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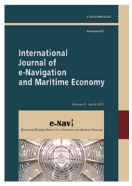

Original article

Analysis of Collision at Sea using Human Error Assessment and Reduction Technique (HEART)

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Abstract

Despite the maritime industry's significant role in the global economy, maritime accidents are a threat to life at sea and maritime economic performance. Furthermore, the human factor still accounted for as the main factor causing maritime accidents. Every year, many maritime accidents occur in Japan and Hong Kong, with collisions being the most common. In this study, Human Error Assessment and Reduction Technique (HEART) method is applied to the collisions data to identify the common mistakes committed by seafarers by determining the generic task, error-producing conditions and the value of Human Error Probability (HEP). This study aims to find the causes of collision in Japan and Hong Kong, compare them between the two countries, and apply HEART methodology to various maritime accidents. The data was sourced from the maritime accident data report of the Japan Transportation and Safety Board and the Government of the Hong Kong Special Administrative Region of the Marine Department from 2008 to 2016. There are 27 collision cases for Japan and 21 for Hong Kong. In general, human error is the most common factor leading to collisions. In conclusion, in Japan's collision assessment, fairly simple tasks performed rapidly or with scant attention are identified as the most common generic task. However, in Hong Kong, most of the accidents occur during complex tasks. Japan has 101 EPCs for 27 cases while there are 115 EPCs for 21 cases that occurred in Hong Kong. Both Japan and Hong Kong have the time shortage, inadequate checking of progress, and poor information exchange among seafarers on the bridge as the common error-producing conditions occurred.

Keywords: collision; error-producing conditions; HEART methodology; human factors

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1. Introduction

Many researchers have studied maritime accidents to explore ways of reducing their number and taking preventive actions because maritime accidents are a threat to both lives at sea and the economic performance of the shipping industry and the environment (for instance, a collision). Therefore, assessing the events leading up to a collision is essential because the human error has been found to be the main implicating factor in 80% of maritime accidents (Soares & Teixeira, 2001, p.300). Several other studies have also pointed out the contribution of human factors in maritime accidents (Graziano, Teixeira, & Guedes Soares, 2016; Sotiralis, Ventikos, Hamann, Golyshev, & Teixeira, 2016).

The International Maritime Organization (IMO) has established regulations for collision avoidance, named the International Regulations for Preventing Collisions at Sea 1972 (COLREG) (Ventura, 2009). In 1974, to determine the minimum standards of construction, equipment, and operation of ships for ensuring the safety of life at sea, the IMO held a convention called Safety of Life at Sea and four years later, the Standards of Training, Certification, and Watchkeeping for Seafarers were established. at reducing the frequency of severe accidents in the maritime industry (Eleftheria et al., 2016, p.283). These efforts, however, have only led to a slight decline in the number of maritime accidents every year, especially in Japan and the Hong Kong Special Administrative Region of the People's Republic of China.

In this study, we utilize the Human Error Assessment and Reduction Technique (HEART) methodology. This methodology was first developed to assess accidents in nuclear incidents (Kirwan et al., 2005; Williams, 1988) and was later adapted for use in other industry sectors—aviation (B Kirwan & Gibson, 2009), railways (Gibson, Mills, Smith, & Kirwan, 2013), and marine operations (Akyuz, Celik, & Cebi, 2016). We use the methodology to identify the causes of collision in Japan and Hong Kong and to find the differences between the two countries. This paper is structured as an introduction; collision data of Japan and Hong Kong; description of HEART methodology; the results of the data analysis, discussion and considerations; and conclusion.

2. Collision Accidents Data

We use the collisions data from Japan and Hong Kong, published on the official government websites. A collision is defined as striking or being struck by another ship, whether underway, moored, or anchored; it also includes a ship striking port facilities and marine life, causing fatality and injury.

2.1 Japan's Collision Data

The collisions data for Japan are provided by the Japan Transportation Safety Board (JTSB) for 2008 to 2016 on their official website. JTSB is a division of the Japanese Ministry of Land, Infrastructure, Transport, and Tourism that conducts scientific and objective investigations into aircraft, railway, and marine accidents and incidents. From 2008 to 2016, there were 2,382 ship collisions recorded by JTSB, accounting for the highest number of maritime accidents in Japan, followed by grounding accidents and occupational accidents.

Table 1: Japan's Collisions Data

Case	Date	Casualties and Injuries
1	2008-22-7	There were no casualties.
2	2009-10-3	The entire crew members of the cargo ship went missing.
3	2009-20-2	There were no casualties.
4	2009-27-10	Six crew members suffered injuries.
5	2010-28-3	One crew member died, another went missing.
6	2011-19-8	There were no casualties.
7	2011-11-9	There were no casualties.
8	2011-27-11	One crew member went missing and the master was injured.
9	2011-6-7	The skipper died and a deckhand was injured.
10	2012-16-7	There were no casualties.
11	2012-3-7	There were no casualties.
12	2012-8-3	The skipper died.
13	2012-7-2	There were no casualties.
14	2012-15-4	The skipper died; one crew member went missing.
15	2012-24-9	Thirteen crew members went missing.
16	2013-23-1	Four crew members were slightly injured.
17	2013-15- 6	There were no casualties.
18	2013-27-9	The entire crew died.
19	2013-23-6	The master went missing.
20	2013-25-2	The master and a crew died.

21	2013-10-1	There were no casualties.
22	2014-18-3	Seven crew members died; two went missing.
23	2014-15-11	There were no casualties.
24	2015-2-11	The master was injured.
25	2015-17-10	There were no casualties.
26	2016-8-1	Three passengers were seriously injured.
27	2016-19-2	The skipper died.

Only some accidents had been fully reported because of uncommon causes while some others with the same causes were not fully reported again. There are 27 collisions data published in the English report that we use in this study. Table 1 below details the collision data used—date and time of the accident and casualties and injuries that occurred. Based on this data, about 70% of the accidents occurred during night time.

2.2 Hong Kong's Collision Data

The Marine Department of the Government of Hong Kong is responsible for all navigational matters and the safety standards of vessels in Hong Kong. There were 1423 collisions recorded by the Marine Department within the territorial waters and 317 outside the territorial waters from 2008 to 2014. Like Japan, in Hong Kong too, collisions are the most common accidents during that period, followed by contact accidents and grounding accidents. According to the accident data report issued, the data on 21 collisions are in English. From this, it shows that passenger vessels are the most common vessel involved in collisions (28%), followed by container vessels and fishing vessels. Like in Japan. in Hong Kong too, about 71% of the collisions occurred during night time.

Table 2: Hong Kong's Collision Data

Case	Date	Casualties and Injuries
1	2008-1-7	Eleven people were injured.
2	2008-2-9	The master died.
3	2008-5-3	There were no casualties.
4	2008-11-1	One hundred thirty-three people were injured.
5	2008-21-10	There were no casualties.
6	2008-22-3	Six crew members were injured; 18 crew members drowned.
7	2009-20-3	Four crew members died; three went missing.
8	2009-20-3	One passenger died.
9	2009-14-11	Thirteen people were slightly injured.
10	2010-7-12	Eight crew members died.
11	2011-1-9	Six crew members were injured.
12	2011-9-3	One coxswain died.
13	2011-13-2	Three crew members were injured.
14	2011-26-6	Eleven people were injured.
15	2012-8-5	The coxswain went missing.
16	2012-13-5	One crew member went missing.
17	2012-9-4	One crew member went missing.
18	2013-5-11	Two crew members were injured.
19	2014-29-10	Thirteen crew members went missing.
20	2014-24-8	Eleven crew members went missing.
21	2014-25-12	One crew member went missing.

Table 2 shows the date and casualties and injuries of the 21 collisions from Hong Kong that were used in this study. Hong Kong had more casualties than Japan.

2.3 The type of ship involved

From the data on 27 collisions in Japan, we find that 54 ships were involved in collisions from 2008 to 2016, of which cargo vessels (35%) are the most common type of vessel involved, followed by fishing vessels (26%), container vessels, tanker vessels, vehicle carriers, passenger vessels, and others. In the Hong Kong data, 43 ships were involved in the 21 accidents analyzed.

The collision data in Hong Kong is different—passenger vessels are the most common type of ship involved in collisions (28%), followed by container vessels, fishing vessels, bulk carriers, cargo vessels, tug boats, and others. Table 3 shows the data on the type of ship involved in the collisions in Japan and Hong Kong.

Table 3: Type of ship

Japan		Hong Kong	
Type of ship	**%**	**Type of ship**	**%**
Cargo Vessel	35	Passenger Vessel	28
Fishing Vessel	26	Container Vessel	19
Container Vessel	19	Fishing Vessel	16
Tanker Vessel	11	Bulk Carrier	12
Vehicle Carrier	4	Cargo vessel	9
Passenger Vessel	2	Tug Boat	5
Others	4	Others	12

3. Human Error Assessment and Reduction Technique Methodology

The HEART methodology has been applied in several maritime accidents, such as grounding accidents, which were the most common accidents in Canada (Bowo & Furusho, 2016), sinking and fire and explosion accidents, which were the most common in Indonesia (Bowo & Furusho, 2018), and occupational accidents that occurred in Australia (Bowo & Furusho, 2017). The methodology was developed by William in 1988 to analyze nuclear accidents (Williams, 1988) and comprises two steps: first, the qualitative step and second, the quantitative step (Kirwan, 1997).

Qualitative step: In the qualitative step, there is a generic task, consisting of 9 tasks, each of which has its nominal human unreliability (NHU). The highest number of NHUs are for generic tasks that are completely unfamiliar, performed with no real idea of the likely consequences. There is a higher probability for accidents on unfamiliar generic tasks than on generic tasks where there is familiarity with the situation or wor but there is no focus while working, or for not following procedures during the task. The generic task describes the working conditions before the accidents occurred. The more often the seafarers do more accessible work, the lower the NHU whereas it is vice-versa if the working conditions are more complicated and the seafarer is unfamiliar with the task. Table 4 shows the generic tasks used in this study.

Figure 1 presents the maximum limit, minimum limit, and average NHU for each generic task. The value of NHU has been established by William (1988) as guidance for the assessor to use the HEART method. The bounds are used to calculate the upper and lower limits for the human error probability (HEP) (Kirwan & Gibson, 2009). In this study, we use the averages for calculation.

Table 4: Generic Tasks

	HEART Methodology Generic Tasks
(A)	Completely unfamiliar, performed rapidly with no real idea of the likely consequences
(B)	Shift or restore the system to a new state on a single attempt without supervision or following procedure
(C)	Complex task requiring a high level of comprehension and skill
(D)	Fairly simple tasks performed rapidly or with scant attention
(E)	Routine, highly-practiced, rapid task involving a relatively low level of skill
(F)	Restore or shift a system to new state following procedures, with some checking
(G)	Completely familiar, but without the benefit of significant job aids
(H)	Respond correctly to system commands even when there is an augmented supervisory system providing accurate interpretation of the system stage
(M)	Miscellaneous task for which no description can be found

Source: B Kirwan (1996, p. 367)

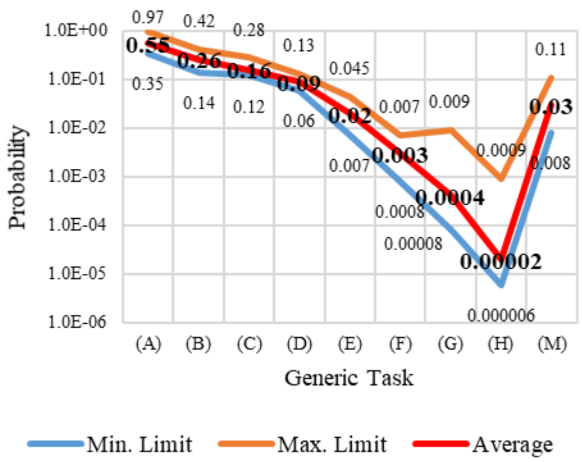

Figure 1: Nominal Human Unreliability of HEART Methodology Generic Task

Source: (B Kirwan, 1996, p. 367)

We next determine the error-producing conditions (EPC), established by William (Williams, 1986), that represent the unsafe acts of the seafarer leading to accidents. The EPC is a detailed factor identified in particular accidents, as shown in Table 5. Consequently, each accident has a different EPC, but some typical EPCs are the same in most of the accidents. We use 38 EPCs in this study.

Table 5: Error Producing Condition (EPC)

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

Source: B Kirwan (1996, p. 368)

Each EPC has a multiplier that is used for calculations in the quantitative step. The multipliers are from the highest number of times an EPC was identified to the lowest—the highest is 17 for EPC number 1 and the lowest is 1.02 for EPC number 38. After determining the EPC, the number of assessed proportion effect (APE) needs to be assigned to each EPC, which represents the entanglement of EPCs in the accident. This APE will be used in the quantitative step.

Quantitative step: The second step of HEART methodology is the calculation. To obtain HEP, the assessed impact value (AIV) is first calculated using the following formula (1). To calculate AIV for every EPC, it needs the multiplier value of selected EPC, as shown in Table 5. The value of APE is a subjective weight from the assessors, and the value is between 0 to 1. The higher APE value assigned for particular EPC means that EPC has more significant effect on the accident.

$$AIV = ((EPC\ Multiplier - 1) \times APE) + 1 \quad (1)$$

The result of AIV is for only one EPC. Therefore, the AIVs of all EPCs have to be calculated for calculating HEP:

$$HEP = NHU \times AIV_1 \times AIV_2 \times \ldots \times AIV_n \quad (2)$$

Calculating HEP requires the NHU from the generic task that was determined earlier and the AIV. The HEP will show the extent of influence of humans in the accidents. The final HEP is between 0 and 1, which indicates whether there is a probability of other factors causing the accident.

4. Results

4.1 Generic Tasks

The generic task is a task that the seafarer performed correctly before the accident occurred. According to HEART methodology, there are nine task classifications. Three of these nine generic tasks were performed just before the accident. The most common generic tasks identified are: fairly simple tasks performed rapidly or with scant attention and complex tasks requiring a high level of comprehension and skill. The most common generic task responsible is different for Japan and Hong Kong.

Table 6 shows the result of the generic task obtained in Japan's collision assessment, where fairly simple tasks performed rapidly or with scant attention is identified as the most common generic task, followed by complex tasks requiring a high level of comprehension and skill. From the 27 cases studied, the fairly simple task performed rapidly or with scant attention is implicated in 17 cases, which means that most of the work done by seafarers just before the accidents was not complex, but it was performed with no or little attention.

In the case of Hong Kong, it is just the opposite—most of the accidents occur during complex tasks. This could be because the seafarers did not have enough experience or training to carry out such difficult tasks on board. The result is shown in Table 7.

Table 6: Generic Task of Japan's Collision

Generic Task	Cases
(D) Fairly simple tasks	17
(C) Complex task	10

Table 7: Generic Task of Hong Kong's Collision

Hong Kong Generic Task	Cases
(C) Complex task	11
(D) Fairly simple tasks	10

The weather and maritime traffic density were also taken into account. In the cases where the weather conditions were terrible and or there was dense maritime traffic, the generic task identified also has higher NHU because in such situations, human performance is critical in keeping the ship safe; in other words, more complex tasks.

4.2 Error Producing Conditions

The number of EPC types obtained from Japan and Hong Kong is 19 out of 38 EPCs and 21 out of 38, respectively. In Japan's collisions, there are 101 EPCs for 27 cases while there are 115 EPCs for 21 cases that occurred in Hong Kong.

Most of the EPC types obtained for Japan and Hong Kong are the same, as many as 16, but there are differences in EPC types because of some cases. The rest of the other EPCs obtained is shown in Table 8 for Japan's EPC result and Table 9 for Hong Kong's EPC result. In Japan's case, inadequate checking is identified as the most common EPC. Inadequate checking is also the most common EPC type identified in Hong Kong.

Table 8: Japan's EPC result

Error-Producing Conditions (EPC)		Total
EPC17	Inadequate Checking	16
EPC2	Time shortage	12
EPC26	Progress tracking lack	10
EPC16	Poor information	9
EPC15	Operator inexperience	7
EPC14	Delayed/incomplete feedback	7
EPC13	Poor feedback	5
EPC10	Knowledge transfer	5
EPC19	No diversity	5
EPC24	Absolute judgement required	5
EPC36	Task pacing	5
EPC33	Poor environment	4
EPC23	Unreliable instruments	3
EPC5	Spatial and functional incompatibility	2
EPC35	Sleep cycle disruption	2
EPC1	Unfamiliarity	1
EPC12	Misperception of risk	1
EPC18	Objectives conflict	1
EPC30	Ill-health	1
	Japan Total	**101**

Table 9: Hong Kong's EPC result

Error-Producing Conditions (EPC)		Total
EPC17	Inadequate Checking	17
EPC14	Delayed/incomplete feedback	15
EPC26	Progress tracking lack	15
EPC2	Time shortage	12
EPC15	Operator inexperience	11
EPC16	Poor information	10
EPC13	Poor feedback	7
EPC11	Performance ambiguity	5

EPC24	Absolute judgment required	4
EPC23	Unreliable instruments	3
EPC7	Irreversibility	2
EPC20	Educational level mismatch	2
EPC22	Lack of experience	2
EPC35	Sleep cycle disruption	2
EPC36	Task pacing	2
EPC5	Spatial and functional incompatibility	1
EPC10	Knowledge transfer	1
EPC12	Misperception of risk	1
EPC18	Objectives conflict	1
EPC27	Physical capabilities	1
EPC30	Ill-health	1
	Hong Kong Total	**115**

In general, time shortage, inadequate checking, and poor information exchange among seafarers are the most common EPC types identified in the collisions in Japan and Hong Kong. EPC 27 (physical capabilities) and EPC 22 (lack of experience) appear only in Hong Kong's collisions. In the HEP calculation, the number of EPC obtained in the case is similar to the final result of the calculation. The more EPCs that are obtained, the higher the final HEP result.

4.3 Human Error Probability

Figures 2 and 3 below show the result of the HEP calculation for Japan and Hong Kong. The HEP is between 0 and 1—if it is 1, other factors caused the accident, and if it is 0, the accident was definitely because of human error. Bad weather is one of the factors that can cause accidents.

Table 9 shows the calculation process of the HEART methodology in Case number 1 for Japanese collision. Table 9 provides generic task D and NHU 0.09 selected EPC, assigned APE, the result of AIV and HEP. The explanation about assigning the GT and NHU has been explained in section 3, whereas GT chosen is due to the working condition of the seafarer at the time of the accidents and also considered the environmental condition. For more difficult tasks and conditions, the GT will be different and will have a more significant value of NHU. To assign the weight of APE for each EPC is based on the subjective judgment of the expert, more significant factor will have the higher weight of APE. After assigning the APE, equation (1) and (2) are used to calculate the AIV and HEP respectively.

Table 9: Human Error Probability Calculation

Case 1 - Japan									
D					0.09				
EPC	APE	EPC	APE	EPC	APE	EPC	APE	EPC	APE
16	0.3	19	0.25	24	0.2	10	0.15	2	0.1
AIV = 1.6		AIV = 1.4		AIV = 1.1		AIV = 1.7		AIV = 2	
HEP					**0.74**				

Figure 2 shows the results of the HEP for Japanese accidents. From the 27 cases analyzed, there are 2 cases where human error is highlighted—the negligence of seafarers. The average HEP number for the Japanese collision accident is 54%.

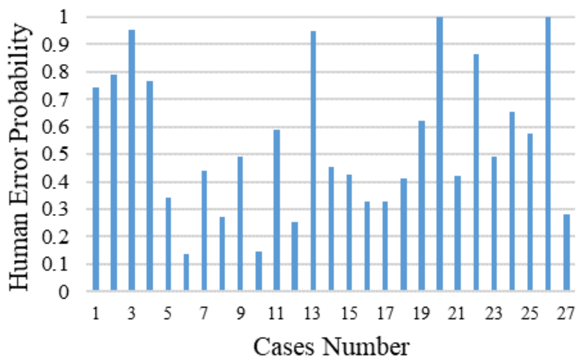

Figure 2: Human Error Probability in Japan

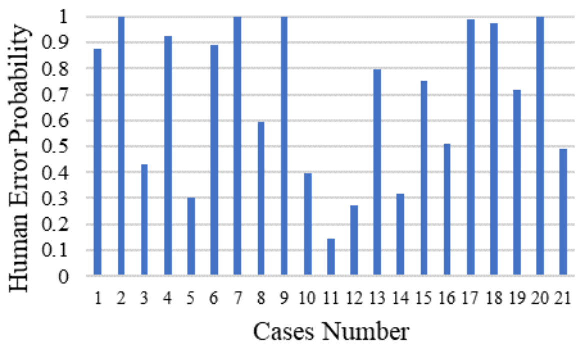

Figure 3: Human Error Probability in Hong Kong

Figure 3 shows the result of Hong Kong's accidents. In 4 of 21 cases analyzed, the final HEP is 1, pointing to human error. The average number for HEP in Hong Kong's collision accident is 68%. It is influenced by the EPC number obtained. The more the EPC obtained, the higher will be the result of HEP.

5. Discussion and Consideration

Every year, many maritime accidents occur in Japan and Hong Kong with collisions being the most common type of accident, as shown by the government's monthly and annual official reports. In the navigation bridge, the seafarers are responsible for delivering cargo or passengers on time safely. According to COLREG, Rule 5, a look-out is to maintain proper watch using sight, hearing, and all available means in the prevailing circumstances to make a full appraisal of the situation and of the risk of collision (Ventura, 2009). It means that seafarers should pay attention to everything while sailing and use all that information continuously to assess the situation and the risk of collision. All the information is obtained using navigational equipment, such as electronic chart display and information systems, automatic radar plotting aid, and radio.

In both Japan and Hong Kong, the seafarers were late in noticing that their ship was heading towards an accident because of improper look-out (it appears as EPC 17, EPC 26, and EPC 23) hence, leaving little time (EPC 2) to avoid the collision. Furthermore, communication among seafarers on the navigational bridge is essential in preventing accidents (it is shown by EPC 13, EPC 14, EPC 16, and EPC 19). Poor communication could lead to the master making wrong judgments because the situation was misunderstood (Mutmainnah & Furusho, 2016). In such cases, some seafarers maintain look-out without supervision from the master. However, the seafarer is not confident of his/her ability due to a lack of experience and knowledge. This condition must be informed to the master well (EPC 15). Moreover, seafarers must give excellent and precise feedback to each other. Poor communication is key in making wrong judgments to prevent collision (EPC 11, EPC 12, EPC 18, EPC 19, and EPC 24).

This is in line with Chauvin in 2013 (Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013), who applied the human factor analysis and classification system (HFACS) framework to analyze 27 recent collision cases involving 39 vessels. He found that the collisions occurred because of decision errors, which, supported by poor visibility and misuse of instruments, led to the loss of situation awareness or poor attention and poor communication among seafarers in bridge resource management Both the HFACS framework and HEART methodology yield the same results of error producing conditions for analyzing collisions.

6. Conclusions

In conclusion, collisions in both Japan and Hong Kong can be attributed to inadequate checking of progress, which causes time shortage in making appropriate judgments to avoid the collision. There should be excellent communication among seafarers while performing look-out. The most common type of vessel involved in collisions in Japan and Hong Kong and the generic task that caused it are different, while the error-producing conditions that cause collisions are mostly the same. HEART methodology can be used to assess collisions thoroughly. The results of HEART are the same as from the HFACS framework.

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