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PROBABILISTIC RISK ASSESSMENT OF THE SHIPYARD INDUSTRY USING THE BAYESIAN METHOD

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ABSTRACT
The shipbuilding industry is characterized by high-risk business activities; therefore, caution should be taken in its operational processes. From upstream to downstream, the shipbuilding industry depends on other industries. In this study, a risk assessment was conducted on the construction of new vessels using the Bayesian network approach; accordingly, the risk assessment was carried out using a probabilistic value at risk (VaR). The study was carried out by PT PAL Indonesia in association with the construction of a new tanker ship (building production codes M271 and M272). An analysis was conducted on three main components of new vessel construction—design components, material and production components, and sub-components of the previous two components. From the study, we could conclude that the probability of delay for new vessel construction caused by design delay is 0.05; the probability of delay caused by material delay is 0.65; and the probability of delay caused by production delay is 0.3. For delays caused by design factors, a yard plan is the sub-component that contributes predominantly to delays (i.e., probability of 0.3). For delays caused by material factors, the sub-component with the greatest impact is hull and machinery outfitting, with a probability of 0.3. For delays caused by production factors, the sub-component with the biggest impact is hull construction, with a probability of 0.39. Thus, we could conclude that a project delay would occur if the material component and the hull construction sub-components were not handled properly.

Keywords: Bayesian network; probability; shipyard industry

1. INTRODUCTION

The shipbuilding industry has attracted increased attention globally, corresponding to growth of the Chinese economy since 2003. A similar scenario has been observed in South Korea, which has experienced a 236% increase in shipbuilding orders over the last five years alone, with the rate of annual growth at about 5.2% per year. In 2006, 496 million CGTs (Compensated Gross Tonage) of new orders were received by South Korea, China, and Japan at 38.3%, 29.6%, and 13.9% shares, respectively (Lee et al., 2007). According to China Knowledge (in Basuki et al., 2010), shipbuilding industries in China received orders for new vessel construction amounting to about 4.1 million tons in July 2009. This amount is equivalent to approximately 70% of total worldwide orders for new vessels.

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According to data released by Lloyd's Register in the 2006 issue of Fairplay (in Basuki et al., 2012), China is the country with the largest number of orders for new vessel construction, with 1,480 units of construction already begun (i.e., 30.1%), followed by South Korea with 1,426 units (29%), Japan with 1,262 units (25.67%), and Indonesia with 68 units (1.38%).

There are several arguments for development of the shipbuilding industry in Indonesia, such as its economic value. The industry possesses a high value in the global sense as it is the mainspring industry for many supporting industries (Basuki et al., 2012). Hence, growth of the shipbuilding industry would facilitate the growth of other industries, thereby creating a multiplier effect for industrialization processes in certain countries. As an illustration applied to the construction of a new vessel, 50%–70% of the cost is intended for materials and equipment purchases. Furthermore, the shipbuilding industry is labor-intensive with a high employment prospect and considerable added values. As the shipbuilding industry continues to grow, independence of the defense sector could be achieved with the anticipated ability to produce our own military equipment.

The shipbuilding industry in Indonesia has been can be characterized according to the following (Basuki et al., 2010): capital-intensive, labor-intensive, slow yield, low added value, complex value chain, non-competitive, high-risk, low demand, high-tech, requires highly skilled personnel for ship design and fabrication, high import level with low level of local material content, low experience levels, and long-term delivery.

Although the shipbuilding industry is characterized as high-risk, there are only limited applications of risk management incorporated into the various production processes. Shipbuilding businesses in Indonesia are spread throughout this country with its variable regional characteristics, and a different risk is associated with each region. A risk-based production approach was adopted in conducting risk evaluations for shipbuilding businesses at strategic and operational levels (management levels). Basically, there are three main components of new vessel construction—design, material, and production processes. Each stage of the production process is characterized by risk at variable levels, including risks caused by design errors, material delays, work-related accidents, production process errors, and schedule deviations. Improperly anticipated risks could affect a company negatively with loss of opportunity and trust bestowed by ship owners. By implementing risk analysis, the impact of delays in new vessel construction was analyzed.

Since formal risk analyses have not been implemented commonly in the shipbuilding industry, this study represents an effort to assess the risk assessment process within Indonesian shipyards using PT PAL Indonesia as a case study. We noted that the majority of new vessels constructed in Indonesian shipyards are delayed to various degrees beyond their anticipated completion dates. Therefore, we aimed to assess the risk related to new vessel construction using a probabilistic approach combined with the Bayesian method.

Numerous risk assessment models have been developed over the years, especially in the nuclear, aerospace, and medical fields. Satoh et al. (2008) and Wreathall and Nemeth (2004) applied probabilistic risk assessment methodology to analyze the combination of fault and event trees. Several studies regarding probabilistic models describe Monte Carlo simulation (Abdullah et al., 2010; Kruizinga et al., 2008; Satoh et al., 2008). Deterministic and statistics methods in probabilistic risk assessment were also carried out by Kruizinga et al. (2008) and Bashiri (2010).

Analyses of risk assessment using the Bayesian approach were conducted by several researchers from various fields. Bayesian risk assessment in deterministic models was developed by Bonafede and Giudici (2007) and Kalantarnia et al. (2009). Additionally, analyses using the Bayesian approach to probabilistic risk assessment and model simulations have been developed by Kalantarnia et al. (2009). Further, dynamic models in Bayesian risk assessment were developed by Whitney et al. (2009) and Kalantarnia et al. (2009). Specific evaluations of risks within the shipbuilding industry based on the application of Bayesian networks and use of questionnaires have been conducted by Lee et al. (2009). These risk analyses were carried out for a large shipbuilding business and a medium-sized shipyard in South Korea. The data used were obtained from interviews and questionnaires completed by 252 experts from 11 large- and medium-scale shipbuilders. From the overall analysis, 26 types of risks that affect shipbuilding businesses of the sizes/scales described here were identified. The main risks include changes in design, manpower, and raw material supply (internal risks), and changes in interest rates (external risk). Researchers are still in the stage of risk identification; they have not reached the stage of risk assessment yet.

2. METHODOLOGY

2.1. Developed Risk Model

The risk terminology used in this study applies to the management level (as the analysis was conducted for operational risks); thus, productivity risk, technological risk, innovation risk, system risk, and process risk are included. The risk approach for each component of the production process was calculated using the following formula: Risk = probability of risk occurrence × consequence of risk occurrence. According to Ben-Azher (2008), the probability of risk occurrence is affected by three factors: the maturity factor (Pm), which reflects the likelihood of risk attributed to the development of new technology; the complexity factor (Pc), which reflects the likelihood of risk due to system development; and the dependency factor (Pd), which reflects the likelihood of risk due to dependency on facilities, contractors, etc. Consequences of risk occurrence are also affected by three factors: performance (i.e., degradation of work performance), cost (i.e., cost increase); and scheduling (i.e., deviation from set schedules).

2.2. Bayesian Network Model

Risk evaluation in the shipbuilding industry using the Bayesian network has been carried out by Lee et al. (2009) using the questionnaire approach. Every node on the network is not considered to have been analyzed until the VaR is obtained. A hazard analysis was developed from this particular study using the *n* to *n* correlation (not the *n* to *n*+1 relationship). For the present study, we have developed a method utilizing the Bayesian network with the *n* to *n*+1 hazard correlation to analyze every node's VaR value. Thus, we have utilized the probability concept in conjunction with application of the Bayesian method. In this study, the weight percentage of each factor was obtained from a sample of recorded historical data from Indonesian shipbuilding companies.

2.3. Problem-solving Utilizing the Bayesian Network

The analysis included an investigation of the hazard correlation (*n* to *n*+1) based on the *likelihood* value of each node in the network using a probabilistic approach. In the Bayesian network model developed in this study, a network for vessel construction includes design, materials, and production factors as partitions. Every partition would produce its own risk probability. A risk-based production concept utilizing the Bayesian network in shipbuilding industry is shown in Figure 1.

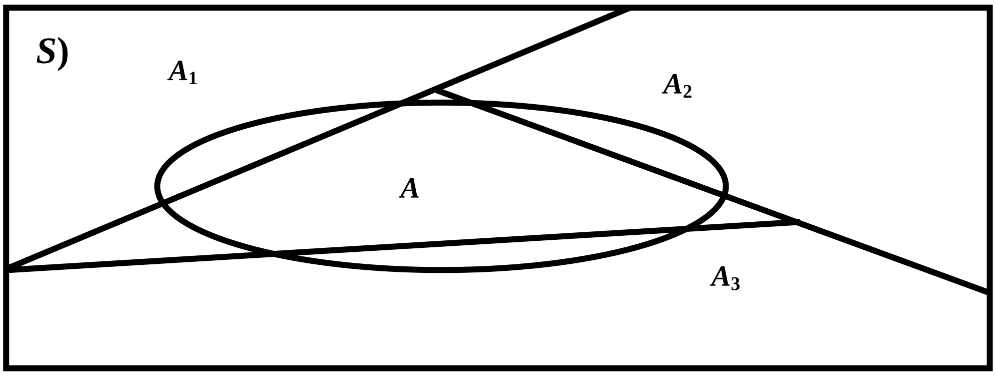

Figure 1 Bayesian partition concept for vessel construction

If $\{A_1, A_2, \ldots\ldots\ldots, A_n\}$ is a partition of sample room S and if the occurrences $A_1, A_2, \ldots\ldots\ldots, A_n$ have probabilities not equal to zero, the following probability is present:

$p(A) = p(A_1).p(A \mid A_1) + p(A_2).p(A \mid A_2) + \ldots\ldots\ldots\ldots + p(A_n).p(A \mid A_n)$, also written as:

$$p(A) = \sum_{j=1}^{n} p(A_j).p(A \mid A_j) \tag{1}$$

Using the required probability:

$$p(A_k \mid A) = \frac{p(A \cap A_k)}{p(A)} = \frac{p(A_k).p(A \mid A_k)}{p(A)} \tag{2}$$

then:

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

In other words:

$$p(A_k \mid A) = \frac{p(A_k).\,p(A \mid A_k)}{\sum_{j=1}^{n} p(A_j).\,p(A \mid A_j)} \tag{4}$$

where $k = 1,2,\ldots\ldots\ldots, n$; $j = 1,2,\ldots\ldots\ldots\ldots, i$
A : vessel construction process
A_1 : design; A_2 : materials; A_3 : production

The three factors (design, materials, and production) were also analyzed using the Bayesian method.

3. RESULTS

From the vessel construction processes observed during the course of this study (vessel production code numbers M271 and M272 at PT PAL Indonesia [Persero]), we analyzed the results and developed the following models: main network model, design network model, material network model, and production network model. In each model, VaR was valued for every node by utilizing the probability concept and applying the Bayesian method. The weight percentage of each factor was obtained from PT PAL Indonesia's historical data recordings.

3.1. Main Network Model

Main network model is first model developed in this study, a diagram of the main network model developed in this study is provided in Figure 2.

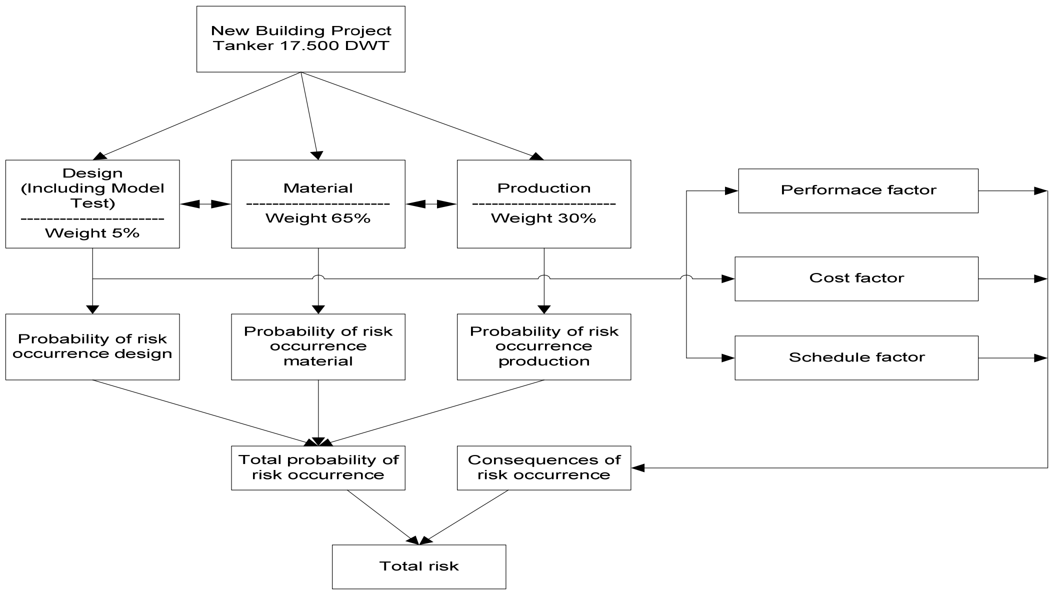

Figure 2 Main network model for the vessel construction process

The three main factors of vessel construction may be analyzed using the Bayesian network to obtain the probability delay value for each factor. The resulting probability value for each factor is the product of 1/3 (as there are three factors) and the weight of each factor (obtained from historical data, as explained previously). Probability values are shown in Table 1.

Table 1 Probabilistic value (VaR) of the main network

Component	Probability VaR	Bayesian Probability
Design (including model test)	0.017	0.05
Materials	0.217	0.65
Production	0.100	0.30
Total	0.334	1.00

3.2. Design (including Model Test) Network Model

Second model in this study is design (including model test) network model, a diagram of the design network model developed in this study is provided in Figure 3.

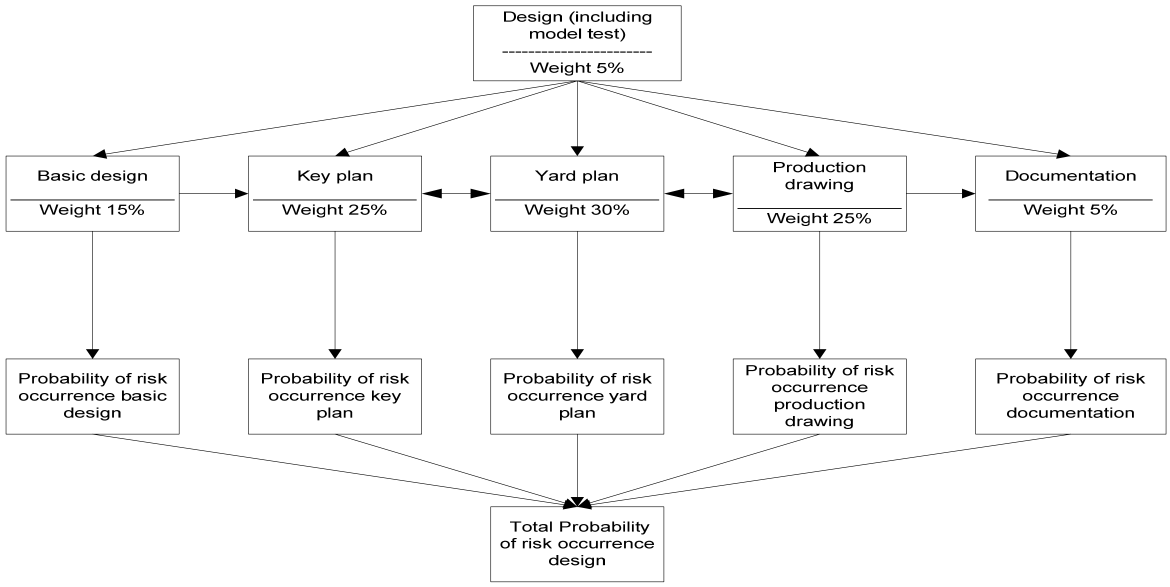

Figure 3 Design network model for vessel construction processes

The probability for each point (VaR) based on the design network is shown in Table 2.

Table 2 Probabilistic value (VaR) of network design

Sub-Component	Probability VaR	Bayesian Probability
Basic design	0.0005	0.15
Key plan	0.0008	0.25
Yard plan	0.0010	0.30
Production drawing	0.0008	0.25
Documentation	0.0002	0.05
Total	0.0033	1.00

3.3. Material Network model

Material network model is third model in this study, a diagram of the material network model developed in this study is provided in Figure 4.

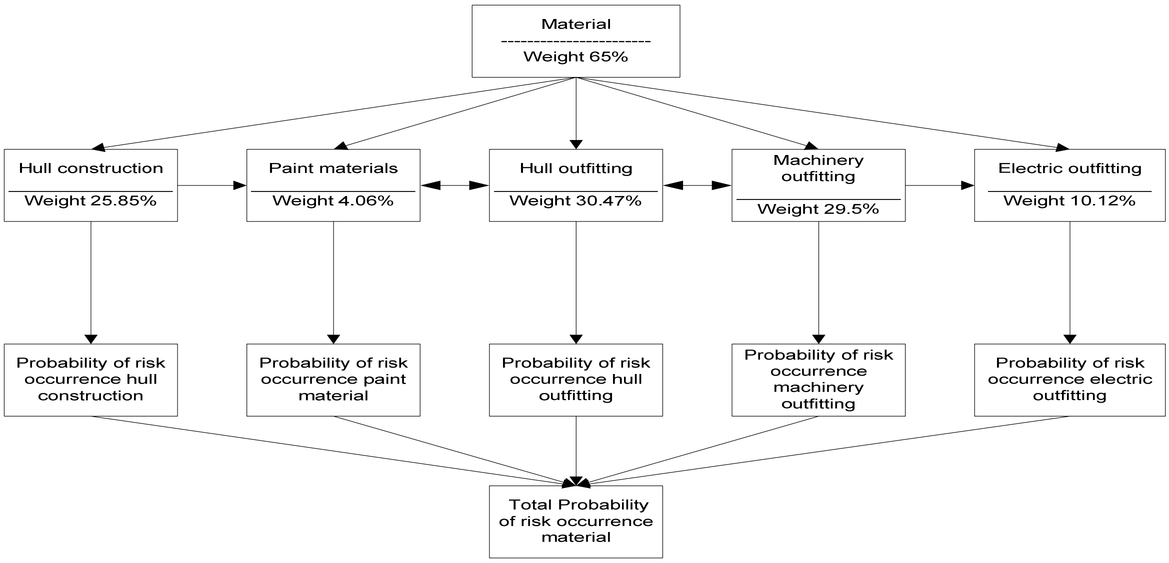

Figure 4 Material network model for vessel construction processes

The probability for each point (VaR) based on the material network model can be found in Table 3.

Table 3 Probability value (VaR) based on the material network model

Sub-Component	Probability VaR	Bayesian Probability
Hull construction	0.0110	0.26
Paint materials	0.0020	0.04
Hull outfitting	0.0130	0.30
Machinery outfitting	0.0130	0.30
Electric outfitting	0.0040	0.10
Total	0.0430	1.00

3.4. Production Network Model

The fourth model in this study is production network model, a diagram of the production network model developed in this study is provided in Figure 5.

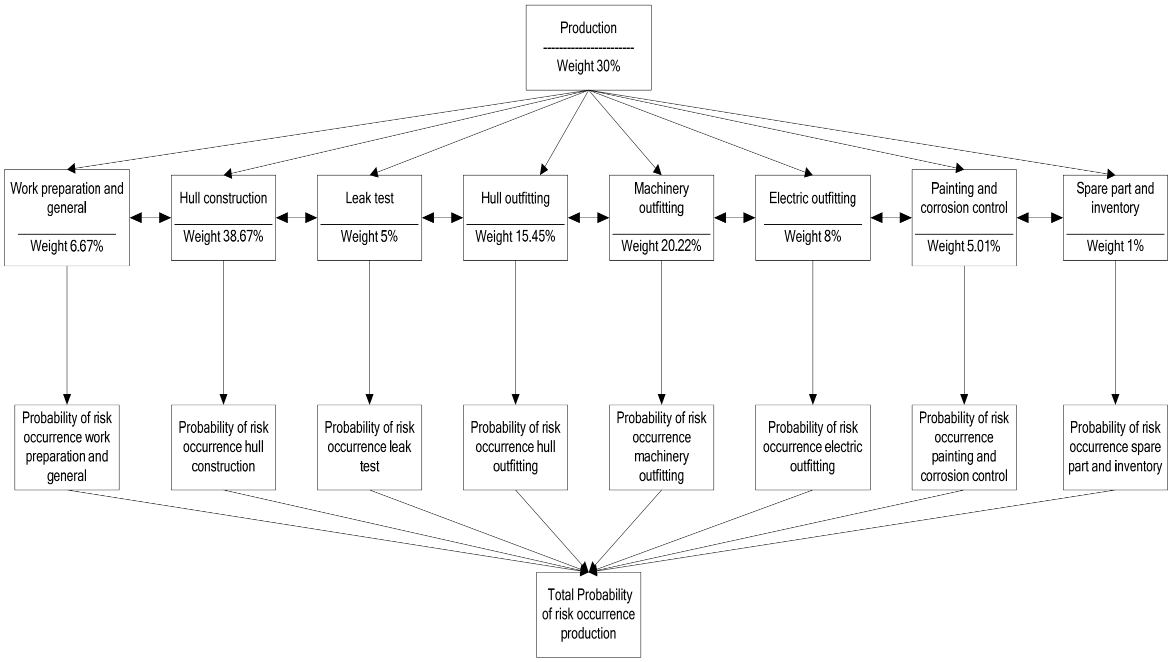

Figure 5 Production network model of vessel construction processes

The probability for each point (VaR) for the production network model can be found in Table 4.

Table 4 Probabilistic value (VaR) based on production network model

Sub-Component	Probability VaR	Bayesian Probability
Work preparation and general	0.0008	0.07
Hull construction	0.0048	0.39
Leak test	0.0006	0.05
Hull outfitting	0.0019	0.15
Machinery system	0.0025	0.20
Electric outfitting	0.0010	0.08
Painting and corrosion control	0.0006	0.05
Spare part and inventory	0.0001	0.01
Total	0.0123	1.00

4. DISCUSSION

The shipbuilding process consists of three major components—design, materials, and production. Design sub-components consist of the basic design, key plan, yard plan, production drawing, and documentation. Material sub-components are hull construction, paint materials, hull outfitting, machinery outfitting, and electrical outfitting. Work preparation, hull construction, leak test, hull outfitting, machinery systems, electrical outfitting, painting and corrosion control, and spare parts/inventory are production sub-components. From the modeling results, we can infer that the material and hull construction sub-components have the greatest probability of affecting the occurrence of project delays. As a result, hull construction sub-components should take precedent in vessel construction processes to prevent delays in construction schedules.

5. CONCLUSION

A VaR probability value and Bayesian probabilistic analysis has been conducted on each node of the vessel construction network model. From the results, we conclude that the Bayesian probability value for the main factors in vessel construction (specifically, production numbers M271 and M272) are, respectively, 0.65 for the material factor, 0.3 for the production factor, and 0.05 for the design factor. For the design component, the sub-component with the highest probability to cause project delays is the yard plan. For the material component, the sub-component with the highest probability for causing project delays is hull and machinery outfitting. For the production component, the sub-component with the highest probability of causing project delays is the hull construction process. Hence, a foremost priority should be given to the material factor in new vessel construction, as it has the greatest impact on schedule delays.

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