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Proposal of new measures for risk assessment in navigation – a case study of the M/V *Cosco Busan* accident

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Abstract

This study discusses the marine accident involving the *Cosco Busan*, the container ship that hit the base of the Delta Tower of the San Francisco-Oakland Bay Bridge in November 2007. An analysis of the elements resulting in the accident and its consequences has been carried out, followed by an analysis of the navigational risk using mathematical and tabular values. Mathematical values refer to the navigational risk in a specific sailing area, while tabular values refer to the navigational risk using a risk assessment. The main goal of this research was to identify and propose new measures that are correlated with a risk assessment. These measures should be applied in areas where an accident takes place so that future marine accidents can be reduced.

Introduction

Maritime safety and accidents have become one of the main research topics in recent years (Salihoglu & Bal Beşikçi, 2021; Zhang et al., 2021). Because of their frequency, one of the main concerns is human-related accidents (Coraddu et al., 2020; (Fan, Blanco-Davis, et al., 2020; Fan, Zhang, et al., 2020; Navas de Maya & Kurt, 2020). This study analyses the marine accident involving the M/V *Cosco Busan*, the Hong Kong-registered container ship carrying an all-Chinese crew, which allied with the base of the Delta Tower of the San Francisco-Oakland Bay Bridge in dense fog in November 2007. An analysis of the elements resulting in the accident and its consequences was carried out, followed by an analysis of the navigational risk using mathematical (navigational risk in a specific sailing area) and tabular values (navigational risk using a risk assessment). The main goal of this research is to detect and propose new measures that can be taken to prevent similar accidents at sea in the future.

Marine accidents

Marine accidents occur due to several causes:

- Weather conditions (storm, reduced visibility, ice, etc.);
- A pilot's navigational errors – accidents in confined waters due to heavy traffic;

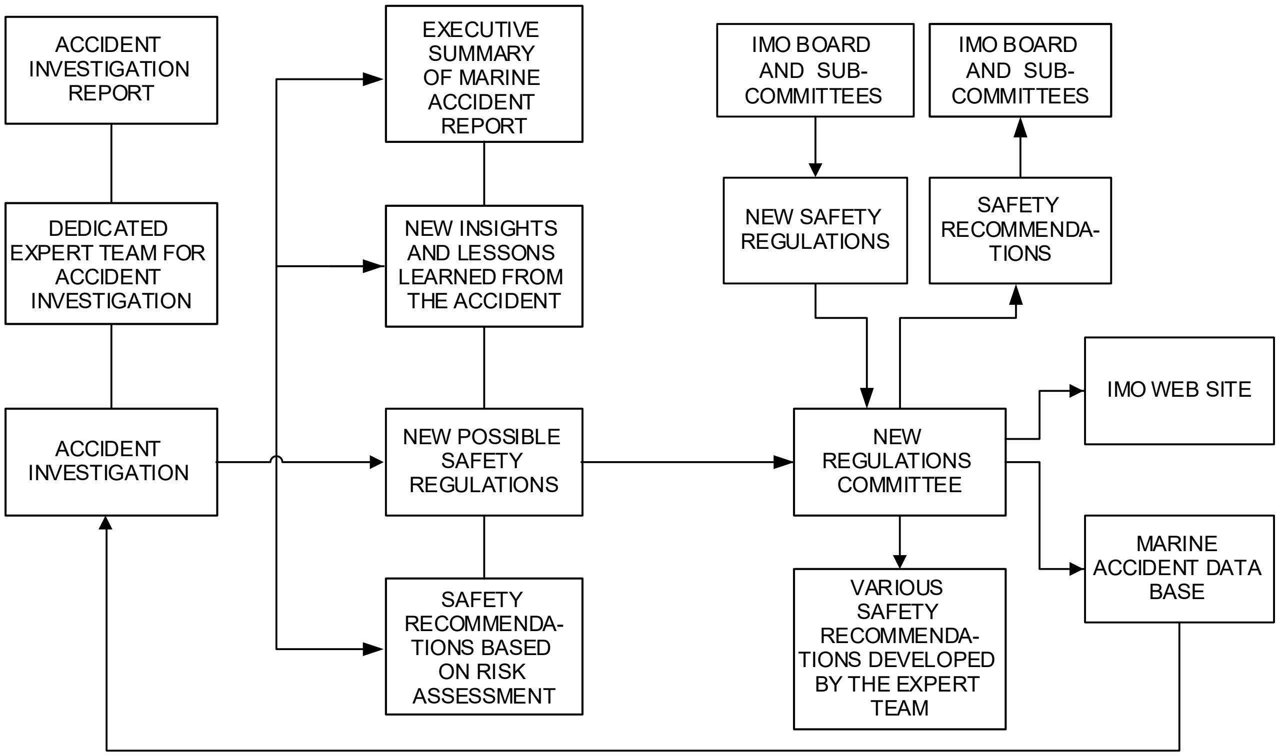

Figure 1. Data flow diagram when investigating a marine accident (IMO, 2004b)

- Collision with unidentified objects and underwater obstacles;
- Collision with other vessels;
- Manoeuvring in confined waters or adverse conditions in a port;
- Carrying dangerous cargo, cargo on deck, or heavy cargo;
- Failure in the steering system, main engine, or other machinery.

Accident investigation reports fall into several categories that are defined by the events that resulted in the accident. These categories include: collisions, grounding, contact, fire or explosion, failure of the hull or water-tight ports, engine room failures, damage to the vessel or equipment, capsizing or listing, vessel disappearance, and accidents associated with life-saving equipment (Zhao et al., 1995). To improve investigations of marine accidents, it is necessary to create an expert group that will, in line with a specific category, analyse the accidents and deliver the following reports: a report on the investigated accident, new insights resulting from the accident, and a presentation of the findings to the seafaring community, including the issues concerning the safety and safety recommendations (Wennink, 1992; Kuehmayer, 2008). Figure 1 presents a flow diagram that can be applied to analyse a marine accident.

Analysis of the M/V *Cosco Busan* accident

On the 7th of November 2007, the container ship M/V *Cosco Busan* allied with the fendering system at the base of the San Francisco–Oakland Bay Bridge. The contact with the bridge tower created a 212-foot-long by 10-foot-high by 8-foot-deep gash in the forward port side of the ship and breached the Nos. 3 and 4 port fuel tanks and the No. 2 port ballast tank. There were no injuries or fatalities that resulted from the accident, but the fuel spill contaminated about 26 NM of shoreline (NM – nautical mile, 1 NM = 1852 m). Total damages were estimated to be $2.1 million for the ship, $1.5 million for the bridge, and more than $70 million for environmental cleanup. The ship cargo consisted of 2529 container units. At 0637, the pilot informed the Vessel Traffic Service (VTS) that he planned to leave berth and pass through the Delta-Echo span, the 2200-foot-long span between towers D and E of the Bay Bridge (pilot – expert in navigating local waters, provided guidance and professional advice to the master for safe navigation in ports, straits, and access to ports). The VTS operator informed him about the reduced visibility due to fog, ranging from 1/8 to 1/4 NM. At 0810, the ship left berth. The black dotted line in Figure 2 shows the ship's intended course (National Transportation Safety Board, 2009).

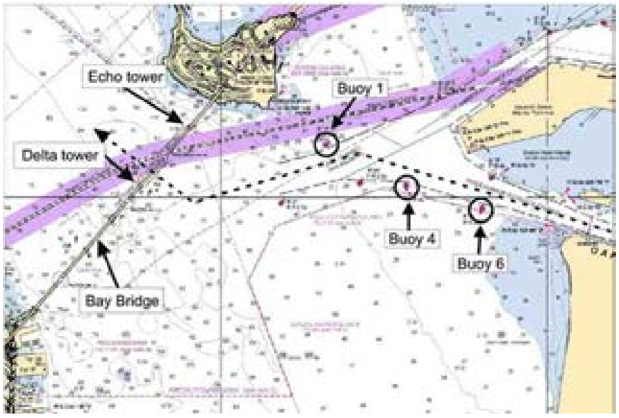

Figure 2. Intended course of the *Cosco Busan* (National Transportation Safety Board, 2009)

Reconstruction of the marine accident and the proposal of new measures

The accident took place at 0830. At 0825, the vessel's heading was 253°, and the pilot ordered rudder to mid-ships (centred), then requested a heading of 250°, followed by 245°. Less than 1 minute later, contrary to his previous instructions, the pilot ordered 10° starboard rudders, then starboard 20°, and the engine to full-ahead to increase thrust over the rudder and achieve greater manoeuvrability. On the loaded *Cosco Busan*, a full-ahead engine would have resulted in an eventual speed of about 17 knots (knot – unit of speed at sea (abbreviation = kn), 1 kn = 1 NM/h). At that moment, the ship's heading was 241°, almost parallel to the bridge. When starboard rudder was applied, the ship's course over ground continued southwest. Figure 3 presents the situation when the pilot ordered 10° starboard rudders, then starboard 20°. At around 0827, the ship's heading was 247°, while her course over ground (her real direction of movement, including leeway) was 236°. The leeway is the angle between the vessel's heading (as indicated by the compass) and the real course over ground, due to the effects of sea currents and wind. A few seconds later, the *Cosco Busan's* heading was increased to 261°, but the course over ground was 235°. The speed remained constant at about 10 knots. The ship was about 1/3 NM (around 620 m) from the bridge. The VTS operator noticed that the vessel deviated from its intended route and was out of position to make an approach to the bridge's Delta–Echo span, and informed the pilot of this. Figure 3 shows the VTS record of the *Cosco Busan* (National Transportation Safety Board, 2009).

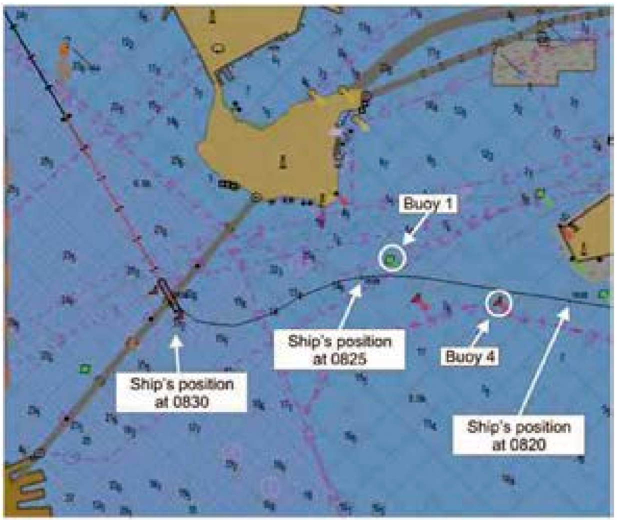

Figure 3. *Cosco Busan's* record of movement (National Transportation Safety Board, 2009)

The "black box" of the voyage, i.e. the Voyage Data Recorder (VDR) showed that when the pilot reported to VTS that he was "steering 280", the ship's actual heading was 262°. The VTS operator did not communicate further with the pilot, as the communication equipment had a time delay. Over the next 2 minutes, the pilot gave rudder orders of hard starboard, mid-ships, starboard 20, and hard starboard. About 10 seconds later, the pilot ordered the rudder to mid-ships. After another 5 seconds, the pilot ordered a hard port rudder. The forward port side of the vessel struck the corner of the fendering system at the base of the Delta tower at 0830. It was later determined that contact with the bridge breached the ship's No. 2 water ballast tank and the Nos. 3 and 4 port fuel tanks (National Transportation Safety Board, 2009).

Results of the *Cosco Busan* accident investigation

According to the VDR, the pilot was not familiar with the symbols on the electronic chart display – he was using the electronic navigation chart but was not sure what the red triangles represented. They were standard International Hydrographic Organization symbols that indicate a conical buoy (Figure 4).

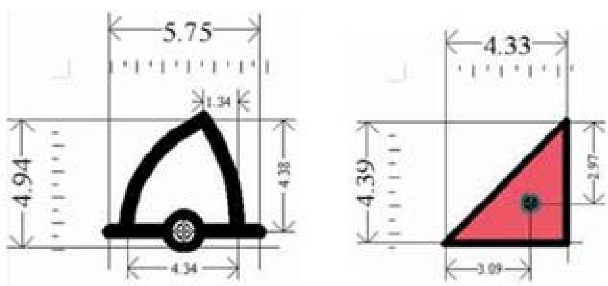

Figure 4. Standard conical buoy symbols: paper chart (left), electronic chart (right) (National Transportation Safety Board, 2009)

Elements established after analysing the accident:

1. Poor familiarisation with the electronic chart symbols (which are standard);
2. The pilot claimed that several minutes prior to contact with the bridge and after repeated rudder orders, the radar image was poor and there was something wrong with the radar (the radar technician later proved that there were no radar image problems and that the radar aids were visible);
3. VTS communication (deviation of the course over ground from the course needed for approaching the bridge in a safe and usual way was excessive, and the pilot was warned about this by VTS);
4. Prescription medications that the pilot used degraded his performance and cognitive functions, which led to several navigational errors;
5. There was no exchange of information, and there was practically no effective communication between the pilot and the master (language and cultural hurdles were too high);
6. The master did not observe the safety management procedures (SMS) implemented by his company;
7. Cultural differences made the master reluctant to assert authority over the pilot;
8. In the minutes before the accident, VTS San Francisco did not provide the pilot with correct and timely information about the vessel's proximity to the Delta tower;
9. VTS did not notify the Coast Guard or Port Authority;
10. Fleet Management, Ltd. failed to adequately train the *Cosco Busan* crewmembers, who were new to the vessel. They provided an SMS manual to the crew only in English, nor in the vessel's working language, which limited the crewmembers' ability to review and follow the SMS and read marine electronic instruments;
11. Fleet Management, Ltd. failed to point out the importance of SMS procedures;
12. Insufficient performance and impact of the master on the pilot's decisions during navigation.

Proposal of new measures after the accident

The M/V *Cosco Busan* belongs to the new generation of fast container ships fitted with modern equipment such as an automatic identification system (AIS), radio detection and ranging (RADAR), electronic chart display integrated system (ECDIS), conning info display (CID), and voyage data recorder (VDR). Ample research has discussed the effect of the above-mentioned equipment on the safety of navigation at sea (Felski & Jaskolski, 2013; Brčic, Kos & Žuškin, 2015; Zhang et al., 2015; He & Feng, 2016; Mao et al., 2018; Rutkowski, 2018). However, the *Cosco Busan* accident proved that advanced equipment alone does not guarantee safe navigation. New measures have been suggested by the authors to prevent or reduce such accidents, including:

1. Visibility must be at least 1/2 NM for the ship's unobstructed passage through a specific area;
2. Each pilot should carry his/her personal computer installed with electronic charts covering specific areas;
3. In the electronic chart, the voyage should be plotted from berth to berth, not between the points of embarking/disembarking the pilot;
4. The master and the pilot must agree on the passage plan, and a written document has to be available to exchange this information.

Proposal of the new procedures and measures for marine accidents

Application and proposal of procedures for marine accidents

Based on the above-discussed case study, existing risks are analysed mathematically and proposals are given for implementing new improved measures for a detailed risk assessment in navigation, which is an essential factor of safe shipping (Heikkilä, 2006; Eliopoulou, Papanikolaou & Voulgarellis, 2016; Grech, 2018; Medić, Lušić & Bošnjak, 2019). The improved measures should be taken before undertaking a maritime adventure. It is suggested that a threat matrix be introduced for analysing a specific navigation process. The threat matrix should feature a list of adequate factors that have – or may have – an impact on the navigation process, according to the coefficient of relevance. It is suggested that a coefficient of relevance CoR, ranging from 1 to 3, be introduced, depending on the specific shipping area where a marine accident may take place:

CoR = 3 is considered a high risk (red), i.e., a hazardous navigation area;

CoR = 2 is considered a moderate risk (yellow), i.e., a moderately hazardous area;

CoR = 1 is considered a low risk (green), i.e., a safe navigation area.

It is suggested that tables be created (Table 2 and Table 3) in correlation with the threat matrix when assessing the risk. The threat matrix should look like Table 1.

Table 1. Threat matrix for performing a navigation process

Coefficient of relevance (CoR)	Factor	Degree of the threat					
		0	1	2	3	4	5
1	Factor 1						
2	Factor 2						
3	Factor 3						

A mathematical analysis should produce a calculated risk, regardless of the coefficient of relevance (CoR). It is suggested that navigation risk in a specific navigation process can be determined through a formula derived from the following source (Zhao et al., 1995):

$$NR_{dp} = \sum_{i=1}^{s} P_{\mathrm{rel}(i)} \times Q_{\mathrm{rel}(i)} \quad (1)$$

where: NR – coefficient of the navigation risk, $P_{\mathrm{rel}(i)}$ – relative measure of the likelihood of an accident, and $Q_{\mathrm{rel}(i)}$ – relative measure of the consequence of the accident.

The overall degree of the threat to the vessel underway can be mathematically computed through the formula that is derived from the source (Macduff, 1974):

$$PL = \sum_{i=1}^{Na} PL_{(i)} \quad (2)$$

where: PL – total voyage, and Na – total frequency of the processed accidents during a voyage.

Applicaion and proposal of measures for risk assessment in navigation

In order to carry out a risk assessment for the above-discussed accident, as well as for other marine accidents with similar consequences, it is suggested that a set of measures be displayed in tabular form. By using them, it is possible to perform a risk assessment. The table suggests the elements on which the risk assessment will be based, as well as the consequences resulting from the elements of risk, whose degree is interdependent with the degree of a hazard. In case of increased risk, we could introduce elements that reduce the level of risk with regard to the corresponding complexity of the navigation process.

The main risk assessment elements can fall into two categories:

- Measure a hazard and consequence for each category of hazard, and
- Probability of a hazard.

Table 2 is suggested for assessing hazards during the navigation process. It should be completed prior to a specific navigation process. Such a table should have been completed for the above case study.

Table 2. Assessment of hazards (Author's adaptation of sources (IMO, 2004a; 2004b))

Category	Definition of consequence
Small	Loss of time No collision, no damage No injured crewmembers No harmful impact on the environment
Medium	Minor damage due to collision Minor injuries in crewmembers Minor damage to the environment
High	Collision causing large damage Fatalities or heavy injuries Substantial pollution of the environment

Table 3 is suggested to assess the probability of hazards during the navigation process. It should be completed prior to a specific navigation process. Such a table should have been completed for the above case study.

Table 3. Assessment of the probability of a hazard (Author's adaptation of sources (IMO, 2004a; 2004b))

Category	Definition of likelihood
Unlikely	Hazard that occurs rarely, according to the experience of those involved in risk assessment
Possible	Hazard that occurs occasionally, according to the experience of those involved in risk assessment
Very likely	Hazard that occurs frequently, according to the experience of those involved in risk assessment

A combination of Table 2 and Table 3 produces Table 4, which allows for a risk assessment. The suggested table can serve as the basis for assessing the risk in a case study.

Table 4. Risk analysis

Severity of the situation	Probability of an event		
	Not likely	Possible	Very likely
High	yellow	red	red
Medium	green	yellow	red
Low	green	green	yellow

Following the table (Table 4), it appears that the key designations for risk assessment can be introduced:

- Red area = unacceptable risk (navigation process is deemed unacceptable and should be stopped or reduced to at least a yellow designation);
- Yellow area = partially acceptable risk (navigation process is deemed partially acceptable and appropriate measures should be taken to reduce the risk to a green designation), and
- Green area = acceptable risk (navigation process is deemed acceptable and no further measures should be taken to reduce the risk).

Based on the risk assessment, the correct course of the ship should have been plotted as in Figure 5.

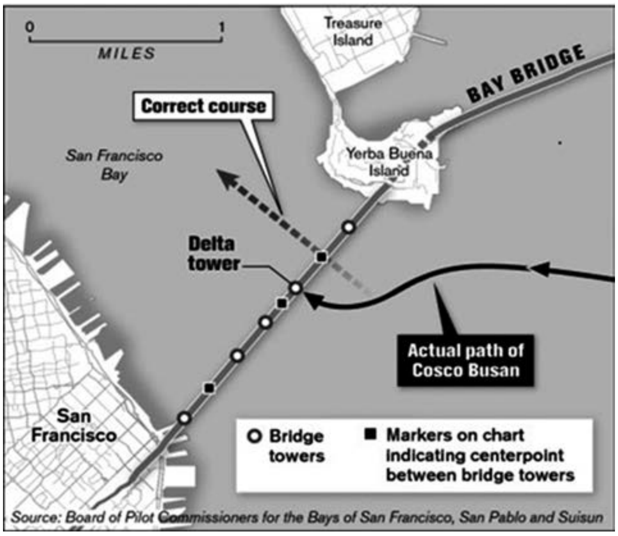

Figure 5. Correct course for passage under the Bay Bridge (National Transportation Safety Board, 2009)

According to Table 4, the risk assessment for this case study was designated as red. In the above example, the navigation process is acceptable, but additional measures need to be taken, given the table values.

The application suggests various adequate measures to prevent such events. These measures include:

- continuing to monitor the position,
- control of the plotted course accuracy,
- control of the position accuracy,
- control of the installed program solutions regulating the accuracy of the entered course,
- control of risk assessment measures, and
- communication with the company regarding a specific risk.

The navigation process of the M/V *Cosco Busan* should have been stopped until the risk assessment was reduced to at least a yellow designation. It is suggested that the above tables should be used to perform a risk assessment in the future.

Conclusions

Most navigation equipment manufacturers tend to supply and install higher-class equipment on board to make a higher profit. On the other hand, a number of shippers and charterers prefer to have the minimum required equipment to reduce operation costs, which puts the safety of human life, ships, cargo, and the environment at risk. The International Maritime Organization sets the minimum equipment requirements for vessels over 500 GT (gross tonnage). It is suggested that a tabular list of mandatory equipment be introduced, with regard to the level of the actual navigational risk and the shipping area where the navigation process takes place. So far, this has not been common practice across the global merchant fleet. Keeping in mind the complexity of the technologies used in navigation and manoeuvring processes, it can be concluded that the system as a whole has not yet reached the necessary level of automation, as the process control still depends, to a large extent, on human factors (e.g., the master and the pilot). Based on the discussed case study, it can be concluded that the recent level of automation on-board new generations of vessels has not yet increased the safety of the navigation and manoeuvring processes involving large ships due to insufficiently trained pilots and masters.

In spite of advanced technologies and the integration of navigation instruments, the system is still considered relatively unreliable because errors have not been eliminated entirely. Pilots and masters remain the key elements of the largest part of the navigational process. The system still cannot forecast situations based on known current parameters of the navigation process.

If the coloured zones presented in Table 4 are applied to Figure 5, then the following can be applied: the green colour zone is the correct course, the yellow zone is the area between the correct course and the actual path, and the red colour is the actual path. This should be considered in voyage plans despite marking safety depth, safety margins, shallow, and deep contours.

It is suggested that further research be performed and new measures designed to increase the safety and operability of the system. Furthermore, continuous monitoring is suggested for the vessels that have been involved in accidents, as well as detailed analyses of the risks that resulted in marine accidents. Finally, measures to reduce navigation risk are suggested based on risk assessment tools.

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