Human Error Assessment of Situation Awareness in Bridge Operations: A Case Study of Indonesian Maritime Accidents

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Abstract. In the maritime industry, the role of human on-board operations is frequently cited in accidents report due to its relation to human error. Furthermore, according to the European Maritime Safety Agency, human error in bridge operations in the 2018 maritime accident cases due to lack of situational awareness has affected 65%. This study aims to assess the Indonesian maritime accidents concerning situational awareness in bridge operation in the collision, grounding, and sinking accidents by applying the new propose HRA method, Maritime Accidents Analysis and Reduction Technique (MAART). Finally, the forty-seven maritime accident data derived from the National Transportation and Safety Committee of Indonesia from 2008 to 2018 are assessed. In conclusion, Indonesian seafarers' situational awareness has to be given more concern because most of the analyzed accidents' causal factors show a lack of continuous monitoring, communication, and coordination on-board operation.

1. Introduction
Human and technology interactions in collaboration and interdependencies to achieve system purposes can be best described as complex socio-technical systems [1]. In the maritime industry, the role of human on-board operations is frequently cited in accidents report due to its relation to human error [2]. In recent technology development, the operator working on-board is the convenience with the introduction of automation. The automation helps seafarers process information and comprehend it before making critical decisions; however, it also unexpected consequences [3]. The convenience of automation frequently left the operator incapable of responding sufficiently to challenges posed by the system. This phenomenon is termed as "Out of the Loop" syndrome [4]. Situational Awareness (SA) definition, in general, is the operator's dynamic awareness of the progressing external situation [5]. The concept of SA was firstly brought by the aviation industry [6] and widely developed in the operation of a complex socio-technical system [7]. The maritime sector, especially on-board process, is a complex socio-technical system consisting of procedures, technologies, and personnel. This dynamic environment may cause accidents [8]. It is proven by the research conducted by EMSA and Grech et al., that more than 60% of human errors can be assigned to SA-related matter [9][10].

In this study, Indonesia's maritime accidents with a strong relation to SA condition, such as collision, grounding, and sinking, will be analyzed. There are 47 vessels studied that occurred in the period from 2008 to 2018 to determine the role of human factors that might have been related to the SA in maritime accidents. The new development method for analyzing human factors in maritime accidents, named Maritime Accident Analysis and Reduction Technique (MAART), is applied. This methodology is based on Human Error Assessment, and Reduction Technique (HEART) developed and adapted to analyze the human error probability in the maritime domain, especially for maritime accident analysis.
This study aims to assess the Indonesian maritime accidents concerning situational awareness in bridge operation in the collision, grounding, and sinking accidents by applying the new propose HRA method, MAART method.

2. Situational Awareness in the maritime industry

The SA on-board operation is required not only for the vessel's crew but also for the pilot who helps the vessel's pilotage to the berth and vice versa. Sharma et al. explained three levels of information requirements for pilotage [11], [12]. Level one is constructing the initial framework, such as information about the vessel's status, equipment status, route, traffic, and weather conditions. The role of communication on the bridge is crucial. It is related to the information sharing about vessel conditions, equipment status, and the weather condition that will be faced during the voyage. This information has to be shared with all the seafarers and all crews that will work on-board, so all the personnel on-board have the same shared mental model to form an accurate picture. Level two comprehends the vessel and system states and learns the effect of traffic and weather compared to planned and expected conditions. In this level, route planning, traffic, and weather conditions are further discussed. It needs good communication and good coordination among seafarers to prepare the plan and mitigate the risk of the voyage.

Moreover, in level three is projecting the information available to different conditions. Here, continuous monitoring from seafarers is critical. Because to project the situation well, the seafarer must process the information received before the voyage and process it with the additional information that faces during the voyage. With these ways, seafarers can create an excellent judgment to create an action to mitigate the risk that might be occurred. Therefore, managing a go communication is an essential dimension that prevents it from the source of misinformation and creates an ambiguous manner that can affect the seafarers working conditions [13], [14]. With recent technological advances in the navigation deck, the technology also provides SA-related information for the seafarers; thus, man-machine interactions are essential things on-board operation [15]. Good planning enables seafarers to minimize the risk. Knowing the probabilities of every condition that might face during the voyage, the seafarers can create the mitigation plan and scenarios to avoid undesirable events.

The human factor is an essential element to keep the SA safe because the loss of SA on-board operation is one of the immediate causes of the maritime accident [16]. According to the EMSA annual overview of marine casualties and incidents report in 2019, 66% of maritime accidents from 2011 to 2018 were attributed to human actions, whereas 65% occurred in on-board operations [10]. They further breakdown the on-board operation working failures into other sub-factors of human activities, such as inadequate training programs, design errors, risk assessment, inefficient procedures, planning and coordination, lack of knowledge, ineffective work methods, and situational awareness. It turns out that inadequate work methods and situational awareness were the two sub-factors most reported causing maritime accidents [10]. Therefore, it is essential to research the SA condition of the seafarers’ on-board operation, especially for the maritime accidents that are related to the SA, such as collision, grounding, and sinking.

3. Data and methodology

3.1. Data collection

There are two ways to gather the data that can be used for analyzing the accidents, first doing the investigation directly to the related parties in the accidents by conducting the interview, known as the primary data source. The data reports prepared by an official investigation board called the secondary data source. This secondary data source is reliable because it is created from primary data sources and analyzing first-hand information obtained by the accident investigator [17], [18]. Many kinds of research used the accident reports as the data sources for investigating the accidents in a particular maritime accident [19]–[21].

2
In this study, the maritime accident data reports were collected from the National Transportation and Safety Committee (NTSC) website. The data report that contained only from 2008 to 2018. Three maritime accident types are strongly related to SA of the seafarers on-board that analyzed is study, collision, grounding, and sinking accidents. In the collision accidents, the vessels involved in the accident were analyzed separately. Therefore the total number of vessels is more than the total number of cases.

| No. | Accidents Type | Cases | Vessels |
|-----|----------------|-------|---------|
| 1.  | Collision      | 14    | 24      |
| 2.  | Grounding      | 4     | 4       |
| 3.  | Sinking        | 19    | 19      |
|     | **Total**      | **37 cases** | **47 vessels** |

The accident reports that were thoroughly analyzed for this study were synopses, general information, analysis sections, and the conclusions. To minimize the subjectivity, the reviewers extracted the embedded information based only on the words that were written in the reports, avoiding further investigation and assumptions that could create subjective opinions. All the data were summarized and analyzed by using Microsoft Excel. The reports were all reviewed by researchers who are experts in the field of human factors.

3.2. **MAART methodology**

Maritime Accident Analysis and Reduction Technique (MAART) method is a methodological extension of the Human Error Assessment and Reduction Technique (HEART) as a qualitative and quantitative approach for human error probability calculation in maritime accident analysis which was introduced by[22]. In the MAART technique, the thirty-eight EPC that has been established by William [23] has been categorized into man, machine, media, and management factors because the thirty-eight EPC was still general, and every EPC are related to factors other than human. This categorization aims to make a better understanding that influences seafarers' conditions that lead to accidents. Furthermore, the MAART method also provides the quantification process to determine the value of the Affect Proportion Effect (APE) by utilizing the TOPSIS to minimize APE value's subjectivity.

Table 2 shows the generic task used in this study to determine the working condition on-board the operation at the moment of the accidents. There are nine GT to describe every task on-board from the unexpected action due to unfamiliarity with the situation which has the highest nominal human unreliability (NHU) to activity that responds to the system correctly even when there is an augmented or automated supervisory system providing an accurate interpretation of the system stage which has the lowest NHU. The assessor will select one of the GT that describes the working condition in the accident report. This selection also strongly relates to the weather condition. If the working conditions are the same in the two or more reports, but the weather conditions are different, it can influence GT selection. The more severe the weather condition, the GT that selected will have a higher value of NHU.

In the generic task, it can differ as a challenging task and convenience task. The challenging tasks consist of generic tasks A, B, and C, which in the description in Table 2, the seafarers do the tasks that required a high level of comprehension and skill, do the job without supervision or procedures from the shipping company to facilitate the seafarers. Worse, the seafarer has to face the task which they do knowing how to handle the task. Those conditions required good handling from the seafarer, which had been taught in the training and education process before working on-board. Due to the high importance of seafarers ability to encounter challenging conditions on-board, the failure to do so will cause a high probability of the accident occurrence.

Besides those three generic tasks, others are considered the convenience task, which the seafarers routinely do. Still, due to the lack of focus and attention, the task was a failure. Moreover, if the condition
was responded correctly and a familiar one, the accidents still can occur due to external factors. Nevertheless, the probability of this occurrence is lower. All of these conditions are explained and differed briefly in Table 2.

**Table 2.** Generic Tasks (GT).

| Code | Type of work | Condition |
|------|--------------|-----------|
| A    | Totally unfamiliar | Performing the work at speed with no real idea of likely consequences. |
| B    | Restore the system to an original state on a single attempt | Doing work without supervision or procedures. |
| C    | Complex task | It requires a high level of comprehension and skill. |
| D    | A fairly simple task | Performing the work rapidly or given scant attention. |
| E    | The routine, highly practiced, rapid task | Involving a relatively low level of skill. |
| F    | Restore a system to original | An error occurred even though following procedures with some verification. |
| G    | Entirely familiar, highly practiced, routine task occurring several times per hour, performed to the highest possible standards by a highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct the potential error | Without the benefit of significant job aids. |
| H    | Respond correctly to the system command | Even when there is an augmented or automated supervisory system providing an accurate interpretation of the system stage. |
| M    | Miscellaneous task for which no description can be found | |

Figure 1 shows the range of NHU value of every GT that has been defined before by the William in the HEART method first development. There are the minimum limitation which stated by the blue line, the maximum value stated by the green line, and the average value stated by the red line. In this study, the average value is used for the calculation process.

![Image of Figure 1: The value of NHU.](image)

**Figure 1.** The value of NHU.

After the selection of GT and determine the value of NHU, the next procedure is selected as the EPC – 4M. There are thirty-eight EPC that have been categorized into 4M factors (man, machine, media, and management) [18], [24] as shown in Table 3. Four main factors categorize into five sub-factors for the man and four sub-factors for management factors. In the table also shown the multiplication factors for every EPC – 4M that will be used for the HEP calculation as shown in the formula (14).

The SA condition on-board operation can be described well with the EPC – 4M. Many factors can influence the SA condition on-board operation. Machinery problems, weather conditions, and important
ones are human conditions. This human condition can differ as to the human element and human to human interactions, which can be mentioned as management factors. All EPC – 4M in communication, coordination, and monitoring subfactors are strongly related to the SA. As mentioned in the previous section, there are three preparation levels for the voyage to maintain good SA [11], [12]. The first level is constructing the initial framework. The EPC – 4M in the communication sub-factors can describe the first level of SA well. In the second level, the seafarers comprehend all the information received on the first level and create the best plan to safely and successfully achieve the goal. The EPC – 4M in the communication sub-factors and coordination sub-factors can represent the second level's causal factors. The third level of SA is projecting all the information in the first and second level. Communications, coordination, and monitoring are essential factors for keeping the SA effective.

| Man Factors | × | Media Factors | × |
|-------------|---|--------------|---|
| **Physical limitations** | | | |
| EPC 27 Physical capabilities | 1.4 | EPC 33 Poor environment | 1.15 |
| EPC 36 Task pacing | 1.06 | | |
| EPC 38 Age | 1.02 | EPC 13 Poor feedback | 4 |
| **Psychological limitations** | | | |
| EPC 21 Dangerous incentives | 2 | EPC 14 Delayed/incomplete feedback | 3 |
| EPC 28 Low meaning | 1.4 | EPC 16 Impoverished information | 3 |
| EPC 29 Emotional stress | 1.3 | EPC 18 Objectives conflict | 2.5 |
| EPC 31 Low morale | 1.2 | EPC 19 No diversity of information | 2.5 |
| EPC 34 Low mental workload | 1.1 | EPC 2 Time shortage | 11 |
| **Experience** | | | |
| EPC 1 Unfamiliarity | 17 | EPC 6 Model mismatch | 8 |
| EPC 12 Misperception of risk | 4 | EPC 10 Knowledge transfer | 5.5 |
| EPC 22 Lack of experience | 1.8 | EPC 24 Absolute judgments required | 1.6 |
| **Skill and Knowledge** | | | |
| EPC 7 Irreversibility | 8 | EPC 25 Unclear allocation of function | 1.6 |
| EPC 9 Technique unlearning | 6 | EPC 37 Supernumeraries/ lack of human resources | 1.03 |
| EPC 11 Performance ambiguity | 5 | EPC 17 Inadequate Checking | 3 |
| EPC 15 Operator inexperience | 3 | EPC 26 Progress tracking lack | 1.4 |
| EPC 20 Educational mismatch | 2 | EPC 4 Features over-ride allowed | 9 |
| **Health** | | | |
| EPC 30 Ill-health | 1.2 | EPC 5 Spatial and functional incompatibility | 8 |
| EPC 35 Sleep cycles disruption | 1.1 | EPC 32 Inconsistency of displays | 1.2 |
| **Machine Factors** | | | |
| EPC 3 Low signal-noise ratio | 10 | | |
| EPC 8 Channel overload | 6 | | |
| EPC 23 Unreliable instruments | 1.6 | | |

Furthermore, to obtain the APE weight for every selected EPC – 4M it applied the TOPSIS calculation in the MAART method. This calculation tool is utilized to minimize the subjectivity in obtaining the APE weight. The Saaty's 1–9 linguistic relative importance scale is used [25], as shown in Table 4. These importance scales will be used by the accidents accessor to determine the importance among the selected EPC, to know about the interdependencies among it.

| Importance scale | Definition | Importance scale | Definition |
|------------------|------------|------------------|------------|
| 1                | Equal importance | 7               | Extreme importance |
| 3                | Moderate importance | 9               | Absolute extreme importance |
| 5                | Strong importance | 2, 4, 6, 8      | Intermediate values |
1. A pair-wise comparison matrix (D) can be established following Formula (1). In the formula, \( x_{ij} \) (\( i = 1, 2, \ldots, m \), \( j = 1, 2, \ldots, n \)) has the relative importance of the \( i \)th element compared to the \( j \)th. In this study, every selected EPC will be compared to the other selected EPCs to determine the interdependencies of EPCs. By comparing these EPCs, it can be observed that every EPC is related to each other, and there will be a tendency for an EPC to be a major factor in an accident.

\[
D = \begin{bmatrix}
x_{11} & x_{12} & \cdots & x_{1n} \\
x_{21} & x_{22} & \cdots & x_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix}
\] (1)

\( x_{ii} = 1 \), \( x_{ij} = 1/x_{ji} \), \( x_{ji} \neq 0 \)

2. The normalized decision matrix is constructed and weighted.
   a. Normalized decision matrix
   To construct the normalized decision matrix, first, the attribute weight (\( w_i \)) for each EPC\( i \) must be obtained by utilizing Formula (2).

\[
w_i = \sqrt{\frac{\sum_{j=1}^{m} x_{ij}^2}{m}}
\] (2)

After obtaining the attribute weight, the normalized decision matrix (\( r_{ij} \)) is constructed by dividing the value from the pair-wise comparison matrix to the attribute weight, as shown in Formula (3).

\[
r_{ij} = \frac{x_{ij}}{w_i}
\] (3)

b. Weighted normalized decision matrix.

\[
p_{ij} = r_{ij} \times x_{ij}
\] (4)

3. The ideal and negative ideal solutions are determined.
   a. Ideal solution

\[
d_{i+}^{ij} = (p_{ij} - p_{i max})^2
\] (5)

b. Negative ideal solution

\[
d_{i-}^{ij} = (p_{ij} - p_{i min})^2
\] (6)

4. The separation from the ideal solution is determined.

\[
d_{i+} = \sqrt{\sum_{j=1}^{n} (d_{i+}^{ij})^2}
\] (7)

5. The separation from the negative ideal solution is determined.

\[
d_{i-} = \sqrt{\sum_{j=1}^{n} (d_{i-}^{ij})^2}
\] (8)

6. Relative closeness to the ideal solution.

\[
\xi_i = \frac{d_{i-}}{d_{i+} + d_{i-}}
\] (9)

7. Normalization.
The summation of all the EPC ideal solution values is not one; it is often more than one and sometimes
even less than 1. Thus, it needs to be normalized before using this value for the HEP calculation. The last value used in the HEP calculation is the normalization value (N) to be the APE weight. This value shows which EPC has the highest value of the importance, which implicates this is the main factor of the accident because its particular EPC is the most important compared with other EPCs. If the weight is approved, then it can be used for the HEP calculation. Therefore, in this study, EPC's highest value was named the top of the EPC series. Formula (10) shows the calculation formula for the normalization value.

$$N = \frac{x_i}{\sum x}$$

8. Consistency verification
The next step proves the consistency of the data. This step verifies whether the comparison pair-wise matrix is consistent or not. The consistency index (CI) can be calculated using the following formula:

$$\sum_{j=1}^{n} x_{ij}N = \lambda_{max}N_i$$

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

A consistency verification calculation is needed to specify a reasonable consistency. The consistency ratio (CR) value was \(\leq 0.10\). Otherwise, expert judges will be revised to obtain consistent results.

$$CR = \frac{CI}{RI}$$

In the equation, RI stands for a random index. It is subjected to several items that are compared in the matrix. The RI values are provided in Table 5. The RI values will be used to calculate the CR value. This RI value shows the number of selected EPC in a case. The number of selected EPC in every case is varied, so the RI in every case is different.

| n  | 1 | 2 | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----|---|---|----|----|----|----|----|----|----|----|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

The formula for HEP calculation is shown in the formula (14). The HEP calculation components in the MAART method are NHU, which can be obtained when selecting the generic task, the multiplication value in the EPC, and APE's weight.

$$HEP = NHU \times \{(\prod_i{(EPC_i - 1)} \times APE_i + 1)\}$$

4. Results
The maritime accidents (collision, grounding, and sinking) in Indonesia will be different by three explanations. The working type of accidents, the EPC – 4M that involve, and the EPC series before accidents.

4.1. Working type
In these results of working type, it explains about the navigation condition and situation before accidents. There are five GT types obtained from all 47 vessels that were analyzed in this study. Table 6 shows GTs result for every kind of accident and stated in the number of cases. A detailed explanation of every selected GT can be found in the previous section. The GT for every type of accidents show a different result. In collision accidents, the accidents occurred in the C, D, E working type, where mostly it occurred in the E generic task, which occurs in the routine task.
Furthermore, only 4 cases occurred in the C working type, where it is stated as a complex task that requires a high level of skill and competency. In grounding accidents, the results for four cases analyzed are even in the four types of GT as follow, generic task A, C, D, and E. Moreover, the results for the sinking accidents is also different from the other two accidents. There are five types of generic tasks discovered in the sinking accidents: generic tasks A, B, C, D, and E. The most occurrence sinking accidents are found when the seafarers on-board faced a complex task that required a high level of skills.

In contrast, it also occurred in a fairly simple task but performing the work rapidly or given scant attention. From all cases, the highest percentage for working type condition that the accidents occurring is the routine, highly practiced, rapid task involving low level of skill. There are 22 vessels in the Indonesian maritime accidents that occurred due to GT E, following by generic task C, D, A and B.

Table 6. GT obtained in Indonesian maritime accidents.

| Accidents   | A  | B  | C  | D  | E  | Total |
|-------------|----|----|----|----|----|-------|
| Collision   | 0  | 1  | 4  | 2  | 18 | 24    |
| Grounding   | 0  | 0  | 1  | 1  | 1  | 4     |
| Sinking     | 2  | 2  | 6  | 6  | 3  | 19    |
| All         | 3  | 2  | 11 | 9  | 22 | 47    |

4.2. Situational Awareness Factors

Table 7 shows the EPC – 4M found in 47 vessels analyzed by using the MAART method. In total, there are 215 EPC – 4M found, with the distribution as follows collision accidents have 104 EPC – 4M, grounding has 20 EPC – 4M, and sinking accidents has 91 EPC – 4M. In the table, the information is written from the most occurrence factors in all accidents. Besides, there are thirty-one EPC – 4M out of thirty-eight EPC – 4M, which distribution as follows, fourteen EPC – 4M in the management factors, fourteen EPC – 4M in man factors, two machine factors, and media factor. Every accident analyzed has different factors and differs from which EPC – 4M occurred in the accidents.

There are twenty-three of thirty-eight EPC-4M found for twenty-four vessels analyzed in the collision accident, where the most common factors are management factors in the monitoring sub-factors. EPC 17 and EPC 26 of EPC – 4M in the monitoring factors are the most common collision accidents. The machinery problem is not a factor causing collision accidents. There are several factors that only found in the collision accidents, such as EPC 13 for poor feedback, EPC 37 for lack of human resources, EPC 29 for emotional stress and EPC 35 for ill health. Furthermore, EPC 5, EPC 15, EPC 6, EPC 14, EPC 25, EPC 8, and EPC 31 were not found in the collision accidents unlike in the grounding and sinking accidents. Moreover, only one case has poor environment as the factor for accidents occurrence in the collision accidents. It means that the rest of the accidents occurred during fine day and good visibility.

There are fourteen of thirty-eight EPC-4M found in the four analyzed cases of grounding accidents in Indonesia. Moreover, management problem in total has the highest cases comparing with other factors. Lack of monitoring, poor coordination, and inadequate communication during working on board operation, causing the grounding accidents in Indonesia. Unlike with the collision accidents, poor environment in the grounding accidents is causing 50% of the total cases.

In sinking accidents, the management factors still dominated the causing factors of the accidents. Monitoring subfactors has the highest number of causal factors found in the cases, following by the inadequate communication and poor coordination. Unlike other maritime accidents, sinking accidents has the highest number of machine factors. Almost 50% of the sinking accidents were caused by the unreliable instrument and machinery on board. Furthermore, the ability of the seafarer for skill and knowledge in the sinking accidents were poorer than other accidents.
4.3. Human Error Probability

Table 8 presents the calculation process of the HEP result for collision accident case number one. The GT that was selected for the condition before the accident is a complex task that requires a high level of comprehension and skill, which has an NHU of 0.16. The reason why this case has generic task C is because it enters the Madura strait without guidance from a local tug boat, whereas in the regulations, this ship must use a tug service to enter the Madura Strait shipping channel. Table 8 presents the EPC series in case one, which has EPC 21 as the top of EPC series, followed by EPC 12, EPC 11, EPC 29, and EPC 1.

Furthermore, in Table 8 it shows the multiplication factors that belongs to every EPC – 4M, the detail of this information can be derived in the previous chapter. Moreover, the value APE of every EPC – 4M is determined by using the TOPSIS calculation process, by determining the interdependencies among selected EPC – 4M factors by using the Saaty’s importance scale and using all the calculation formula in the TOPSIS. The value of the APE weight calculation can be processed further if it passed the requirements, Consistency Ratio (CR) is below or equal to 0.1. if the number is exceed 0.1, then the pair-wise comparison matrix has to be re-analyze again. In the example below, the number of CR is 0.061, since the CR value is < 0.1, so the value can be used and it is stated in the table below.
Table 8. HEP Calculation.

| TOP | BODY |  |
|-----|------|---|
|     | EPC 21 | EPC 12 | EPC 11 | EPC 29 | EPC 1 |
| ×   | APE   | ×   | APE   | ×   | APE   | ×   | APE |
| 2   | 0.47  | 4   | 0.32  | 5   | 0.11  | 1.3 | 0.09 |
|     | 17    | 0.003 | 0.71  |

In Table 9, there is the information about the year and date of the collision accident occurrences. As mentioned in the data section, two vessels involve several cases of collision accidents. It is stated with the same case number. The EPC series consists of TOP EPC, which has the highest weight of APE and followed by the rest of EPC -4M, respectively. The number of EPC -4M in every case is different, it is because of the condition and complexity of information that provide in the case itself. The average of the HEP value for collision is 18%.

Table 9. Collision's HEP Value.

| No. | Year | Date | Top EPC | EPC | EPC | EPC | EPC | EPC | EPC | HEP |
|-----|------|------|---------|-----|-----|-----|-----|-----|-----|-----|
| 1   | 2009 | 22-M | 21      | 12  | 11  | 29  | 1   |     |     | 0.71|
| 2   | 2010 | 19-M | 13      | 17  | 26  | 2   | 11  | 37  |     | 0.14|
| 2   | 2010 | 19-M | 12      | 20  | 17  | 2   |     |     |     | 0.14|
| 3   | 2010 | 2-Jun| 29      | 17  | 26  | 24  | 28  |     |     | 0.04|
| 3   | 2010 | 2-Jun| 13      | 10  | 26  | 2   | 17  | 22  |     | 0.2 |
| 4   | 2010 | 4-Aug| 20      | 22  |     |     |     |     |     | 0.04|
| 4   | 2010 | 4-Aug| 12      | 17  | 28  | 20  | 11  | 18  | 26  | 34  | 0.09|
| 5   | 2011 | 18-Mar| 16     | 13  | 12  |     |     |     |     | 0.1 |
| 5   | 2011 | 18-Mar| 22     | 17  | 12  | 20  | 37  | 34  | 11  | 2   | 0.06|
| 6   | 2011 | 26-Sep| 9      | 22  | 12  | 33  |     |     |     | 0.52|
| 6   | 2011 | 26-Sep| 17     | 22  | 26  | 37  | 34  |     |     | 0.21|
| 7   | 2012 | 26-Sep| 11     | 13  | 12  |     |     |     |     | 0.16|
| 7   | 2012 | 26-Sep| 26     | 13  | 21  | 10  | 11  |     |     | 0.06|
| 8   | 2012 | 11-Dec| 34     | 10  | 21  | 19  |     |     |     | 0.57|
| 9   | 2013 | 31-May| 26     | 12  | 16  | 23  |     |     |     | 0.07|
| 9   | 2013 | 31-May| 36     | 26  | 12  | 17  |     |     |     | 0.04|
| 10  | 2014 | 1-Apr | 17     | 18  | 21  | 22  | 23  | 10  | 16  | 0.56|
| 11  | 2016 | 19-Nov| 26     | 17  | 36  | 23  | 37  |     |     | 0.29|
| 11  | 2016 | 19-Nov| 26     | 23  | 17  |     |     |     |     | 0.03|
| 12  | 2017 | 7-Apr | 26     | 13  | 17  |     |     |     |     | 0.06|
| 12  | 2017 | 7-Apr | 26     | 13  | 17  |     |     |     |     | 0.06|
| 13  | 2018 | 22-May| 37     | 35  | 34  |     |     |     |     | 0.02|
| 14  | 2018 | 19-Jul| 17     | 13  |     |     |     |     |     | 0.09|
| 14  | 2018 | 19-Jul| 13     | 23  |     |     |     |     |     | 0.07|

Table 10 is the EPC series and HEP value for four cases of grounding accidents. The average of the HEP value for grounding is 48%. The number of EPC – 4M selected in every case varies; it depends on the cases' complexities. The case number 4 in the grounding accidents has the HEP value 1. It means that it definitely because of human factors. This value can occur if the selected generic task has a higher NHU value, which is had by the challenging task and needs a high level of comprehension and skill to do the task.
Table 10. Grounding's HEP Value.

| No. | Year | Date   | Top EPC | EPC | EPC | EPC | EPC | EPC | EPC | HEP |
|-----|------|--------|---------|-----|-----|-----|-----|-----|-----|-----|
| 1   | 2016 | 22-Dec | 19      | 16  | 10  |     |     |     |     | 0.07 |
| 2   | 2017 | 12-Jun | 17      | 23  | 5   | 33  |     |     |     | 0.74 |
| 3   | 2018 | 20-Feb | 24      | 5   | 36  | 12  | 10  | 17  | 22  | 0.63 |
| 4   | 2018 | 10-Aug | 21      | 15  | 9   | 33  | 23  |     |     | 1   |

Table 11 shows the EPC series and HEP value of sinking accidents in Indonesia from 2008 to 2018. The average of the HEP value for sinking is 43%. In the sinking accidents EPC series, in some cases, it shows that the main factors of the accidents are not because of the lack of communication, monitoring, and coordination but machinery problems. Furthermore, machinery problems are also found in other sinking cases as one factor that leads to accidents.

Table 11. Sinking's HEP Value.

| No. | Year | Date   | Top EPC | EPC | EPC | EPC | EPC | EPC | EPC | HEP |
|-----|------|--------|---------|-----|-----|-----|-----|-----|-----|-----|
| 1   | 2008 | 17 May | 22      | 1   |     |     |     |     |     | 1   |
| 2   | 2009 | 11-Jan | 15      | 20  | 22  | 2   |     |     |     | 1   |
| 3   | 2009 | 22-Nov | 8       | 9   | 5   | 16  | 15  | 26  | 18  | 0.37 |
| 4   | 2010 | 6-Mar  | 22      | 16  | 10  | 14  | 15  | 5   |     | 0.12 |
| 5   | 2011 | 27-Aug | 16      | 12  | 23  | 24  |     |     |     | 0.94 |
| 6   | 2013 | 24-Dec | 23      | 24  | 19  |     |     |     |     | 0.14 |
| 7   | 2013 | 3-Jul  | 17      | 16  | 19  | 26  | 1   |     |     | 0.94 |
| 8   | 2014 | 26-Aug | 22      | 14  | 26  |     |     |     |     | 0.22 |
| 9   | 2014 | 3-Jan  | 17      | 26  | 14  | 11  | 24  |     |     | 0.91 |
| 10  | 2016 | 14-Oct | 26      | 12  | 17  | 23  |     |     |     | 0.27 |
| 11  | 2016 | 4-Mar  | 6       | 22  | 26  | 9   | 19  | 21  | 17  | 0.71 |
| 12  | 2016 | 13-Dec | 17      | 21  | 6   | 25  | 26  | 18  |     | 0.13 |
| 13  | 2016 | 29-Dec | 16      | 23  | 22  | 5   | 33  |     |     | 0.71 |
| 14  | 2017 | 20-Mar | 28      | 17  | 23  |     |     |     |     | 0.38 |
| 15  | 2017 | 6-May  | 23      | 26  | 33  |     |     |     |     | 0.14 |
| 16  | 2017 | 17-Sep | 21      | 23  | 34  |     |     |     |     | 0.31 |
| 17  | 2018 | 3-Jan  | 26      | 12  | 9   | 24  | 6   | 5   |     | 1   |
| 18  | 2018 | 27-Jan | 9       | 15  | 20  | 23  | 25  | 5   |     | 0.12 |
| 19  | 2018 | 18-Jun | 17      | 20  | 18  | 5   | 15  | 23  | 33  | 0.99 |

The HEP value of collision accidents is lower than the grounding and sinking accidents. The generic task selected for collision accidents is mostly E generic, which has lower NHU value than other selected generic tasks.

5. Discussion and Considerations

In Indonesia, maritime transportation plays a vital role in Indonesia's social-economic situation as an archipelagic country. However, the safety of maritime transportation in Indonesia is needed to be improved in specific ways. The analysis results show that most of Indonesia's accidents were routine jobs requiring low-level high skill. In the generic task that belongs to MAART, nine GT describes the working condition on-board, where three out of nine are considered the difficult task under challenging situations. The three GT includes in this explanation are GT A, B, and C. The working type is working in terrible weather and traffic condition and terrible bridge team condition on sailing.

Furthermore, the rest of the GT is considered a convenient working type because it occurred in the routine task and only needs a low level of skill. The seafarers have much training in the situations. However, in this study, most of the maritime accidents analyzed in this study show that accidents occurred in the convenience condition, which they should control adequately. Based on EPC – 4M, the required information regarding the causal factors affecting Indonesian maritime accidents can be found,
especially the SA condition factors. Factors that lead the accidents in Indonesia are management, man, and machine problems. In the management factors, lack of monitoring, communication, and coordination while working on-board are the traits and increase the probability of accident occurrences. Furthermore, most of the accidents occurred in a conducive weather condition. It means that mostly the accidents occurred due to a lack of maintaining the progress voyage.

As explained by Endsley [12], the three levels of SA requirements on-board, according to the EPC – 4M factors, every level of it can be represented by the EP – 4M sub-factors. In the first level, where all the information has to be collected and shared with the rest of the crew on-board to have a shared mental model, communication is essential. For instance, the information about upcoming weather conditions during the voyage must be checked well before departure. The seafarers can plan the mitigation to avoid or minimize the bad weather's impact on the vessel. In the second level of SA condition, comprehends the vessel and system states and learns the effect of traffic and weather on planned and expected conditions requires good communication and good coordination. For this level, the seafarers on-board, whether it is the bridge team or the bridge team, and pilot, have actively checked the actual traffic by using all available means to prevent the accidents. The seafarers rely not only on the plan themselves but also on the actual situation that might sometimes be different. Active and effective communications while monitoring the voyage are essential to inform about the traffic situations and the vessel conditions; they help all the crew on the bridge coordinate well.

Furthermore, in the third level, projecting the information available to different conditions, continuous monitoring tasks, and coordination is crucial. Most of the collisions are occurred due to the failure to continuously monitoring the voyage, mainly when they sailed in the good weather. They are lulled by the conditions they think are safe, so they relax their attention to continue to monitor the situation. It also found out that the machinery problems had taken place in most of the accidents. From forty-seven vessels analyzed, seventeen vessels with unreliable machinery conditions, which occurred mostly in the sinking accidents, even became the main factor of the sinking accidents. The shipping company and the seafarers on-board have to give more concern to the maintenance schedule and its quality.

The MAART method is a proposed method in the extension of the HEART methodology that has been established by William in the 1980s. The HEART methodology is a robust method that helps assessors analyze the accidents based on qualitative and quantitative processes in a single method. However, due to its first development in the nuclear power plant analysis, it needs some adjustments to analyze other industries, especially the maritime industry. The application of MAART in Indonesian maritime accidents suggests the relation between EPC and the 4M factors, making a better understanding of which related factors cause accidents.

The difficulty in conducting this study is that the availability of maritime accident reports that can be accessed openly from the NTSC official website is limited. The larger number of reports that can be accessed will contribute to the more significant validation of the results. Regardless, these are the implications that can be drawn from these findings. First, the information about SA derived through to EPC – 4M can improve seafarer's workplace habits and shipping company procedures for the operation and machine maintenance. Second, the MAART method can be utilized well to analyze maritime accidents. Furthermore, it can provide information regarding the accidents' causal factors and the human error probability value. This value can be based on the authorities to set the mitigation action and judge for better policy. Understanding the maritime accidents' causal factors can derive more information that the maritime stakeholders can learn from the accident analysis [11].

6. Conclusion

The study explored Indonesian maritime accidents involving the SA theory and the seafarers working type in the accident's occurrences. This study aims to assess the Indonesian maritime accidents concerning situational awareness in bridge operation in the collision, grounding, and sinking accidents by applying the new propose HRA method, MAART method. In conclusion, Indonesian maritime society has to give more concern to seafarers' quality on-board by giving them more training to encounter
the undesirable conditions and the quality of machinery, whether it is the main engine or the supporting machinery. Furthermore, the application of the MAART method to analyze maritime accidents concerning SA can perform well. The EPC – 4M that consists of the MAART method can breakdown the causal factors in the maritime accidents well and explain the categorization of the EPC to 4M and its sub-factors.

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Glossary
APE : Assessed Proportion Effect
EPC : Error Producing Conditions
HEP : Human Error Probability
GT : Generic Task
NHU : Nominal Human Unreliability
MAART : Maritime Accident Analysis and Reduction Technique

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