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Engine Room Module Installation System Risk Analysis Based on Bayesian Network

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Abstract. Implementation of system installation risk on engine room module aims to anticipate ship production delays. However, in its implementation, there is the problem of ship delivery delays in various shipbuilding companies. This research will analyze the risk analysis of the installation of the engine room module system by identifying risk factors and parameters that affect performance as a hazard identification that has the potential to cause delivery delays. The object of the research is the Indonesian Navy's Auxiliary Hospital Ship, which has 6 zones with a pilot project developed in zone 2. This includes an engine room that contains important constructions in the form of a main motor foundation, auxiliary motor, and other machinery, where the system was integrated. Moreover, there are some works consisting of construction, outfitting, and commissioning which are very complicated and require high accuracy. The aim of the implementation of risk analysis of the installation system in the engine room's module is to assess potential risks, the effect of risk on project delays, and project cost overruns. The research method uses a Bayesian network because it is able to assess the most potential risks and predict the possibility of delays at network nodes. The primary risk is associated with electrical activities, specifically electrical outfitting on wiring, clamping, and compound sub-components with a probability of (0.0002560) in the Machinery Outfitting and Electrical Department. This risk stems from inappropriate steps during drawing revisions, which have the potential to cause delays in equipment installation, cable material procurement, and the generation of cable cutting data. Therefore, early coordination with production planning control, design, and the supply chain is crucial.

Keywords: Bayesian network; Installation engine room module; Risk analysis

1. Introduction

According to the Governing Council of the Indonesia National Ship Owner's Association (DPP INSA), the total ship class acceptance units, based on PT. BKI's report on new buildings from 2009 to 2018, show that the increase in class acceptance reached its peak in 2013. Furthermore, there was a decline from 2014 to 2017, and at the beginning of 2018, there was a growth of 829 units of ships compared to in 2016. This has a positive impact on the

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growth of national shipyards. Based on shipbuilding data at PT. PAL Indonesia, from 2011 to 2015, the development of shipyards in East Java experienced delays in two ships in the form of a 17.500 LTD tanker, two Tug ships of 2400 HP, and a SSV Philippines Navy ship."In the case of PT. Dumas Tanjung Perak shipyards, there were four shipbuilding delays from 2011 to 2020, including the 3500 DWT Hull No 109 tanker, 3500 DWT Hull No 111 tankers, 60 meters, and Fast Patrol Boat. Whilst PT. Dock and Shipping Surabaya was delayed in the production of Landing Craft Tank ships, Landing Craft Tank 100 TEUS, Tanker 6.500 DWT, and Self-Propelled Barge Cement Carrier.

The condition description of PT. PAL Indonesia, PT. Dumas Tanjung Perak shipyards and PT. Dock and Shipping Surabaya has suffered considerably due to a late penalty of delivery. Other losses are also in the form of loss of trust from the ship owner and the bank as a lender. Besides, it declines the company's performance. The latest developments in East Java shipyards are accelerating production with the modular (Zone) system method on hospital auxiliary ships whose construction plan was carried out on September 16, 2019. It planned handover of September 30, 2021, but there is a setback until December 8, 2021, because of various obstacles during production, especially the complex system in zone 2 of the engine room. The loss of shipbuilding delays can actually be reduced or anticipated if the risk management process is implemented and executed properly at the beginning of the project. The probability of risk can be calculated by various methods, one of which is the Bayesian network (BN) approach. BN can be used in various dynamic security and risk analyses due to its flexible structure on the cause of failure and mutual conditional dependence by performing probability updates. Meanwhile, quantitative risk analyses, such as Bow-tie, Barrier block diagram, and Petri net, show an inability to consider conditional dependencies amongst underlying events Zarei *et al.* (2017). The Bayesian method has also proven capable of being used in complex model development Burova *et al.* (2021) by using a weighting method to evaluate business economics risk Lyukevich *et al.* (2020). The advantages and flexibility of the Bayesian network method are chosen in the risk analysis of the complex system installation of the engine room zone 2.

Risk measurement using the AHP (Analytic Hierarchy Process) is also carried out by (Zhong, Lv, and Zhang, 2019; Jia, Zhao, and Zhang, 2013). Moreover, Zhong collects the risk factors that are potential from company T projects adapted to the Delphi method. After a few rounds, it got 22 factors of level three from the factors of level 6 is original. Then, filter 22 factors of level three to identify TOP 10 factors using the Analytic Hierarchy Process (AHP). Then, calculate the weights of all factors and get a list of the top 10 critical factors. Likewise, a market risk mitigation strategy using the FUZZY FMEA method has been carried out by Rahmatin *et al.* (2018) in food companies by increasing promotion strategies, promotion strategies are used as mitigation aspects. Risk for contractor expectations versus insurance company policies by Hatmoko, Astuti, and Farania (2021), which causes the head office to lose insurance claim benefits. Probabilistic Risk Assessment of COVID-19 Patients by Ting, Zakariah, and Yusri (2022) using the Logistic Regression instrument. Risk Control Failure of Iron Pipes by Suwandi, Zagloel, and Hidayatno (2021). However, the interactions are not clear and measurements have not been carried out. While the impact of the risk variable cannot be seen, its effect on the performance system.

Bayesian Risk Measurement in banking institutions and the construction industry has been carried out by (Eschmann *et al.*, 2019; Erango and Goshu, 2019; Zhou *et al.* 2018; Do and Yin, 2018; Fong *et al.*, 2017; Kim *et al.* 2012; Kumar, 2010). In addition, Zhou *et al.* (2018) did a risk assessment and showed that the Bayesian network method performs risk assessment effectively and works flexibly with offshore wind power construction. The results inform risk mitigation measures by identifying risk sources using a Bayesian dynamic model. The measurement of the risk of the shipbuilding industry with the Bayesian network with a questionnaire approach has been carried out by Lee, Park, and Shin (2009). The model developed for each network at its node has not been analyzed until the risk value (VaR/Value at Risk) is obtained. The activities carried out are limited n to n relationships, meaning that one potential risk has an influence on one risk. Then, a risk analysis is carried out on material components Basuki *et al.* (2014). The subcomponents that are most likely to cause project delays are the hull and engine equipment, so they become the main priority in the installation of the engine room and its equipment.

The duration of shipbuilding in the Indonesian Navy's Auxiliary Hospital shipbuilding zone there are 6 zones. The construction time of the engine room zone reaches the longest time, which is 76% of the total ship construction time. The total blocks that make up the engine room zone reach 30% of the weight of the 6 zones of ship arrangement. It contains complex systems integrated into the form of main motor foundations, auxiliary motors, and other machinery, as well as complex construction, outfitting, and commissioning that require high accuracy. The engine room is the most urgent object of the research on the W000302 shipbuilding process at PT PAL Indonesia's shipyard.

The previous studies such as (Ting, Zakariah, and Yusri, 2022; Suwandi, Zagloel, and Hidayatno, 2021; Zhong, Lv, and Zhang, 2019; Basuki *et al.*, 2014; Jia, Zhao, and Zhang, 2013), researchers are still in the stage of risk identification, they have not thought about how to proceed with the research. Many studies have shown that the implementation of the Bayesian Network leads to better results. The purpose of this research is to identify and assess engine room installation risks of the Navy Auxiliary Hospital shipbuilding by using Bayesian Network. However, in this study a quantitative measurement of the risk analysis has been carried out using the Bayesian method in relation to the risk variable in each activity in each production workshop. This was due to various constraints during production, especially complex systems in the zone 2 machine room. The gaps from previous research include: The use of Bayesian is still rare in the field of ship production. Research from Basuki *et al.* (2014) has used Bayesian methods, but what is done is measuring the probability of shipbuilding globally. However not all modules on the ship have the same work, so it is less precise or less specific when applied to modules that are complex in nature with work that requires a large volume of work. In the engine room zone, although it has a small module form compared to other modules in the ship's body, it is a specific zone that requires a high level of difficulty and a large volume of work. This engine room zone absorbs the most cost and the longest time compared to other parts of the zone on the ship's body. This is what requires a separate study to measure the probability and impact of the risk evaluation. This is a gap from research studies regarding engine room installations, so this research is very important to be carried out in the construction of the Navy Auxiliary Hospital shipbuilding.

The risk measurement with conditional probabilities in the engine room module installation model using a Bayesian network. This model is expected to be able to analyze the magnitude of the dominant factors that affect the delay in the installation of the engine room zone in ship construction. The findings of risk priorities at engine room installation points are used as a reference for mitigation strategies for shipyards in overcoming delays. This research does not end with Bayesian analysis but must be continued with quantitative impact measurements. Not only with the solution of the shipyard management policy, but there should be scientific results based on the calculation of the model formulation. Daszyńska-Żygadło (2012) advocates the use of scenario analysis in risk management studies in future research. Risk evaluation using the scenario analysis approach allows users to evaluate the impact of risks on the production process and develop strategies for risk management in future studies.

2. Methods

As given in the previous section, this study focuses on PT. PAL Indonesia on the engine room installation of a new building code W000302. It focuses on assessing the probability of risks that are affecting the engine room installation activities. Risk identification is carried out on each production component of the workshop related to engine room installation activities by identifying all risks of project completion delays. Risk probabilities are needed to build a Bayesian network that includes the investigation of hazard correlation based on the number of nodes in the network using a probabilistic approach Basuki *et al.* (2014). Bayesian Networks (BN) is a powerful probabilistic approach often used for reasoning, diagnosis, prediction, and decision-making under uncertainty. The engine room installation activity has an impact on the occurrence of risks that are influenced by three kinds of factors Ben-Asher (2008), namely:

a. Performance factor, which is a factor that reflects a decrease in performance.
b. Cost factor, which is a factor that reflects the additional cost.
c. Schedule factor, which is a factor that reflects the delay in the schedule

Based on the occurrence of the engine room installation process, there are several potential risks, risk events, and risk agents. The potential risk is assessed using the Bayes theorem probability, where there is a partition relationship between the parts that make up the entire sample space as shown in Figure 1.

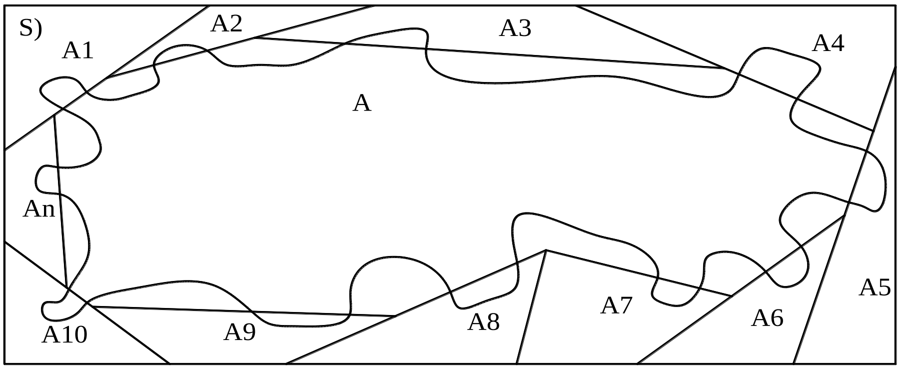


Figure 1 Partitions concept for engine room installation production process

According to Figure 1, A: Production process of engine room installation; A1: Machinery Outfitting; A2: Electric, Electrical Outfitting A3: Steel Work; A4: Piping System; A5: Fabrication; A6: Assembly; A7: Erection; A8: Painting and Protection; A9: Outfitting Manufacturing; A10: Accommodation Package in the Engine Room Area. Ten workshops associated with codes (A1 to A10) were analyzed by a Bayesian method.

According to Figure 1, it can be formulated in equation 1-4 for Bayesian solutions as follows: If $\{A_1, A_2 \ldots\ldots, A_n,\}$, is the partition space of the sample space S and if the partition $A_1, A_2 \ldots\ldots\ldots, A_n,$ have probabilities not equal to zero, then the probability is:

$$p(A) = p(A_1).p(A|A_1) + p(A_2).p(A|A_2) + \ldots\ldots\ldots\ldots + p(A_n).p(A|A_n), \qquad (1)$$

or can be written as follows: Source: (Basuki *et al.*, 2014).

$$p(A) = \sum_{j=1}^{n} p(A_1).p(A|A_1), \qquad (2)$$

p(A) : Probability on engine room installation production process
Where j: 1,2 … …, n; is the name partition of the 1st to nth

Using conditional probability: $p(A_k|A) = \frac{p(A \cap A_k)}{p(A)} = \frac{p(A_k).p(A|A_1)}{p(A)}$, then

$$p(A_k|A) = \frac{p(A_k).p(A|A_k)}{p(A_1).p(A|A_1)+p(A_2).p(A|A_2)+\ldots\ldots\ldots+p(A_n).p(A|A_n)}, \tag{3}$$

$p(A_k|A)$: The conditional probability between A_k and A, or

$$p(A_k|A) = \frac{p(A_k).p(A|A_k)}{p(A_1)p(A|A_1)}, \text{ Bayes Theorem} \tag{4}$$

$p(A|A_k)$: The conditional probability between A and A_k
Where k: 1,2 … . , n; is the number of partition

The Bayesian Network Model based on the Bayes theorem will be described in more detail in accordance with the identification of risks in the work of several workshops related to the production process of engine room installation, according to Figure 1. Figure 1 explains the installation system in the engine room has synergy and close interrelationships in it. This system cannot function properly without mutual support between sub-models in the engine room installation work. The successful execution of this work requires full cooperation among these sub-models within the series of engine room installation systems. The method consists of four stages, including:

- Risk identification on the sub-model in the engine room installation system is done by collecting risk identification as information or primary data to be taken in the field in the form of surveys, interviews, and filling out questionnaires by the shipyard.
- Determine the weighting factor of each ship repair activity. The basis for the preparation of weighting factors in work activities based on "Proportional production progress" means that the balance in carrying out production is divided into several stages of work. The weighting factor is based on either the volume of block weight or the man-hour budget. The estimation of man-hours for each activity is based on existing experience and the level of difficulty. The difficulty factor is obtained from the experience of the workshop or workers in carrying out the activity process. Essentially, the man-hour budget for each job or activity already takes into account both the volume and the difficulty factor. The weighting factor obtained varies depending on the workload in each process.
- After the weighting factors are given to the BN network model, the calculation of the chances of each activity against the constraining factors that affect these activities in each workshop begins. The risk opportunities for each activity are summed up in total, so they become the total risk opportunities for activities in each workshop. These delay factors will be used as the basis for creating a Bayesian network involved in the engine room installation.
- Measuring delay factors using Bayesian theory with the latest measurements, conclusions are drawn from the results of risk analysis in engine room installation. The analysis of high-risk constraints in delay values serves as a reference for developing further mitigation strategies.

3. Results

Based on the occurrence of the engine room installation process and the results observed during the study on the production code W000302, the researcher analyzed the results and developed the following model under the Machinery Outfitting (MO) and Electrical Outfitting (EO) Departments, including the piping workshop, machinery outfitting, steel work, electrical, electrical outfitting. Meanwhile, activities under the Hull Outfitting and Accommodation Outfitting Department include Outfitting Manufacturing workshops, Package Accommodations in the Engine Room area, and Painting and

Protection. In contrast, the activities are under the Department of Hull Construction. It includes fabrication, assembly, and erection. All of these workshops had a role in the construction of the W000302 ship engine room system installation, PT. PAL Indonesia was found to have several potential risks. Researcher apply the concept of probability and the Bayesian method with the weight of each factor obtained from historical data records of PT. PAL Indonesia, as shown in Figure 2. The basis for the preparation of weighting factors in work activities is based on Proportional production progress. The value of the weight of each process is obtained from data collected by the shipbuilding company. The weight values will differ for different shipbuilding processes and shipbuilding companies. It depends on the ship base owned by the shipbuilding company. The factor is the target value carried out by each activity workshop.

Ten related workshops that make up the engine room installation can be analyzed by using a Bayesian network to get the delay probability value for each factor. The probability value for each factor is the multiplication result of 1/10 (since there are ten factors) and the weight of each factor (derived from historical data, as described earlier). Probability on Bayesian networks is needed to assess any possible delays in the production process as the focus of this study.

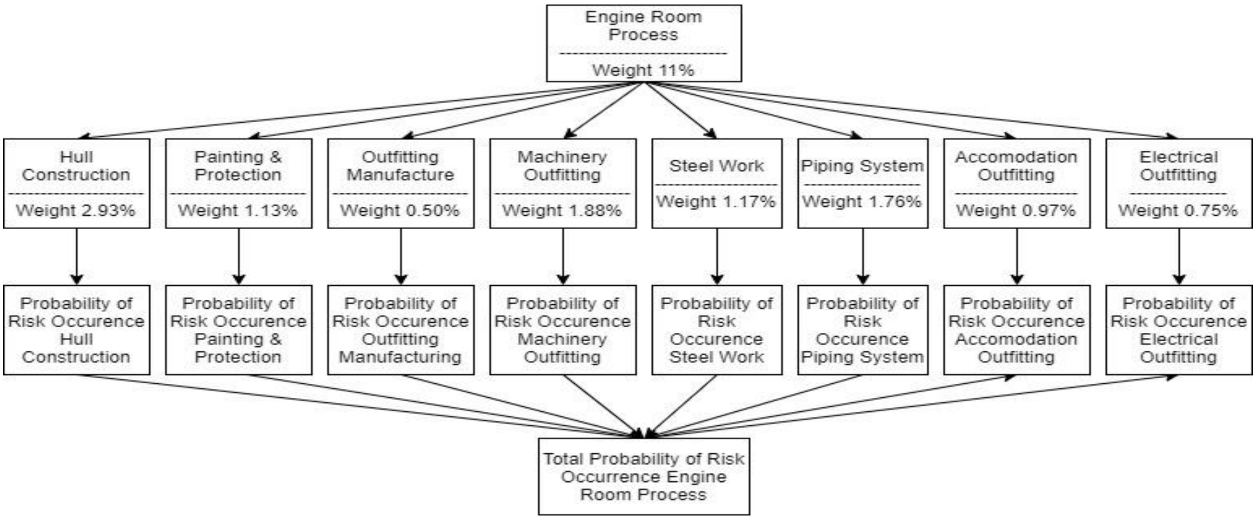


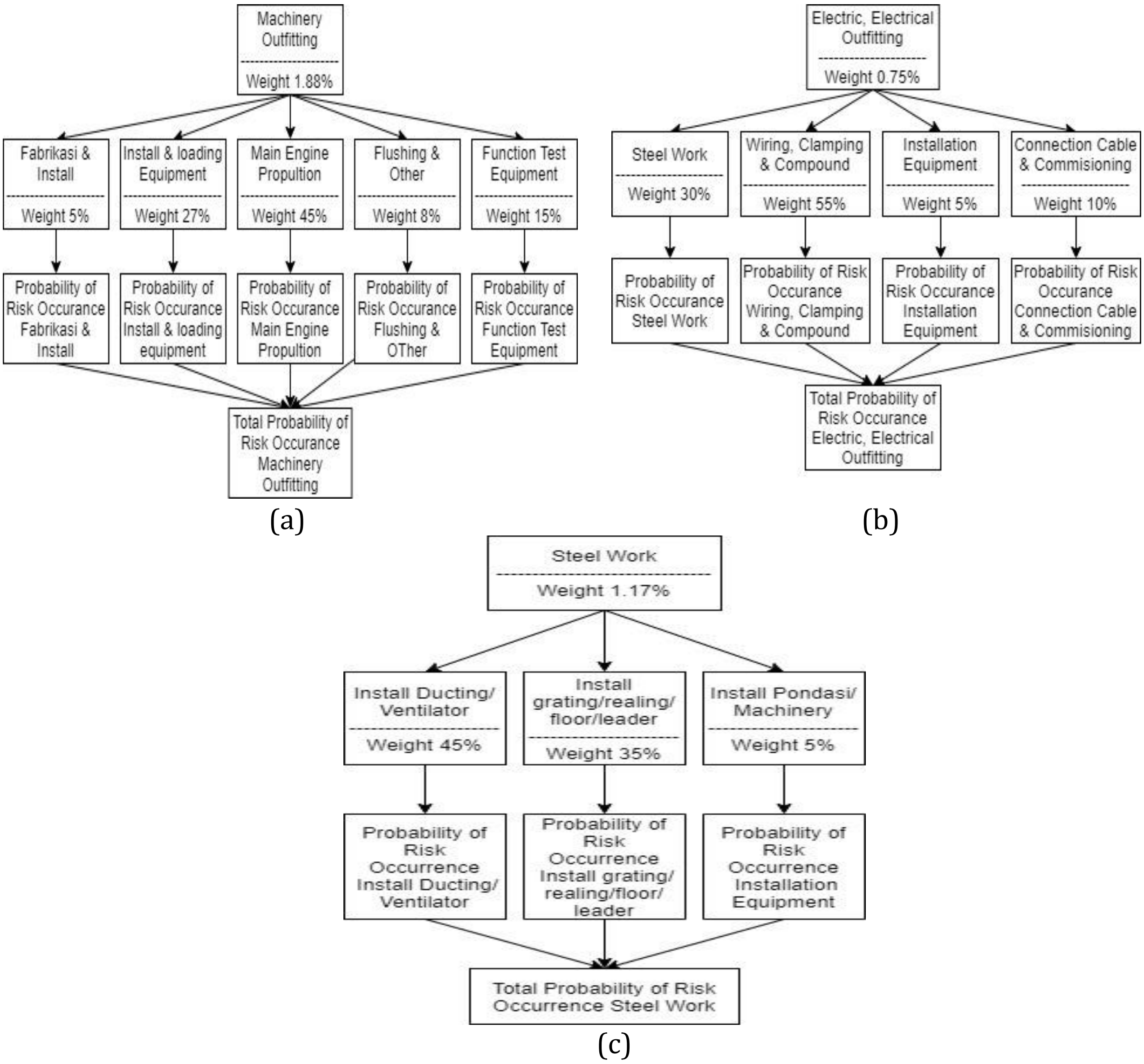
Figure 2 The weighting of the Bayesian main network model in the engine room

The risk approach for each activity of the Bayesian network new building engine room model was calculated using the following formula: Risk = probability of risk occurrence x consequence of risk occurrence. The delay of the engine room installation process is obtained from the conditions in the shipyard. The results of this probability of risk occurrence are the basis for the variable values of the factors that cause delays in each workshop. The value of this variable causes the performance value of the workshop to decrease from the initial planning. The decline in the performance of each workshop affects production delays that cause delays in production time, financial losses, and even the most severe contract cancellation. For this reason, it is very necessary to apply risk evaluation in every shipbuilding project to anticipate losses early. Bayesian probability in each activity of the Bayesian network new building engine room model is shown in Table 1.

The network model under the Department of Machinery Outfitting and Electrical Outfitting includes the Bayesian network model of Machinery Outfitting, shown in Figures 3(a), (b), (c), and (d).

Table 1 The probability of the Bayesian network engine room model

Activity	Factor Weight	Probability
Machinery Outfitting (MO)	0.0188	0.0003760
Electrical Outfitting (EO)	0.0075	0.0004650
Steel Work	0.0117	0.0003900
Piping System	0.0176	0.0001340
Fabrication	0.0082	0.00020377
Assembly	0,0141	0.00035252
Erection	0.0071	0.00017721
Outfitting Manufacturing	0.0050	0.0000830
Accommodation Outfitting	0.0097	0.0001940
Painting & Protection	0.0113	0.0003770
Total	0.1100	0.0027790



(a) (b)

(c)

Figure 3 Bayesian networks: (a) Machinery outfitting; (b) Electric outfitting; and (c) Steel Work

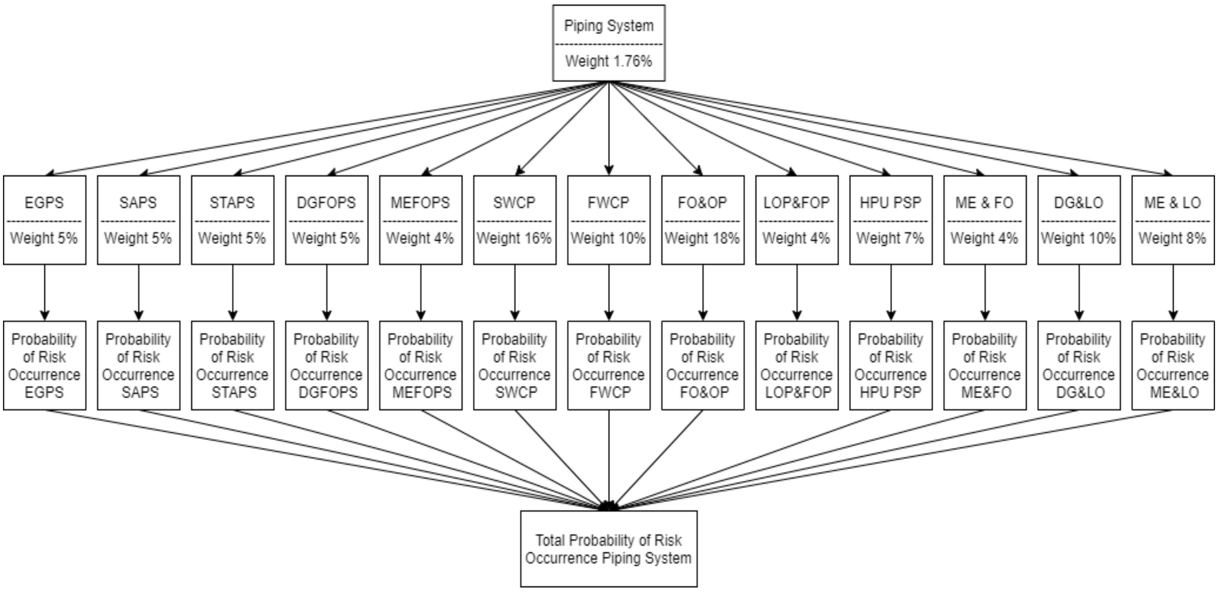


Figure 4 Bayesian network Piping system

In Figure 3(a), the Bayesian Machinery Outfitting (MO) network comprises 5 activities with the weight assigned to each factor. In Figure 3(b), the electrical outfitting network has 4 activities with the weight of each factor. Figure 3(c) represents the full outfitting block system and steelwork with 3 activities and the weight of each factor. Additionally, Figure 4 illustrates the piping system with 13 activities and the weight assigned to each factor. This also applies to the network model under the Hull Outfitting & Accommodation Outfitting Department and the network model under the Hull Construction Department. Bayesian probabilities for each point in the machinery outfitting (MO) workshop, steel work, electrical, electrical outfitting, and piping workshop based on the material network model can be found in Table 2.

Table 2 Probability of Bayesian network model in Machinery Outfitting

Activity	Probability	Weight Factor
Machinery Outfitting		
Fabrication & install instrument Tank	0.0000188	0.05
Install & loading equipment	0.0001015	0.27
Function Test Equipment E/R	0.0000564	0.15
Main Engine & propulsion equipment	0.0001692	0.45
Flushing & Other	0.0000300	0.08
Sub Total	0.0003760	1.00
Electric, Electrical Outfitting		
Steelwork (EO)	0.0001390	0.30
Wiring, Clamping & Compound	0.0002560	0.55
Installation Equipment	0.0000230	0.05
Connecting Cable	0.0000460	0.10
Sub Total	0.0004650	1.00
Steel Work		
Install ducting/ ventilator	0.0001800	0.45
Install grating/realing/ floor/leader	0.0001400	0.35
Install pondasi / machinery	0.0000800	0.20
Sub Total	0.0003900	1.00
Piping System		
Main Engine Lubricating Oil service and Hydraulic Power pack Unit piping system (ME & LO)	0.0000110	0,08

Table 2 Probability of Bayesian network model in Machinery Outfitting (Cont.)

Activity	Probability	Weight Factor
Piping System		
Diesel Generator Lubricating Oil service and Lubricating Oil transfer piping system (DG & LO)	0.0000130	0.10
Main Engine fuel Oil service transfer piping system	0.0000050	0.04
HPU piping system propulsion system (HPU PSP)	0.0000100	0.07
Lubricating Oil purifying & fuel oil purifying piping system (LOP & FOP)	0.0000059	0.04
Fuel Oil transfers and overflow piping system (FO&OP)	0.0000240	0.18
Fresh Water Cooling piping system (FWCP)	0.0000140	0.10
Sea water cooling piping system (SWCP)	0.0000220	0.16
Main Engine Fuel Oil service piping system (MEFOBS)	0.0000050	0.04
Diesel Generator Fuel Oil Service (DGFOBS)	0.0000070	0.05
Starting air piping system (STAPS)	0.0000050	0.04
Service air piping system. (SAPS)	0.0000065	0.05
Exhaust gas piping system (EGPS)	0.0000060	0.05
Sub Total	0.0001340	1.00

Bayesian probabilities for each point in the fabrication workshops, assembly and erection based on the material network model in Hull Construction Department be found in Table 3.

Table 3 Probability of Bayesian network model in hull construction

Activities	Probability	Weight Factor
Fabrication		
Marking	0.0000101883	0.05
Cutting	0.0001426360	0.70
Bending	0.0000407000	0.20
Handling	0.0000101883	0.05
Sub Total	0.0002037660	1.00
Assembly		
Preparation/Handling	0.000035252	0.10
Fitting	0.000211512	0.60
Welding	0.000070504	0.20
line heating	0.000035252	0.10
Sub Total	0.000352520	1.00
Erection		
Transporter process, block transferring	0.000044303	0.25
Back process, lift/loading block	0.000026582	0.15
Adjusting	0.000044303	0.25
Fitting & welding	0.000062024	0.35
Sub Total	0.000177214	1.00

Bayesian network model under the Hull Outfitting and Accommodation Outfitting Department includes Outfitting Manufacturing, Accommodation Packages in the Engine Room area, and Painting and Protection. Every detailed activity is carried out to calculate the opportunities in each workshop. The Bayesian probabilities for each workshop Outfitting Manufacturing, Accommodation Package in the Engine Room area, Painting, and Protection based on network design are shown in Table 4.

Table 4 Probability of Bayesian network model in painting and protection

Activities	Probability	Weight Factor
Painting and Protection		
Power tool	0.0001500	0.40
Final painting	0.0001300	0.35
Base painting	0.0000900	0.25
Sub Total	0.0003700	1.00
Outfitting Manufacturing		
Steelwork independent tank	0.0000170	0.20
Seat pump	0.0000250	0.30
Seat auxiliary engine	0.0000250	0.30
Seat Diesel Generator	0.0000080	0.10
Seat bearing	0.0000040	0.05
Overhead crane	0.0000040	0.05
Sub Total	0.0000830	1.00
Accommodation Package in the Engine Room Area		
Insulation	0.0000485	0.25
Lining	0.0000388	0.20
Ceiling	0.0000388	0.20
Cementing (deck Covering)	0.0000388	0.20
Vinyl	0.0000291	0.15
Sub Total	0.0001940	1.00

4. Discussion

The impact of risk occurrence is based on three factors, the scheduling factor for ship delivery, late or not. The cost factor is a manifestation of costs that must be incurred by the shipyard due to delays in the ship delivery schedule and company performance factors that will determine public confidence in the shipyard's performance and capabilities (this factor is difficult to determine to measure it). So that only scheduling and cost factors can be measured. Scheduling factors that cause engine room installation delays in anticipation of production delays require a risk analysis of the inhibiting factors during the production process, as follows: In the Machinery Outfitting (MO) and Electrical Outfitting (EO) Departments, the highest risk potential for wiring production activity, clamping and compound reaches a delay probability of (0.000256). This is due to the potential for revisions to delays in equipment installation, cable material, and cable cutting data lately, so it is necessary to coordinate with Production Control Planning, Design, and Supply Chain early. The Hull Construction Department has the highest potential risk of fitting activities reaching a delay probability of (0.000211512). The equipment installation was delayed because of the consists of one side welding machine being damaged, the Import Profile lately, and the block dimension accuracy nonappropriate, so initial coordination with the project, procurement division, accuracy and design team. The Hull Outfitting & Accommodation Outfitting Department has the highest potential risk of power tool activities reaching a delay probability of (0.00015). Repainting is necessary due to burn-age (welding and fairing), dust, worker dirt, and the difficulty of painting caused by the complex position of the area. To enhance the work method during the erection stage, it is essential to focus on maintaining, protecting the surface, and ensuring a high-quality paint finish. The delay in the installation of the engine room has an effect on the cost factor incurred by the shipyard. The delay in the schedule described in the shipping contract reached IDR 764,552,010,000 based on the contract agreement. Every 1-day delay will be fined 1 per mill with a maximum fine of 5% of the contract value. The calculation of the amount of the fine is by multiplying the number of days of delay multiplied by the value of the shipbuilding contract.

5. Conclusions

The method shown in this study is applicable to Zone 2 engine room installations of new buildings. However, there are some adjustments required for different types of shipbuilding projects. The risk identification and probability assessment is based on the engine room installation of project W000302. Therefore, little or no bias is introduced. The Bayesian network produced has provided a visual interpretation, cause and effect, which is very helpful in analyzing the risk potential of each activity. From the engine room installation activity, the highest potential probability is in the wiring production activity, clamping, and compound that reach a delay probability of (0.000256). This is due to the revision of drawings, which have the potential to delay the installation of equipment, late cable material, and late cable cutting data, so it is necessary to coordinate early with Production Control Planning, Design, and Supply Chain. This variable value causes a decrease in the performance of each workshop, which affects production delays in terms of production time, financial losses, and even the most severe contract cancellation.

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Authors Contributions

Intan Baroroh and Buana Ma'ruf contributed equally as the main contributors to this article. All authors have accepted responsibility for the entire content of this manuscript and approve the final article.

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