are brought for 2 weeks before installation, while the purchase planning is conducted in 14 to 18 months. In shipyard operation, procurement of material earlier supports timely production. This must be considered from the financial payment factor, ensuring that there are sufficient funds for the procurement of goods in the period-adjusted planning.

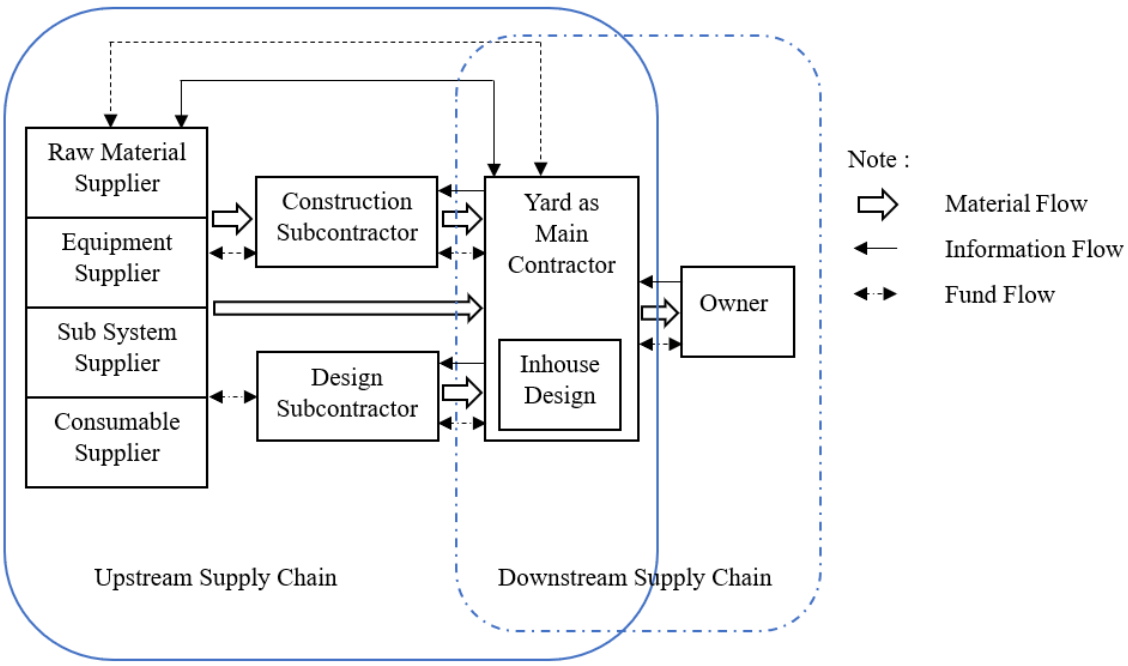

Figure 3. Supply Chain Model in Indonesian Shipyard

In shipyard supply chain structure, there are 3 flows, namely material, money, and information (Pujawan, 2005). The flow of material starts from the supplier after receiving an order letter from shipyard. The flow of money originates from shipyard as payment for the materials purchased. Meanwhile, the flow of information occurs along supply chain structure and between the parties included in each flow of money and materials. The general structure consists of shipyards, local and international suppliers, national and international forwards, national and international land transportation operators, shipping companies, customs, and financial institutions. According to supply chain theory, the channel must support each other in order to fulfill the satisfaction of the end consumer.

3. RESULTS

3.1. Risk identification of supply chain activities

Ship production process is related to shipyard facilities, development technology, human resources, government policies, imported materials, capital, and the speed of providing the completeness of the entire equipment as well as equipment system. Based on the construction of ship, the implementation of PWBS to increase productivity in bulk is performed with a batch production system, namely producing the same blocks in one batch and assigned to different shipyards. There is one main shipyard to assemble (hull erection) into ship body from blocks that have been made in others. However, the quality between blocks is different because work is performed by various supporting shipyards. In shipbuilding activities with PWBS, a parallel series system is used to achieve faster time

N0.	Risk-related material procurement activities	
	Activity	Risk
1	LC payment	• Late payments to 3rd parties. • Availability of goods is difficult to obtain. • Limitations of goods providers.
2	Procurement of consumable row materials and components	
3	Procurement of SEWACO, electrical & electronic materials	
	Risk-related procurement activities	
4	Services, production (negotiations with subcontractors)	• Failure to negotiate the availability of hard-to-obtain goods. • Document imperfections • Delays in imported goods. • Delays in Customs Processing
5	PO release (Issuance of Letter of Agreement/Work Order)	
6	Procurement of import-export services (IMEX Procurement)	
7	Customs process (custom clearance)	
	Risk-related to warehousing procurement activities	
8	Receipt of incoming material that has been inspected	• Limited storage/warehouse capacity. • Materials do not arrive as ordered.
9	Material management in the warehouse	

Table 1. Hazards that occur during supply chain performance at shipyards

The hazards identified are collected data obtained from shipbuilding process by assessing construction operations using BN, to allow for the control of potential failure. In this research, hazards were identified by determining the factors triggering failure in the construction of modular ship at Surabaya shipyard. This would produce the necessary mitigation recommendations by identifying risk from the elements that make up shipyard supply chain, as shown in Table 1.

3.2. Bayesian model concept in shipyard supply chain

Risk identification is the most important stage for risk assessment. Identifying potentially relevant risk at the production process level forms a strong foundation for continuing the analysis and evaluation stages. One of the most important tasks is to determine the boundaries for assessment, as there is a high tendency to deviate from production process to organizational/industry-level risk. The best way to define these boundaries is by discussing with the team to assess risk and consensus on the scope. Moreover, the relationship between supply chain activities can be described using BN model which is developed into several material procurement, service, and warehousing activities as follows:

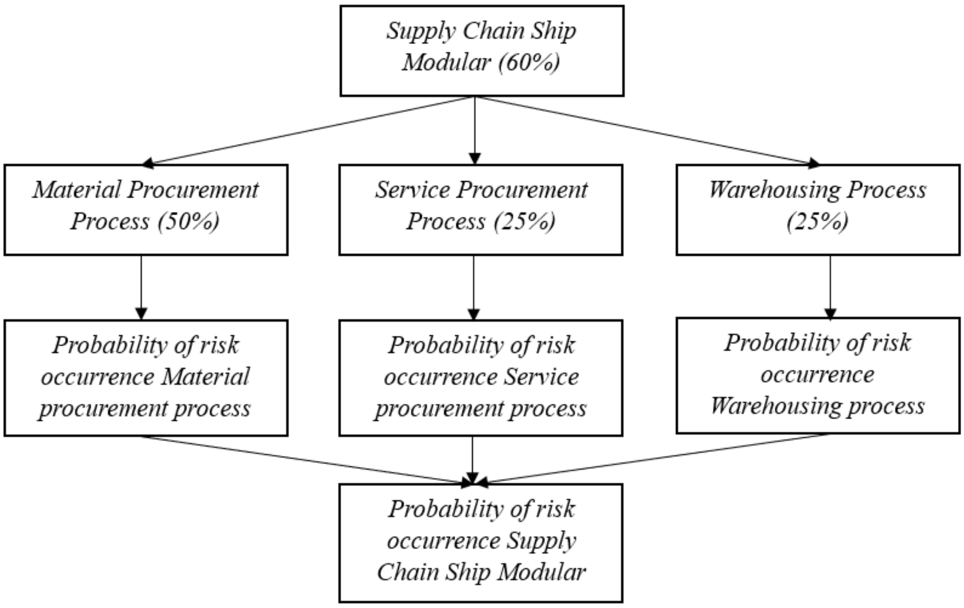

Figure 4. Main supply chain network for modular ship construction

The weighting factor was initially based on the instruction for work execution (IPP), regarding the cost programmed for each activity. Along with the development of time and project composition division, the weighting factor is carried out based on an agreement between shipyard and the owner to describe the progress of the project. A key reference for determining the adjustment is the implementation of previous projects that have been completed and modifications in line with experience or budget given by Company's Strategic Planning Division (PSP). More importantly, each new shipbuilding project can be weighted differently depending on the agreement between the owner and shipyard. The basis for the preparation of weighting factors in work activities is based on “Proportional progress of production”, indicating that the balance of production is divided into several stages of work. This method allows for proportional progress of production distributed in each activity such as supply chain during procurement, services, and warehousing processes. In proportional production progress method, the weighting factor is based on existing experience and the level of difficulty obtained from each activity. Therefore, the factor obtained varies depending on the workload in each process.

Activity	Wight Factor	Probability
Material procurement	0,3	0,008
Procurement activities	0,15	0.001875
Warehousing procurement	0,15	0.00375

Table 2. Weighting of supply chain activities and total probability

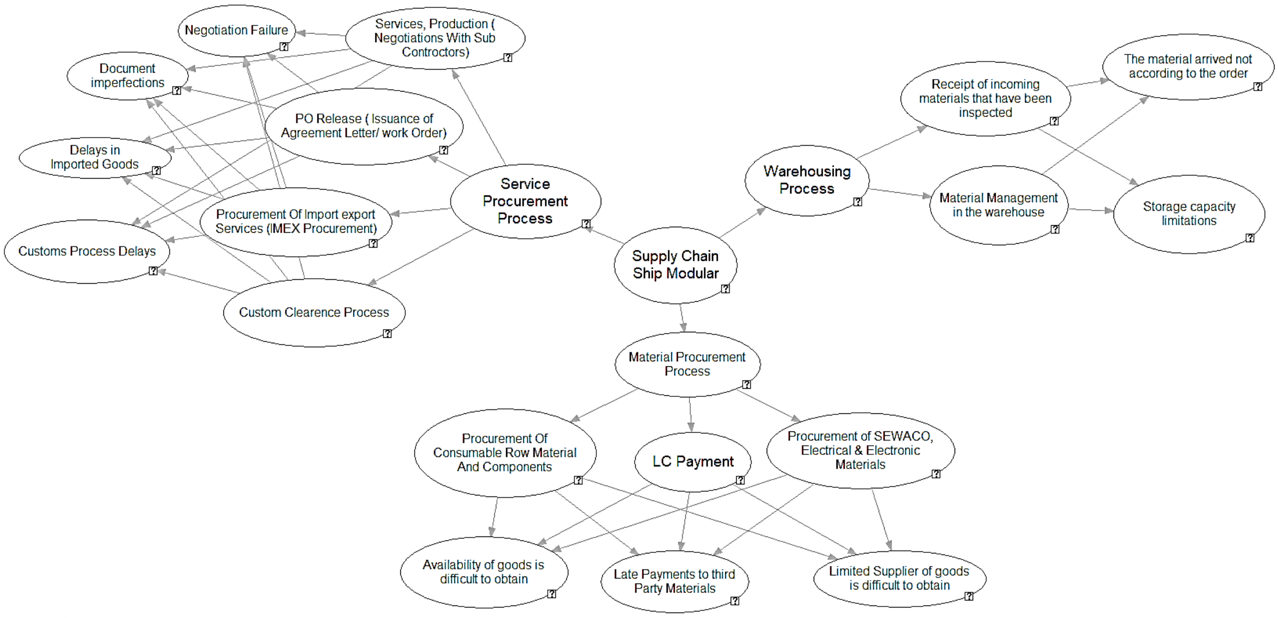

Figure 5. BN for service procurement, material procurement, and network of warehousing/

The network model under supply chain department in Figure 5 is a service procurement BN that has 4 activities with weights assigned to each factor. Generally, BN of material procurement has 3 activities with the weight of each factor. This structure is also applied to BN of warehousing activities that have 2 activities, each with an assigned weighting factor.

3.3. Calculating Bayesian Probability in Shipyard Supply Chain

In formulation (4), an assessment of probability of risk occurring is carried out and the results obtained are shown in Table 3. These values represent BN model probability for material procurement, service procurement, and warehousing implementation. The total risk depends on how many delay factors influence each activity in the production workshop.

Activity	Wight Factor	Probability	Criteria	Consequences (days)	Criteria
Material procurement activities					
LC payment	0.15	0.005	*Likely*	*50*	*Moderate*
Procurement of consumable row materials and components	0.045	0.005	*Likely*	*10*	*Minor*
Procurement of SEWACO, electrical & electronic materials	0.045	0.0015	*Likely*	*30*	*Moderate*
Procurement activities					
Services, production (negotiations with subcontractors)	0.03	0.000375	*Unlikely*	*5*	*Insignificant*
PO release (Issuance of Letter of Agreement/Work Order)	0.03	0.000375	*Unlikely*	*10*	*Minor*
Procurement of import-export services (IMEX Procurement)	0.06	0.00075	*Almost Certain*	*10*	*Minor*
Customs process (custom clearance)	0.03	0.000375	*Unlikely*	*10*	*Minor*
Warehousing procurement activities					
Receipt of incoming material that has been inspected	0.05	0.00125	*Possible*	*10*	*Minor*
Material management in the warehouse	0.10	0.0025	*Possible*	*3*	*Insignificant*

Table 3. Results of measuring probability and consequences as well as categories of each activity in supply chain

In BN model which was developed and described into several material procurement, service, and warehousing activities, between realization and planning, the material procurement stage showed the highest probability of delays. Due to the significant impact, this stage must be included in risk matrix based on provisions of the Australian New Zealand Risk Management Standard (AS/NZS 4360: 2004). The results of risk mapping in each department are shown in the quantitative analysis matrix of supply chain. Specifically, this mapping categorizes risk levels across several workshops based on the impact of delays caused by supply chain. As shown in Figure 4, this matrix describes the level of probability (Likelihood) and the magnitude of the consequences (Potential Consequences) for each supply chain activity sub-model.

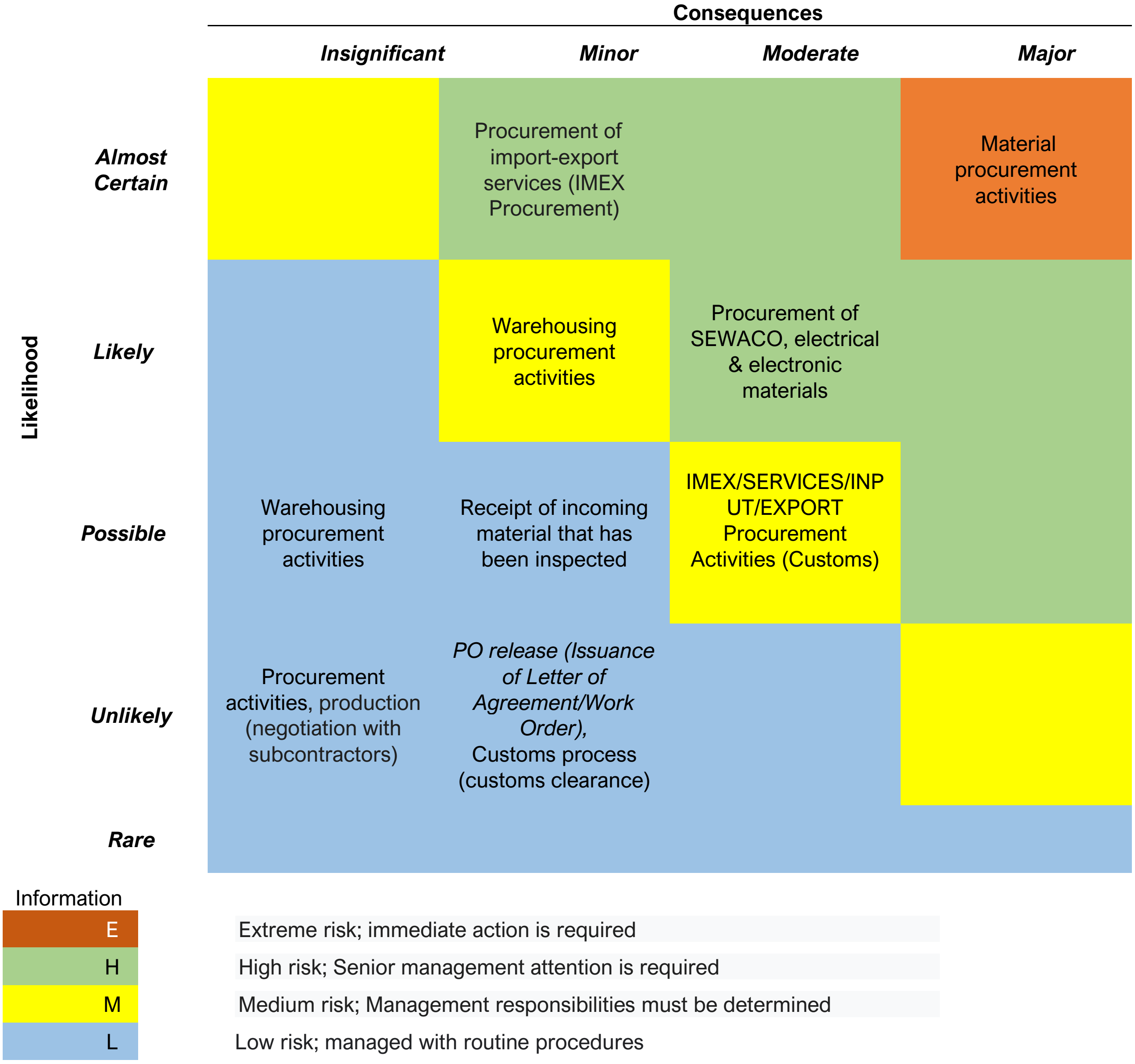

Figure 6. Risk mapping for each activity in the new ship construction supply chain.

As shown in Figure 6, several stages of activities that make up supply chain have individual risk levels based on the impact of delays caused by supply chain. In line with the analysis, several stages are in the high-risk category, namely procurement of SEWACO, electrical and electronic materials, as well as IMEX Procurement. The low-risk category includes material management activities in the warehouse, SC Services, production (negotiations with subcontractors, receipt of incoming materials that have been inspected, PO release (Issuance of Letters of Agreement/Work Orders), and customs clearance processes. Meanwhile, material procurement activities are included in an extreme risk category. IMEX/SERVICES/INPUT/EXPORT Procurement Activities (customs and Excise) and Warehousing Activities are included in the moderate risk category. These results will influence the strategy applied to overcome production delays at each workshop by handling different risks.

3.4. Evaluation of Mitigation Strategies

- By observing the potential risk in Figure 6, each stage of activity in supply chain carries its own risk level, influenced by specific factors contributing to delays. The results of the risk mapping that applies to each stage of supply chain activities are as follows:
- Material procurement activities as a whole have risks with extreme categories, provided that the material procurement stage activities include:
- High-risk category: In SEWACO electrical and electronic material procurement, the availability of goods is often difficult to ensure because of sudden changes in specifications and requests for materials with complex requirements. This affects the project schedule, causing delays and deviations from the original plan. Additionally, equipment prices become significantly more expensive, and procurement lead times are extended. To mitigate the issues, coordination with the relevant division has been increased by requesting confirmation on specific technical specifications during the equipment selection process.
- IMEX/SERVICES/INPUT/EXPORT Procurement activities (customs) as a whole have a risk with a medium category, with the provisions of the activities in the stages in the form of:
- High-risk category: In IMEX Procurement, delays occur due to issues in the international supply chain and logistical challenges.
- Moderate-risk category: In the service supply chain, production negotiations with subcontractors often fail due to the absence of a price agreement between the service provider and the buyer. This leads to higher service prices and financial losses. As a mitigation measure, renegotiations are conducted, and alternative service providers offering competitive prices are sought.
- Low-risk category: In the service supply chain, the issuance of Purchase Order (PO) documents, such as Letters of Agreement or Works Orders, is imperfect, leading to differences in interpretation between parties. This is often due to unclear or missing provisions, leading to future conflicts, disputes, or ambiguities that may be exploited or cause uncertainty. Mitigation efforts focus on ensuring that all requirements in the documents are clearly defined and well-structured. A thorough review process is also conducted before issuance to verify the completeness and accuracy of the content.
- Extreme-risk category: In the service supply chain, delays in the customs clearance process often occur due to incomplete or inaccurate documentation, leading to high storage costs. To mitigate this issue, all documents are thoroughly checked for completeness and accuracy. The process is carried out in strict compliance with customs rules and regulations.
- Warehousing activities as a whole have a medium risk category, with the provisions of the activities in the stages in the form of:
- High-risk category: After receipt of incoming materials that have been checked, some materials do not match the order due to supplier error and damage during the transportation process. This has an impact on time losses due to the process of returning, resending, and re-procurement. Mitigation is performed by making a claim to the supplier, ensuring every material delivery.
- Low-risk category: In the management of materials in the warehouse, there is limited storage/capacity due to the presence of several materials/terminated goods and simultaneous arrival. This has an impact on the storage of materials not according to the characteristics of the goods. In some cases, materials are not dedicated to the project and the process of loading/unloading materials is hampered. Therefore, several mitigation placement strategies are established for some materials at the production site.

4. CONCLUSION

In conclusion, analyzing the potential risk and the impact of time delay using BN model provides valuable information on supply chain activities, including material procurement, services, and warehousing. The results show that risk causing a high probability does not have a severe level of impact. The observations of risk mapping of matrix obtained are as follows:

- Material procurement activities show the highest risk, particularly in SEWACO material procurement, as well as electrical and electronic components. The availability of goods is difficult to obtain because of sudden changes in specification and material requests with complicated specifications project schedules were not according to plan. Additionally, equipment prices are very expensive, leading to longer procurement time.
- IMEX/SERVICES/INPUT/EXPORT Procurement activities (customs) have the highest risk in IMEX procurement. There are delays due to problems in the international supply chain or logistical problems, which have an impact on customer dissatisfaction and unexpected additional costs.
- Warehousing activities have risk with a low category of incoming material receipts. This suggests that the material arrived not as ordered because of supplier error and damage during the transportation process, causing time losses due to the process of returning, resending, and re-procurement.

Overall risk material procurement activities show extreme risk, while IMEX/SERVICES/INPUT/EXPORT Procurement activities (customs) and warehouse activities have moderate risk. Based on the business planning model, supply chain scheduling is connected with stakeholders, suppliers, customers, buyers, and transportation in single or multiyards. Suppliers related to imported materials, which account for 70% of materials, including machinery and main equipment, still show the highest risk value. Regarding transportation for connecting modular ship hull construction, multi-yards allow for a relatively close distance using sea. Based on the assembly of modular ship, construction module is carried out by sea culminating at the 50,000 DWT graving dock and the 300-ton Goliant crane. In further research, a business model for scheduling supply chain of modular shipbuilding for single yard and multiyards was recommended. Mitigation strategies should also be implemented in supply chain business model in the construction of modular ship in single and multiyards using system dynamics method.

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CONFLICT OF INTEREST

Author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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