A Hybrid Methodology for Human Reliability Assessment in Maritime Cargo Accidents

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Abstract. The maritime cargo shipment is always looking for implementing new safety measures to reduce the cargo accident rates. However, it is challenging to find the root cause that led to a specific cargo accident. The accidents result from a complex chain of events, where there is usually more than one factor solely responsible for maritime cargo accidents. The present contribution aims to find the causal factor of the accidents and predict human error probability after the accidents using the hybrid methodology. The hybrid methodology that uses this study to assess human error of maritime cargo accidents is Human Error Assessment and Reduction Technique (HEART) – 4M and TOPSIS with Technique for Risk Perception. The HEART methodology assumes that any predicted reliability of task performance may be modified according to the presence of identified Error Promoting Conditions (EPCs). A technique for Risk Perception decomposes a task into sub-task steps for which quantification data are provided. The corresponding results show that the most common situation that maritime cargo accidents occurred due to the man factor is during the loading and unloading process.

1. Introduction
Nowadays, maritime cargo shipment was developing from time to time. It is also called that the maritime cargo shipment is the backbone of the world economy that more than 90% of world trade is carried by sea [1]. Furthermore, total cargo containerization was handled in container ports worldwide, estimated at 793.26 million twenty-foot equivalent units (TEUs), and 64% of container handling occurred in the Asia region [2].

Indonesia is one of the countries in the Asia region that the maritime cargo shipment was increased rapidly. Indonesia is an archipelagic country with an abundance of natural resources, located strategically between the Indian and the Pacific oceans, with approximately two-thirds of its area being the sea [3]. Due to Indonesia’s condition, maritime shipping is major transportation in Indonesia [4] and the Indonesian economy’s backbone. However, the number of accidents that occurred is directly proportional to the number of maritime cargo shipments. Both the instances above occur during shipping on land or at sea [5].

Safety is an essential subject of maritime transportation. It directly affects human life, the environment, and the transported commodities [6]. Maritime authorities have approved a set of regulatory rules and specifications to improve safety and minimize accidents in the maritime industry [7]. More and more new requirements and amendments to existing regulations for safe maritime transport were introduced by the International Maritime Organizations (IMO) [8]. The human element is one of the essential contributory aspects of the causation and avoidance of accidents, and human error is responsible for more than 80% of maritime accidents [9], [10].

Not only IMO, but also the International Labour Organization (ILO) and International Association of Classification Societies (IACS) that form maritime regulatory authorities are overly concerned about the possibility of the occurrence of maritime accidents due to human factor issues [11]. Some reliability analysis techniques have been used in every industry to reduce the risk of accidents [12], and one of
them is Human Reliability Assessment (HRA). The main reason for HRA to evaluate human reliability and the uncertainty of the data concerning human factors is the complexity of human behavior [13]. HRA is a significant analysis required to analyze the task, identify errors, and reduce error impact if required, making it more than a quantifying index [14].

At this point, this paper’s present contribution is to find the causal factors of maritime cargo accidents and to predict the human error probability after the accidents of maritime cargo shipment. The paper integrated the HEART (Human Error Assessment and Reduction Technique) – 4M and TOPSIS with Risk Perception Technique to achieve this purpose.

HEART is a practical tool to calculate Human Error Probability (HEP) [15]. HEART is a simple, flexible, and effective method for determining the human error involved in accidents. Therefore, it has been used in various industries with complex systems, such as nuclear power plants, railway transportation, aviation, off-shore platforms, and the maritime industry [16]. On the HEART – 4M method, the Error Producing Conditions (EPCs) are categorized into four factors: man, machine, media, and management. In this paper, the HEART – 4M method combines with the technique for order preference by similarity to ideal solution (TOPSIS) that development introduced by Bowo [16]. This method evaluates the HEP in maritime cargo accidents at every stage (loading process, sailing process, and unloading process).

After HEP every stage was assessed, the aggregate of HEP of maritime cargo accidents was evaluated using the risk perception technique. Risk Perception is defined as a psychological process that describes the subjective (conscious and unconscious) evaluation (as opposed to objective risk assessment) of the probability to be affected by an imminent undesirable event in a specific situation and an assessment of one’s own perceived vulnerability and coping resources [17].

2. Methodology
This paper prompts a hybrid approach to determine HEP’s aggregate by integrating HEART – 4M and TOPSIS with Risk Perception Technique. Accordingly, this section provides a brief description of methodologies.

2.1 HEART – 4M
HEART is preliminarily introduced by William [18] to assess human error with defined values. HEART comprises of two fundamental parameters, such as Generic Task (GT) and Error Producing Condition (EPC). The GT parameter consists of nine qualitative descriptions of the appropriate task in the accident process, and every GT provides the value of generic error probability, named nominal human unreliability (NHU). The proposed NHU was based on engineers’ or researchers’ experience, but William [18] also provided the number of NHU as guidance to the assessor to analyze the task. Table 1 presents the GT and NHU used in this study. The other one is EPC, which indicates the relevant performance shaping factors for humans during a task and can affect HEP’s value [16]. There are 38 EPCs defined in the HEART method, directly influencing HEP value for a specific.

| Code | Type of work | Condition | NHU |
|------|--------------|-----------|-----|
| A    | Totally unfamiliar | Works performed at speed with no real idea of likely consequences | 0.55 |
| B    | Restore the system to an original state on a single attempt | Doing it without supervision or procedures | 0.26 |
| C    | Complex task | Task requires a high level of comprehension and skill | 0.16 |
| D    | A fairly simple task | Works performed rapidly or given scant attention | 0.09 |
| E    | The routine, highly practiced, rapid task | Works involving a relatively low level of skill | 0.02 |
F Restore a system to original
Entirely familiar, highly practiced, routine task occurring several times per hour, performed to 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

G Even when there is an augmented or automated supervisory system providing an accurate interpretation of system stage

H Respond correctly to the system command

M The miscellaneous task for which no description can be found

If there is more than one EPC, the assessed proportion of effect is determined. In this context, HEP is calculated with the following equation.

\[
\text{HEP}_\text{value} = NHUX\left(\prod_i (EPC_i - 1) APE_i + 1 \right)
\]

In the equation, EPC\(_i\) is the \(i\)th (\(i = 1,2,3, \ldots; n \leq 38\)) error producing condition, and APE\(_i\) (0 < \(i\) \(\leq 1\)) is assessed of proportion effect, which is weighted the each EPC basic of its importance [15]. As the EPC influence becomes more critical, the value of the APE will be higher.

The HEART – 4M method is the HEART method’s developments introduced by Bowo and Furusho [19]. In the HEART – 4M method, there is a categorization of the EPCs into the 4M framework, consisting of man, machine, media, and management. The 38 EPCs established by William describe the working condition, which means the interaction between humans, human-machine interactions, and working environment conditions. William also provides the multiplication for each EPC. Table 2 presents the EPC – 4M categorization and the multiplication number.

| Man Factors | X | EPC 8 | Channel overload | 6 |
| Physical limitations | | EPC 23 | Unreliable instruments | 1.6 |
| EPC 27 | Physical capabilities | 1.4 |
| EPC 36 | Task Pacing | 1.06 |
| EPC 38 | Age | 1.02 |
| Psychological limitations | | EPC 33 | Poor environment | 1.15 |
| EPC 21 | Dangerous incentives | 2 |
| EPC 28 | Low meaning | 1.4 |
| EPC 29 | Emotional stress | 1.3 |
| EPC 31 | Low morale | 1.2 |
| EPC 34 | Low mental workload | 1.1 |
| Experience | | EPC 19 | No diversity information | 2.5 |
| EPC 1 | Unfamiliarity | 17 |
| EPC 12 | Misperception of risk | 4 |
| EPC 22 | Lack of experience | 1.8 |
| Skill and Knowledge | | EPC 24 | Absolute judgments required | 1.6 |
| EPC 7 | Irreversibility | 8 |
| EPC 9 | Technique unlearning | 6 |
| EPC 11 | Performance ambiguity | 5 |
| Monitoring | | EPC 17 | Inadequate checking | 3 |
| EPC 15 | Operator inexperience | 3 |
| EPC 20 | Educational mismatch | 2 |
2.2 TOPSIS

TOPSIS is one method of multi-criteria decision-making tool proposed by Hwang and Yoon (1981) to determine the best alternative based on the compromise solution concept [20]. This technique comprises of some steps. The first one is to analyze the decision-making problem and divide it into smaller parts, then a pair-wise comparison matrix is established for each criterion. Table 3 shows that the Saaty’s pair-wise comparison scale [21]. The comparison matrix $A$ is a $n \times n$ real matrix, where $n$ denotes the number of evaluated criteria. Each criterion $x_{ij}$ ($i = 1, 2, …m, j = 1, 2, …n$) inserted in the matrix $A$ represents the ith’s relative importance against to the jth. The following formula (2) is used to establish a comparison matrix $A$.

\[ x_{ii} = 1, \quad x_{ij} = 1/x_{ji}, \quad x_{ji} \neq 0 \]

Table 3. Saaty’s pair-wise comparison scale.

| Importance | Definition                        |
|------------|----------------------------------|
| 1          | Equal importance                 |
| 3          | Moderate importance              |
| 5          | Strong importance                |
| 7          | Very strong importance           |
| 9          | Absolute extreme importance      |
| 2,4,6,8    | Intermediate values              |

The next step is to calculate the relative weights of criteria. The priority weight ($w$) can be found with the following formula.

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

Calculate the normalized decision matrix ($r_{ij}$).

\[ r_{ij} = \frac{x_{ij}}{w_i} \]

Calculate the weighted normalized decision matrix.

\[ p_{ij} = r_{ij} \times x_{ij} \]

The ideal solution is determined.

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

The negative solution is also determined.

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

The separation from the ideal solution is determined

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

The separation from the negative ideal solution is determined.

\[ d_i^- = \sqrt{\sum_{j=1}^{n} (d_{ij}^-)^2} \]
Relative closeness to the ideal solution is calculated.

$$\zeta_i = \frac{d_i^+ - d_i^-}{d_i^+ + d_i^-}$$  \hspace{1cm} (10)

The normalization value is determined.

$$N = \frac{\zeta_i}{\sum \zeta_i}$$  \hspace{1cm} (11)

And the final step is to check the consistency of the decision maker’s evaluation. In this step, the consistency of data inserted in matrix A is consistent or not. The consistency index (CI) can be calculated using the following formula.

$$\sum_{j=1}^{n} x_{ij}/N = \lambda_{max}N_i$$  \hspace{1cm} (12)

$$CI = \frac{\lambda_{max}-n}{n-1}$$  \hspace{1cm} (13)

The consistency ratio (CR) should be calculated to check the consistency. The CR value can be found in the following formula.

$$CR = \frac{CI}{RI}$$  \hspace{1cm} (14)

In the equation, RI is the random index that Saaty provides the values in table 4.

Table 4. Random index values [22].

| n  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----|----|----|----|----|----|----|----|----|----|----|
| RI | 0  | 0  | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 |

2.3 Risk Perception
Risk perception could be related to attitudes that were found to be correlated with each other and with behavior [23]. In this paper, the aggregate HEP of maritime cargo accidents is determined using HEP every stage on maritime cargo shipment obtained from HEART – 4m and TOPSIS technique. The risk perception technique used is represented by an HRA event tree [24], as shown in figure 1.

![Figure 1. HRA event tree](image)

Using the HRA event tree, a graphical description of the task’s procedural steps is illustrated in the logical framework. A binary decision point represents the current action’s failure or success [25]. Thus, at every binary branching, the probability of the events must sum to 1.0. Finally, the aggregate HEP was obtained by analyzing the HRA event tree and using the following formula.

$$aggregate\ HEP = a(B/a) + A(b/A) + A(B/A)$$  \hspace{1cm} (15)

3. Data
The historical maritime cargo accident data analyzed in this study were obtained from the Indonesia maritime cargo adjusting and surveying company that engages in the marine cargo consultant of insurance. The detail of the marine cargo accident data showed in table 5 below.

Table 5. Maritime Cargo Accidents Data.
4. Result

4.1 EPC – 4M

There are three shipment processes in maritime cargo shipment: the loading process, sailing process, and unloading process. In this study, the EPC – 4M were determined in every maritime cargo shipment process, and in every process, were found more than one EPC. Thus, 97 EPC – 4M factors were found in Indonesia’s seven maritime cargo accidents. Management factors had the most EPCs, 52, consist of communication, coordination, monitoring, and procedures subfactors.

EPC’s total in the man factor is 40 consist of physical, psychological, skill and knowledge, and health. Moreover, the other EPCs there are three from machine factor and two EPCs from media factor. The list of EPCs found in the analysis is presented in table 6.

Table 6. EPC – 4M results.

| No | Vessel’s Name | Origin | Destination | Date of Casualty | Cargo | Casualty |
|----|----------------|--------|-------------|------------------|-------|---------|
| 1  | United Tristan Da Cunha | Kwangyang, South Korea | Jakarta, Indonesia | 21 April 2014 | Coil Rolled Steel | The truck accident during the unloading process |
| 2  | Ambassador Bridge | Bandung, Indonesia | Dhaka, Bangladesh | 16 May 2014 | Fabric | The truck accident during the loading process |
| 3  | Hyundai Highway | Suzhou, China | Batam, Indonesia | 28 May 2014 | Battery cells | Rough handling during the unloading process |
| 4  | Kota Harmuni | Singapore | Bogor, Indonesia | 30 May 2014 | Haulotte vertical mast | Rough handling during the unloading process |
| 5  | Hamburg Bridge | Antwerp, Belgium | Tangerang, Indonesia | 20 June 2014 | Stray field machine | Rough handling during the sailing process |
| 6  | Hyundai | Suzhou, China | Batam, Indonesia | 6 June 2014 | Battery cells | Rough handling the unloading process |
| 7  | KSD 06 | Batam, Indonesia | Jakarta, Indonesia | 27 December 2015 | Steel crap | The vessel capsized |
4.2 HEP Calculation

In this study, the author calculated the HEP at every process of maritime cargo accidents. However, in this section, we consider only one case in one process. The following calculation description is from case no 1 in the unloading process. There are five EPCs selected, EPC 2, EPC 15, EPC 17, EPC 22, and EPC 35. The data are processed using TOPSIS to get the HEP, and the process as follows:

4.2.1 Pair-wise comparison matrix

The EPCs selected caused the accident constructed in the pair-wise comparison matrix, as shown in table 7. The proportion of every EPC was calculated using formula (2), and the attribute weight \( w_i \) was calculated using formula (3).

### Table 7. Pair-wise comparison matrix and attribute weight.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 | \( w_i \) |
|-------|--------|--------|--------|--------|-----------|
| 1     | 5      | 0.33   | 0.5    | 2      | 5.51      |
| 0.2   | 1      | 0.17   | 0.25   | 0.33   | 1.11      |
| 3     | 6      | 1      | 2      | 4      | 8.12      |
| 2     | 4      | 0.5    | 1      | 2      | 5.02      |
| 0.5   | 3      | 0.25   | 0.5    | 1      | 3.25      |

4.2.2 The normalized decision matrix

Table 8 shows the normalized decision matrix was calculated using formula (4).

### Table 8. Normalized decision matrix.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 |
|-------|--------|--------|--------|--------|
| 0.18  | 0.91   | 0.06   | 0.09   | 0.36   |
| 0.18  | 0.90   | 0.15   | 0.22   | 0.30   |
| 0.37  | 0.74   | 0.12   | 0.25   | 0.49   |
| 0.40  | 0.80   | 0.10   | 0.20   | 0.40   |
| 0.15  | 0.92   | 0.08   | 0.15   | 0.31   |

4.2.3 The weighted normalized decision matrix

After the normalized decision matrix determined, the weighted normalized decision matrix was calculated using formula (5). The maximum weight (max) and minimum weight (min) of every EPC decided from those results, as shown in table 9.

### Table 9. Weighted normalized decision matrix and maximum-minimum weight.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 | max | min |
|-------|--------|--------|--------|--------|-----|-----|
| 0.18  | 4.54   | 0.02   | 0.05   | 0.73   | 4.54| 0.02|
| 0.04  | 0.90   | 0.02   | 0.06   | 0.10   | 0.90| 0.02|
| 1.11  | 4.43   | 0.12   | 0.49   | 1.97   | 4.43| 0.49|
| 0.80  | 3.18   | 0.05   | 0.20   | 0.80   | 3.18| 0.05|
| 0.08  | 2.77   | 0.02   | 0.08   | 0.31   | 2.77| 0.02|

4.2.4 The ideal solutions and its separation
The ideal solution was calculated using formula (6), and its separation was calculated using formula (8). The results show in table 10.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 | \(d^i\) |
|-------|-------|-------|-------|-------|-------|
| 18.97 | 0     | 20.40 | 20.18 | 14.53 | 21.86 |
| 0.74  | 0     | 0.76  | 0.71  | 0.64  | 0     |
| 11.05 | 0     | 18.56 | 15.52 | 6.06  | 0     |
| 5.70  | 0     | 9.82  | 8.91  | 5.70  | 0     |
| 7.25  | 0     | 7.56  | 7.25  | 6.06  | 0     |

Table 10. Ideal solution matrix and its separation.

4.2.5 The negative ideal solution matrix and its separation
The negative ideal solution was calculated using formula (7), and its separation was calculated using formula (9). The results show in table 11.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 | \(d^-i\) |
|-------|-------|-------|-------|-------|-------|
| 0.03  | 20.40 | 0     | 0.0006| 0.50  | 0.48  |
| 0     | 0.76  | 0     | 0     | 0.01  | 0     |
| 0.38  | 15.52 | 0.14  | 0     | 2.18  | 0.38  |
| 0.56  | 9.82  | 0     | 0.02  | 0.56  | 0.56  |
| 0     | 7.56  | 0     | 0     | 0.08  | 0     |

Table 11. Negative ideal solution matrix and its separation.

4.2.6 Relative closeness to the ideal solution and normalization
The relative closeness to the ideal solution was calculated using formula (10), and its normalization was calculated using formula (11). The result shows in table 12.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 | Total |
|-------|-------|-------|-------|-------|-------|
| 0.022 | 1.00  | 0.002 | 0.001 | 0.09  | 1.12  |
| 0.019 | 0.90  | 0.002 | 0.0005| 0.08  | 1.00  |

Table 12. Relative closeness to the ideal solution and its normalization.

4.2.7 Consistency verification
The consistency of data inserted in a pair-wise comparison matrix is checked to verify whether the matrix is consistent or not. This step calculates CI using formula (13) and calculates CR using formula (14). If the CR values are \(\leq 0.01\), the judgments are considered consistent and reasonable, as shown in table 13.

| CI    | RI   | CR   |
|-------|------|------|
| 0.02  | 1.11 | 0.022|

Table 13. Consistency check.

4.2.8 HEP calculation
After APE’s weight was determined using the TOPSIS technique, the HEP can be determined using formula (1), and the result of HEP for case no one at the unloading process shown in table 14.

| EPC 2 | EPC 15 | EPC 17 | EPC 22 | EPC 35 |
|-------|-------|-------|-------|-------|
| x     | APE   | x     | APE   | x     | APE   |
| 11    | 0.019 | 3     | 0.90  | 3     | 0.002 |
| x     | APE   | x     | APE   | x     | APE   |
| 1.1   | 0.08  | 1.1   | 0.08  | 1.1   | 0.08  |

Table 14. HEP calculation.
HEP calculation process, as the way above, was applied to the other cases in all of the maritime cargo shipment process. Table 15 shows HEP’s result in seven maritime cargo accidents in all processes (loading process, sailing process, and unloading process).

Table 15. HEP calculation for seven maritime cargo accidents.

| Case no | HEP in the loading process | HEP in the sailing process | HEP in the unloading process |
|---------|----------------------------|----------------------------|----------------------------|
| 1       | 1                          | 0.42                       | 0.54                       |
| 2       | 0.75                       | 0.55                       | 0.82                       |
| 3       | 0.13                       | 0.14                       | 0.13                       |
| 4       | 0.11                       | 0.17                       | 0.05                       |
| 5       | 0.56                       | 0.42                       | 1                          |
| 6       | 0.11                       | 0.14                       | 0.16                       |
| 7       | 0.79                       | 1                          | 1                          |
| Average | 0.49                       | 0.41                       | 0.53                       |

4.3 Aggregate HEP calculation

In this step, the aggregate HEP was determined using the risk perception technique, which used the HRA event tree and the formula (15). To clarify this matter, figure 2 shows the example of the HRA event tree of case no 1. A capital letter indicates the shipment process’s failures that the value is HEP of each process, as shown in table 15. In contrast, the small letter indicates the successes of the process.

![HRA event tree case no 1](image)

Figure 2. HRA event tree case no 1

In case no 1, the cargo’s accidents were shipped from the unloading port to the consignee’s place using a truck (unloading process). Using the HRA event tree, the aggregate HEP of case no 1 is F1. The value of F1 was determined by using the formula (15) and was obtained 0.23. The remaining six maritime cargo accidents in Indonesia were analyzed, and the result is shown in table 16.

Table 16. Aggregate HEP of maritime cargo accidents.

| Case no | Aggregate Hep | %HEP |
|---------|---------------|------|
| 1       | 0.23          | 22.68|
| 2       | 0.86          | 86.28|
| 3       | 0.002         | 0.24 |
| 4       | 0.0009        | 0.09 |
| 5       | 0.56          | 56   |
| 6       | 0.002         | 0.25 |
| 7       | 0.79          | 79   |
| Average | 0.3493        | 34.93|
5. Discussion
The definition of maritime cargo accidents is any accident that occurred within the maritime cargo shipment. Maritime cargo shipment includes all the casualties of any means of transport from the shipper (seller) to the loading port, sailing process, and shipment from the unloading port to the consignee (buyer) does not have to be a ship. The data on maritime cargo accidents are challenging to retrieve because this data is not recorded by the government institution but only the party involved in this accident, like adjusting surveying company and the insurance company. In this study, the human error probability analysis was determined in every process of maritime cargo shipment. The management factor becomes the most common EPC – 4M factor found in these cases. It means that the tasks related to management, such as communication, coordination, monitoring, and procedures, must receive more attention. The management factor could occur because the maritime cargo shipment process needs more intention to coordinate every process.

Based on the HEP calculation result, the HEP value in the unloading process is highest than the other process, followed by the HEP value in the loading process and the sailing process. The handling of the cargo mostly occurred during the loading and unloading process rather than the sailing process. The loading process is the first process of maritime cargo shipment. Thus the operator or other party is more concerned about cargo handling in the loading process. However, it is inversely proportional to the unloading process. Maritime cargo accidents mostly occurred in the unloading process. Therefore the HEP value in the unloading process is higher than the loading process.

In this study, the HEART – 4M combines with the TOPSIS methodology to determine the HEP in every process of maritime cargo shipment. Then the aggregate HEP was assessed using the risk perception technique. The integration of these methods suggests the relation between the EPC – 4M, HEP in every process, and aggregate HEP can involve the accidents.

6. Conclusion
Human reliability analysis is a method that quantifies the probability of human error and provides information for mitigating maritime cargo accidents [19]. In this study, seven maritime cargo accidents in Indonesia were analyzed using the hybrid methodology HEART – 4M and TOPSIS with the risk perception technique. The purpose of this paper is to find the causal factor of maritime cargo accidents in Indonesia. There were 97 EPM – 4M factors found as causal factors, where management factors were the most common factors found.

The other purpose is to predict the HEP of maritime cargo accidents. HEART – 4M and TOPSIS were used to get the HEP value for every maritime cargo shipment process. The average HEP in the loading process was 0.49 (49%), the sailing process was 0.41 (41%), and the unloading process was 0.53 (53%). After the HEP, every process was determined, then the aggregate HEP was determined using the risk perception technique, and the average of aggregate HEP is 0.3493 (34.93%). Finally, the hybrid method proposed in this study provides a practical tool to determine the value of HEP in maritime cargo accidents.

7. References
[1] M. Grote et al., “Dry bulk cargo shipping — An overlooked threat to the marine environment?,” Mar. Pollut. Bull., vol. 110, no. 1, pp. 511–519, 2016.
[2] U. N. C. and T. D. (UNCTAD), Review of Maritime Transport 2019, no. October. 2019.
[3] Rumaji and A. Adilia, “Port Maritime Connectivity in South-East Indonesia: A New Strategic Positioning for Transhipment Port of Tenau Kupang,” Asian J. Shipp. Logist., vol. 35, no. 4, pp. 172–180, 2019.
[4] N. Tu, D. Adiputranto, X. Fu, and Z. C. Li, “Shipping network design in a growth market: The case of Indonesia,” Transp. Res. Part E Logist. Transp. Rev., vol. 117, no. January 2017, pp. 108–125, 2018.
[5] R. E. Prilana, L. P. Bowo, and M. Furusho, “Maritime Cargo Accidents in Indonesia for the Period 2013 - 2018,” in Asia Navigation Conference 2019, 2019.
[6] E. Akyuz and M. Celik, “Application of CREAM human reliability model to cargo loading process of LPG tankers,” J. Loss Prev. Process Ind., vol. 34, pp. 39–48, 2015.
[7] E. Akyuz and E. Celik, “A modified human reliability analysis for cargo operation in single point mooring (SPM) off-shore units,” Appl. Ocean Res., vol. 58, pp. 11–20, 2016.

[8] E. Eleftheria, P. Apostolos, and V. Markos, “Statistical analysis of ship accidents and review of safety level,” Saf. Sci., vol. 85, pp. 282–292, 2016.

[9] E. Ashmawy, “The Maritime Industry and the Human Element Phenomenon,” 13th Annu. Gen. Assem. IAMU Expand. Front. - Challenges Oppor. Marit. Educ. Train., pp. 277–288, 2012.

[10] L. P. Bowo and M. Furusho, “Human Error Assessment and Reduction Technique for Marine Accident Analysis: The Case of Ship Grounding,” Trans. Navig., vol. 3, no. 1, pp. 1–7, 2018.

[11] E. Akyuz, M. Celik, and S. Cebi, “A phase of comprehensive research to determine marine specific EPC values in human error assessment and reduction technique,” Saf. Sci., vol. 87, pp. 63–75, 2016.

[12] J. Tu, W. Lin, and Y. Lin, “A Bayes-SLIM based methodology for human reliability analysis of lifting operations,” Int. J. Ind. Ergon., vol. 45, pp. 48–54, 2015.

[13] M. Konstandinidou, Z. Nivolianitou, C. Kiranoudis, and N. Markatos, “A fuzzy modeling application of CREAM methodology for human reliability analysis,” Reliab. Eng. Syst. Saf., vol. 91, no. 6, pp. 706–716, 2006.

[14] B. Kirwan, R. Kennedy, S. Taylor-Adams, and B. Lambert, “The validation of three human reliability quantification techniques THERP, HEART and JHEDI: Part II - results of validation exercise,” Appl. Ergon., vol. 28, no. 1, pp. 17–25, 1997.

[15] E. Akyuz and M. Celik, “A hybrid human error probability determination approach: The case of cargo loading operation in oil/chemical tanker ship,” J. Loss Prev. Process Ind., vol. 43, pp. 424–431, 2016.

[16] L. P. Bowo, R. E. Prilana, and M. Furusho, “A Modified HEART – 4M Method with TOPSIS for Analyzing Indonesia Collision Accidents,” vol. 14, no. 3, 2020.

[17] M. T. Kinzeder, E. D. Kuligowski, P. A. Reneke, and R. D. Peacock, “Risk perception in fire evacuation behavior revisited: definitions, related concepts, and empirical evidence,” Fire Sci. Rev., vol. 4, no. 1, 2015.

[18] J. Williams, “A data-based method for assessing and reducing human error to improve operational performance,” in Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants, 1988, vol. 72, no. DOT/FAA/AM-01/3, pp. 436–450.

[19] L. P. Bowo and M. Furusho, “Usability of Human Error Assessment and Reduction Technique with a 4M framework (HEART-4M) – A Case Study on Ship Grounding Accidents,” J. ETA Marit. Sci., vol. 2, no. 1, pp. 41–46, 2019.

[20] C.-L. Hwang and K. Yoon, Multiple Attribute Decision Making: Methods and Applications. 1981.

[21] T. L. Saaty, “Axiomatic Foundation of the Analytic Hierarchy Process,” vol. 32, no. 7, pp. 841–855, 1986.

[22] T. L. Saaty, “How to make a decision: The analytic hierarchy process,” Interfaces (Providence)., vol. 24, no. 1, pp. 19–43, 1994.

[23] D. Dinh, N. H. Vù, R. C. McIlroy, K. A. Plant, and N. A. Stanton, “Effect of attitudes towards traffic safety and risk perceptions on pedestrian behaviours in Vietnam,” IATSS Res., 2020.

[24] D. Swain and H. E. Guttmann, “Handbook of reliability analysis with emphasis on nuclear plant applications,” no. August, 1983.

[25] F. Vanderhaegen, M. Cassani, and P. C. Cacciabue, Efficiency of safety barriers facing human errors, vol. 11, no. PART 1. IFAC, 2010.