Risk Evaluation of Ferry in the Bali Straits using FMEA Method

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Abstract. Improving marine safety of transportation is very important. The Bali Straits is a strategic area that connects between Java island and Bali island. This strait is categorized as a busy strait. Bali straits also categorized as a tourist area. The strait separates Java Island (in the west) and Bali Island (in the east). The Bali Strait is connected by ferry services to the Gilimanuk Port (in Bali) and the Ketapang Port (in Java). Marine traffic safety has given benefit for life. Total ferry operating in one day is around 32 ferries. In this study we have analyzed and evaluated risk of maritime traffic. FMEA method was developed in this paper. RPN value was determined by considering the variables O (occurrence), S (severity) and D (detection). Development of scenario was established to analyze the behavior of the accident risks, with respect to changes in the surrounding traffic condition, meteorological and geographical.

1. Introduction

Improving safety in sea transportation is an important step that should be implemented. This will have an impact on the economic sector. Safety in sea transportation is the key to sustaining the success of other factors. This paper will discuss the risk evaluation on ferries in the Bali Strait. Regarding the safety in ferry transportation, ship operators are also required to improve services, including the safety equipment on board and so on.

The Bali Strait is a strait that separates Java island and Bali island. It is also connects the Indian Ocean and the Bali Sea. The coordinates of the Bali Strait are at -8° 05' 60.00" S and 114° 25' 29.99" E. The depths of the Bali Strait have intervals from 10 to 160 meters [1].

The Bali Strait is one of the important straits in Indonesia because Bali was categorized as tourism island. Transportation activities in the Bali Strait are carried out using ferries. The facilities used are Ketapang and Gilimanuk port facilities. The increasing volume of sea transportation activities is in line with the increasing tourism industry in Bali and Banyuwangi. This condition causes traffic density in the Bali Strait [1]. The high density has the risk of ship accidents such as ship collisions, fire and sinking which has a high level of consequences [2][3][4][5].

There are several factors that contribute to ship accidents. Some of these factors are ship condition, human error, weather, machinery or electrical failure and others [6] [7] [8]. In table 1 shows several
ships accident in the Bali Strait since 2010-2018. Table 1 shows some of the ferry accidents that occurred in the Bali Straits from 2010-2018. Table 1 shows the ship’s accidents. The ship accidents have occurred every 1-2 years in strait of Bali. So, a risk evaluation should be carried out. This paper will discuss the risk evaluation on ferries in the Bali Strait using the FMEA method.

Table 1. Ship’s accident in the Bali Straits

| Years | Type of Accident       |
|-------|------------------------|
| 2010  | Collision and grounding|
| 2013  | Sinking                |
| 2013  | Collision              |
| 2015  | Collision              |
| 2016  | Sinking                |
| 2017  | Collision and grounding|
| 2018  | Grounding              |

This study aims to conduct a risk evaluation using the FMEA method. Regarding the FMEA method, many methods are used to conduct risk evaluations. This paper uses the FMEA method to evaluate risks in sea transportation in the Bali Strait. Ferry is used as transportation in the Bali Strait. In the FMEA method, the risk level is obtained by determining the RPN value. RPN value is the result of multiplication between occurrence, severity and detection. In this context, 10 rating are used in the evaluation of risk resulting in an RPN value. The RPN value indicates the level of risk and serves as reference for risk mitigation.

FMEA method has proven to be very good which results in a level of risk by using RPN. The risk evaluation is very important as input to stakeholders in the Bali Strait to be more careful and give priority to safety [9].

2. Research Area

Figure 1 shows the Bali Straits. It is separates between Java Island (on the west) and Bali Island (on the east). The Bali Strait is connected by ferry services to the Gilimanuk Port (in Bali) and the Ketapang Port (in Java). The Bali Strait has quite beautiful underwater views. Therefore, the safety of sea transportation really needs to be improved. Risk evaluation is needed to carry out mitigation measures and provide information so that safety is always prioritized. Bali Strait is also a strait that has a density of transportation because Bali is a tourist area.

Figure 1. Bali Straits: Ketapang Ferry Port (A) and Gilimanuk Ferry Port (B)
Figure 1 shows the Ketapang ferry port (A) and Gilimanuk ferry port (B). Those port are key facilities in the Bali Straits. Enhancing safety of the ferry is an important step for the survival of the community and will support the economic, tourism and so on in the Bali Island and Banyuwangi island.

3. Method
FMEA is a methodology used to evaluate failures that occur in a system, design, process, or service. Identification of potential failures is determined by assigning score to each failure mode based on the level of occurrence, severity and detection rate [9]. In this paper, the FMEA method is implemented to evaluate risks on ferries as sea transportation in the Bali Strait. This method is effective because it will produce an accurate RPN value.

Risk priority number (RPN) value is the product of the occurrence, severity, and detection. RPN determines the priority of failure. This value is used to rank potential process failures. The RPN value could be shown by the following equation:

$$RPN = \text{Occurrence} \times \text{Severity} \times \text{Detection}$$  \hspace{1cm} (1)

Regarding occurrence in marine transportation, it could be defined as the possibility of an accident. This occurrence value is given for each cause of failure. Severity is defined as the effect of a failure or the effect of an accident on sea transportation. Detection could be defined as how far the cause of failure could be detected. Consists of a rating of 1-10. The estimation by expert using a scale from 1 to 10 could be shown in tables 2-4 [9].

There are several steps to determine FMEA method [10]:
- Determine the items analyzed.
- Determine the function of the item to be analyzed.
- Classifies and identifies all potential failure modes for objects.
- Establish and determine the causes for each potential failure mode.
- Determine and identify the effects of each potential failure mode.
- Make and determine appropriate recommendations based on the risk evaluation carried out.

After going through the process on all items for each failure, ranking the severity, occurrence and detection is determined. Failure modes with higher RPN are considered as more important and will be given higher priority for evaluation [10].

| Table 2. Rating of occurrence |
|-------------------------------|
| Rating of occurrence | Classification | Description |
|-------------------------|----------------|-------------|
| 9–10                    | Very High      | > 1 in 2     |
|                         |                | 1 in 3       |
|                         |                | 1 in 8       |
|                         |                | 1 in 20      |
| 7–8                     | High           | 1 in 80      |
|                         |                | 1 in 400     |
|                         |                | 1 in 2000    |
| 4–6                     | Moderate       | 1 in 15,000  |
|                         |                | 1 in 150,000 |
| 2–3                     | Low            | < 1 in 1,500,000 |
| 1                       | Remote         |              |
Table 3. Rating of severity

| Rating of severity | Classification | Description                                                                 |
|--------------------|----------------|-----------------------------------------------------------------------------|
| 9–10               | Very High      | Very serious effect on environment, asset and people.                        |
| 7–8                | High           | High effect on environment, asset and people.                                |
| 4–6                | Moderate       | Moderate effect on environment, asset and people.                           |
| 2–3                | Low            | Low effect on environment, asset and people.                                |
| 1                  | Remote         | Remote effect on environment, asset and people.                             |

Table 4. Rating of detection

| Rating of detection | Classification | Description                                                                 |
|--------------------|----------------|-----------------------------------------------------------------------------|
| 9–10               | Remote         | Remote in detecting potential failure or accident                           |
| 7–8                | Low            | Low in detecting potential failure or accident                              |
| 5–6                | Moderate       | Moderate in detecting potential failure or accident                         |
| 3–4                | High           | High in detecting potential failure or accident                             |
| 1–2                | Very High      | Very high in detecting potential failure or accident                        |

Table 2 shows the scale of occurrence value and its description according to FMEA standard. The scale is from 1-10. The table also shows a description of the condition of the remote to very high. Regarding severity, table 3 shows the severity values on a scale 1-10. For detection scale shown in table 4 from 1-10.

4. Result and Discussion

By using the FMEA method, the evaluation of risk in the Bali Strait has been carried out. In this study, 8 scenarios were conducted. The scenario is based on data that caused ship accident in the Bali Strait. By determining the RPN value, the risk level was determined. The value of occurrence, severity and detection is obtained from interviews with the crew and stakeholders in the Bali Strait. The interview was designed based on the FMEA method. The value given is based on FMEA standard and scale. The higher of occurrence value have the chance of an accident. The information about the level of risk was needed. It could be used to mitigate and provide input to stakeholders to improve the safety of ferries on marine traffic in the Bali Strait. The RPN values are shown in table 5.
Table 5. Risk level based on FMEA

| Scenario | Process                        | Occurrence | Severity | Detection | RPN  | Rank |
|----------|--------------------------------|------------|----------|-----------|------|------|
| 1        | Head on position               | 7          | 8        | 4         | 224  | 5    |
| 2        | Crossing position              | 9          | 8        | 5         | 360  | 3    |
| 3        | Overtaking Position            | 5          | 6        | 6         | 180  | 7    |
| 4        | Failure of Machinery and electricity | 4     | 6        | 5         | 120  | 8    |
| 5        | Human Error                    | 9          | 9        | 8         | 648  | 1    |
| 6        | Bad Weather                    | 8          | 9        | 7         | 504  | 2    |
| 7        | Ship condition                 | 7          | 7        | 4         | 196  | 6    |
| 8        | Visibility                     | 8          | 7        | 5         | 280  | 4    |

Human error leads in the first rank for ship accidents of ferry in the Bali Strait. Regarding human error, as shown in table 5, the occurrence value is 9, the severity value is 9 and the detection value is 7. The description of the scale on occurrence, severity and detection are shown in Table 2-4. Based on data from the Indonesian government, human error is the highest factor that contribute the ship accident. It was reaching 86%. Based on the FMEA method in the Bali Strait, human error also has the highest RPN value. So human error must be a major concern in the marine traffic.

As shown in table 5, bad weather has position in the second rank. The occurrence value is 8, severity is 9 and detection is 7 with a total RPN value of 2. Based on data, ship accidents that occurred in the Bali Strait were also caused by bad weather factors. Rank 3 is the crossing position. Crossing position is a position that have categorized as dangerous position in the marine traffic [11]. This condition requires carefully when the navigator navigate the ship. Overall, the RPN value is shown in table 5. The higher the RPN value have more the risk of ship accidents. Visibility in fourth position. The visibility is important factor in the safety of navigation.

The ship's condition has position in rank 6. The occurrence value is 7, the severity value is 7 and the detection value is 4. The total RPN value is 196. The ship's condition includes the age of the ship, the distance between ships, and the condition of the ship's performance. In the Bali Strait, old ferries are recommended to be replaced with new ones. This will increase ship safety and reduce the risk of ship accidents.

Then, overtaking is presented in position 7 with the occurrence value is 5, the severity value is 5 and the detection value is 6. The total RPN value is 180. This overtaking position requires the attention of the crew to avoid ship accidents or collisions. The position of head on, crossing and overtaking according to COLREG can be seen in Figure 2.
The lowest RPN rank is failure of machinery and electricity. Based on historical data, almost no accidents have been caused by machinery and electricity damage. Based on result of this evaluation, ship’s navigators at Bali Straits should take more carefully in navigating ferries. This result also could inform to the stakeholders in the Bali Straits. Other results could be shown in table 5.

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5. Conclusions
Risk evaluation on the traffic area in strait of Bali has been explored and determined using the FMEA methodology. FMEA is systematic methodology to evaluate risk and for enhancing safety. FMEA could provide an overview not only of what problems that occur but also the severity of the consequences and detection.

Based on evaluation results, human error has the highest RPN value. In fact, ship accidents in the strait of Bali are mostly caused by human error. Then, bad weather has a second RPN value. Several accidents in strait of Bali are caused by bad weather. The other result could be shown in table 5. For future work, we will develop a study of digital collision avoidance in dangerous waters areas.

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