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KEY NAVIGATION SAFETY FACTORS IN TAIWANESE HARBORS AND SURROUNDING WATERS

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Key words: maritime incidents, navigation safety, factor analysis, Taiwanese waterways.

ABSTRACT

This study investigated navigation safety in Taiwanese harbors and surrounding waters. The key factors that influence navigation safety were summarized by reviewing relevant literature and by interviewing experts. A questionnaire survey was used to assess the degree of importance of these different factors, including human, vessel, harbor traffic, and climatic and environmental factors. A factor analysis was used to design a systematic hierarchical structure for clustering these factors. This study suggests that duty officers can prevent maritime incidents from occurring by taking precautions against the various key factors identified here.

I. INTRODUCTION

Taiwan, as an island country, relies on maritime traffic for international trade. Every year, the amount of goods shipped by sea accounts for over 90% of all imports and exports in Taiwan (Taiwanese Ministry of Transportation and Communications, 2014). Because Taiwan is heavily reliant on maritime trading as an economic lifeline, maritime incidents not only cause great damage to the financial interests of shipping companies and human lives, but also risk jeopardizing the international trading activities that are crucial to the economy. Moreover, the maritime environment is also negatively affected. Therefore, it is imperative that the occurrence of maritime incidents is prevented. The government and shipping industries should maintain navigation safety and reduce such occurrences by increasing human and material resources.

Numerous vessels commute around Taiwanese waters. As the economy expands with increased trading on international markets, these vessels increase in number and become larger and more specialized, which increases the value of the vessels as well as the goods transported. Hence, planning and risk management for maritime traffic and navigational safety are becoming increasingly crucial for the protection of human lives and the maritime environment, as well as for the development of the national economy and trade.

Few studies have sought to determine the critical factors that cause maritime accidents and affect navigational safety in Taiwanese waterways. This study, therefore, attempts to fill in the gaps in the literature to help improve navigation safety in Taiwanese waterways. The critical factors that influence navigation safety, derived from a literature review and interviews with field experts, are summarized in Sections 2 and 3. A statistical analysis is presented in Section 3 to assess the degree of importance for each factor, followed by a detailed discussion (Section 4). Factor analysis was applied to design a systematic hierarchical structure for clustering the factors that affect navigation safety within Taiwanese waterways. Finally, based on these findings, Section 5 suggests that duty officers can prevent maritime incidents from occurring by taking precautions against the various key factors identified in this paper.

II. LITERATURE REVIEW

The shipping crew, vessel owners, society, and the natural environment all pay a heavy price when maritime incidents occur. Therefore, all maritime countries endeavor to reduce maritime incidents and enhance navigation safety (Chen, 2002; Kuo et al., 2007; Arslan and Turan, 2009; Chen et al., 2013; Park et al., 2013). Chen (2000) stated that the risks encountered in vessels were often due to personnel, mechanical equipment, and the potential dangers of accumulated cargo within vessels with limited carrying capacity. These risk factors are likely to turn into serious incidents. Accordingly, a

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safe vessel operating system is composed of four main components: the crew, vessel and cargo, navigation environment, and vessel companies.

Xu et al. (2006) suggested that while vessels are traveling within the waters around a harbor, they should separate their operating system into the vessel operator, vessel, and environment as categories for safety assessment. Liu et al. (2006) analyzed the maritime incident reports from 1992 to 2003 of four Taiwanese international harbors, and suggested that investigations and assessments into maritime incidents be separated into six key elements: the number of maritime accidents, casualty rate, number of people dead or missing, number of ships damaged, number of people injured, and number of ships sunk. Hetherington et al. (2006) reviewed the investigations and analyses performed in the same area and discovered that apart from human factors, most of the maritime incidents were caused by other factors such as automation, fatigue, stress, health, situation awareness, decision making, communication, teamwork, and safety culture. Lu and Tsai (2008) studied the factors influencing the maritime incidents of vessels and the assessments revealed that management safety practices, supervisor safety practices, safety attitude, safety training, job safety, and coworker safety practices were also influential factors in causing maritime incidents. Management safety practices, safety training, and job safety have significant effects on accidents involving the crew; whereas only job safety has a significant influence on vessel malfunction incidents. In addition to human factors, environmental factors also contribute to maritime accidents (Akten, 2004; Toffoli et al., 2005; Awal et al., 2010). Hsu (2010) stated that in addition to human factors, the vessel traffic service (VTS), harbor landmark equipment, maritime pilots, fishing boat operating conditions, tugs, characteristics of operators, vessel factors, climatic and geographical conditions, and other relevant factors could all influence navigation safety. To visualize the locations where incidents occurred, Dobbins and Abkowitz (2010) employed Geographic Information Systems and Google Earth to investigate the most frequent allision, collision, and grounding accident locations on the inland waterway network in the United States.

Liu et al. (2004) noted that because the conditions of the natural environment could not be forecast accurately by humans, an analysis of the natural environment where a maritime incident had occurred could reduce the probability of such incidents from reoccurring. Toffoli et al. (2005) referenced and assessed data from Lloyd's Maritime Information Service between 1994 and 1999 on 650 accounts of maritime incidents. They suggested marking areas where the sea or environmental conditions were rapidly changing as hazardous regions.

Taiwan is surrounded by the sea and has a highly developed economy and international trading connections; hence, maritime traffic is regarded as the lifeline of the economy. Over 400 vessels sail in the waters around Taiwan daily (Chou, 2006). Those aiming to sail into or out of Taiwanese harbors account for 70%-80% of traffic, whereas the rest simply pass through the waters near Taiwan. The vessels passing through often result in many vessel encountering areas. Chung (2008) referenced the maritime incidents data from the Taiwanese Coast Guard Administration during the period from 2005 to 2007 and discussed the areas where maritime incidents occurred. He discovered that these areas were mainly in the waters surrounding Taiwan. Yao (1993) investigated maritime incidents from 1982 to 1991 and concluded that Taiwanese waters were moderate-risk maritime environments. To explore the analyses of maritime incidents and the efficiency of the search and rescue teams in national rescue areas, Guo (1993) examined the maritime incidents in surrounding Taiwanese waters and found that for normal vessels, there were more incidents occurring within the harbor than outside the harbor; whereas for fishing boats, the chances of incidents occurring within the harbors were low. Cockcroft (1983) found that the chances of a vessel in a confined water area colliding was positively proportional to the density of vessels in that water area in square meters. Furthermore, future potential hazards can be foreseen because vessels are becoming more professionalized and increased in size. Lin (2007) claimed that collisions between fishing boats were mainly due to inadequate adherence to the International Regulations for Preventing Collisions at Sea, as well as night fishing habits.

Although a considerable number of studies have analyzed maritime accidents, maritime traffic, and human factors that cause maritime accidents, few of them have focused on navigational safety in Taiwanese waterways. To understand the critical factors that cause maritime accidents and affect navigational safety, this study attempts to fill the gap in the literature.

III. METHODOLOGY

This study focused on the harbors and surrounding waters where maritime incidents are concentrated, and analyzed and clarified the potential factors that vessels should assess when traveling through these areas. We first interviewed pilots, captains, deck officers, experienced maritime employees, and experts with excessive knowledge of maritime traffic. Those with navigation experience provided information on practical experience and views on navigation safety assessment, whereas the maritime academic experts offered views on identifying the factors that influence navigational safety. After integrating the differences between them, we archived and mailed an official assessment questionnaire for evaluating the key criteria for navigators to sail safely in and out of harbors, as well as in the surrounding waters.

1. Research Design

For vessels to navigate safely to their destinations, various factors must be assessed throughout the journey. In addition to professional knowledge and skills, practical experience in navigation is crucial to assessing these factors. This study used various experts with experience in navigation as the

Table 1. The major causes of maritime incidents.

Factor	Commercial vessel								Fishing boat							
	Harbors and surrounding waters				Outside the harbor				Harbors and surrounding waters				Outside the harbor			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
Human	**V**	**V**		**V**			**V**						**V**	**V**	**V**	**V**
Vessel				**V**			**V**								**V**	**V**
Harbor traffic	**V**															
Climatic and environmental		**V**											**V**	**V**		

Note: (a) Collision, (b) Grounding, (c) Mechanical malfunction, and (d) Fire.

survey subjects. The research program was designed and separated into four steps: (1) questionnaire design, (2) questionnaire writing, (3) pretesting, and (4) establishment of the formal questionnaire.

1) Questionnaire Design

The questionnaire was divided into two categories: the background of the respondents and navigation safety variables. The background information included age, level of education, corporate titles, work experience, and the type of vessel served. Navigation safety variables used a five-point Likert scale for assessment, ranging from 1 (*very unimportant*) to 5 (*very important*).

Svein (2004) indicated that concentrating on solving one aspect of risk could result in neglecting other associated aspects. Various assessments should be conducted during the safe navigation of vessels to analyze wide-ranging comprehensive measures and ensure navigation safety. These include an operations assessment between a person and machinery, a performance assessment between the machinery and the environment, and an assessment between a person and the environment. Thus, this study grouped navigation safety variables into four dimension of factors: human, vessel, harbor traffic, and climatic and environmental factors.

2) Questionnaire Writing

On the basis of past analyses of various maritime incidents involving collision, grounding, mechanical malfunction, and fires (Chou, 2006), we determined that the major causes of incidents were as follows:

(a) Collision: violations of international regulations for preventing collisions (International Regulations for Preventing Collision at Sea, 1971), noncompliance with local laws related to navigation, poor operating conditions of fishing or other vessels, negligence or lack of preparation by duty officers, the inability to respond in time, and force majeure factors.
(b) Grounding: environmental factors such as poor visibility, being hit by large waves caused by typhoons, and strong winds or currents; and human factors such as not correcting ship charts, accidentally running into shallow reefs, inadequately calculating ship positions and water depth, and not paying attention to the anchor, resulting in the anchor drifting away.
(c) Mechanical malfunction: a lack of regular inspections or maintenance by personnel on board, the old age of machinery, prolonged erosion by the sea, and improper operation by new crew members unfamiliar with the machinery.
(d) Fire: improper cooking, unsafe repair work or wires, the accidental ignition of easily combustible materials on board, the spontaneous combustion of cargo on board, high cabin temperatures igniting other aspects, and combustion or explosions caused by various other accidents.

This paper analyses the records of maritime incidents that occurred within and nearby Taiwanese waters in the recent five years, with the major causes listed in Table 1. The results show that: (a) collisions were mainly caused by human, harbor traffic, and climatic and environmental factors, with incidents involving commercial vessels occurring mainly within the harbor, and those involving fishing boats occurring mainly outside the harbor; (b) groundings were mainly caused by human and climatic factors, where commercial vessel incidents were distributed in the harbor and surrounding waters, whereas fishing boat incidents occurred mainly outside of the harbor; (c) mechanical malfunctions were mainly caused by human and vessel factors, where the incidents involving both commercial vessels and fishing boats were highest in the waters outside the harbor; and (d) fire incidents were mainly due to human and vessel factors, with those involving commercial vessels occurring mainly in the harbor, whereas those involving fishing boats occurred mainly outside of the harbor.

3) Pretesting

After isolating the causes of the maritime incidents, we administered interviews with 14 maritime experts and academics to pretest the original questionnaire, and held a discussion with them. We then developed a questionnaire from the issues they raised, and each expert and academic provided recommendations on the questionnaire. We compared the differences of feedback on each question and integrated them into one questionnaire. With the recommendations, we also

Table 2. Background information of the respondent.

	Type	Amount	Ratio (%)
Age	20~30 years	3	5.3%
	31~40 years	10	17.9%
	41~50 years	13	23.2%
	51~60 years	21	37.5%
	Over 60 years	9	16.1%
Level of education	College	25	44.6%
	University	19	33.9%
	Master	10	17.9%
	PhD	2	3.6%
Corporate titles	Maritime pilot	15	26.8%
	Captain	19	33.9%
	Chief officer	14	25.0%
	Academics	3	5.4%
	Others	5	8.9%
Work experience	1~5 years	3	5.4%
	6~10 years	8	14.2%
	11~15 years	9	16.1%
	15~20 years	12	21.4%
	Over 20 years	24	42.9%
Type of vessel	Container	39	69.6%
	Bulk	35	62.5%
	Tanker	22	39.3%
	Ferry	1	1.8%
	Ore carrier	21	37.5%
	General cargo	28	50.0%
	LNG/LPG	2	3.6%
	Others	24	42.9%

Table 3. The descriptive statistical analysis of human factors.

Human factors (C_1)	Mean (ranking)	Standard deviation
C_{11}: Steady control of the vessel while navigating within the harbor area	4.8393 (1)	0.37059
C_{12}: Inaccurate judgment of how other vessels navigate	4.5357 (4)	0.53815
C_{13}: Duty officers not fulfilling their responsibilities	4.4000 (8)	0.55922
C_{14}: Crews lacking language skills	4.1607 (11)	0.78107
C_{15}: Violation of the rules of the harbor, either by oneself or by other vessels	4.6607 (3)	0.47775
C_{16}: Failure by the crew to prepare for work properly on time	4.4286 (6)	0.62834
C_{17}: Failure to respond safely when encountering or cross-encountering vessels	4.7143 (2)	0.49412
C_{18}: Poor physical and mental condition of the crew	4.2500 (10)	0.74468
C_{19}: Inability to comprehend the operating characteristics of the vessel	4.4821 (5)	0.57179
C_{110}: Cooperation between the tugs and the vessels when berthing	4.2679 (9)	0.55567
C_{111}: Misjudging the effects of the natural environment caused by the lack of navigation experience	4.4107 (7)	0.65441
C_{112}: Vessel management system of the shipping company	3.7455 (12)	0.74390

amended ambiguous questions and finalized the formal questionnaire. The validity of the questionnaire was achieved by amending the style and direction of the questionnaire with the suggestions and comments from the experts and academics.

4) Establishment of the Formal Questionnaire

After pretesting, the questionnaire was finalized and delivered for testing. The test variables included: human factors (shown in Table 3), vessel factors (Table 5), harbor traffic factors (Table 7), and climatic and environmental factors (Table 9).

IV. DATA ANALYSIS

1. Data Analysis and Result Discussion

Of 81 questionnaires sent by mail, 59 were returned. Three of them were eliminated because of unclear or repeated answers, resulting in 56 valid questionnaires for analysis and an effective response rate of 69.1%. The background information of the respondents are summarized in Table 2. The respondents were mainly aged 51-60 years (37.5%), 41-50 years (23.2%), and 31-40 years (17.9%). The level of education achieved was mainly college (44.6%) and university-level (33.9%). Most of the corporate titles were captain (33.9%), followed by maritime pilot (26.8%), and deck officer (25.0%). Regarding work experience, 42.9% had over 20 years of experience, 21.4% had 15-20 years of experience, and 16.1% had 11-15 years of experience. Because most of the respondents had experience serving in various vessels, the data on type of vessel is represented differently; for example, 39 of 56 respondents had experience serving on container vessels (69.6%), but might also have served on other types of vessels.

1) Human Factors

The human factors influencing navigation safety are shown in Table 3, ranked by average importance. The six highest ranked factors are (1) C_{11}: steady control of the vessel while navigating within the harbor area (mean = 4.8393); (2) C_{17}: failure to respond safely when encountering or cross-encountering vessels (mean = 4.7143); (3) C_{15}: violation of the rules of the harbor, either by oneself or by other vessels (mean = 4.6607); (4) C_{12}: inaccurate judgment of how other vessels navigate (mean = 4.5357); (5) C_{19}: inability to comprehend the operating characteristics of the vessel (mean = 4.4821); (6) C_{16}: failure by the crew to prepare for work

Table 4. Human factors listed by order of importance to each type of surveyed subjects.

Ranking	Pilot	Captain	Deck officer	Academics	Others
1	C_{11}	C_{11}	C_{12}	C_{13}	C_{11}
2	C_{15}	C_{17}	C_{17}	C_{17}	C_{15}
3	C_{17}	C_{15}	C_{11}	C_{111}	C_{12}
4	C_{19}	C_{13}	C_{15}	C_{11}	C_{14}
5	C_{111}	C_{19}	C_{18}	C_{16}	C_{18}
6	C_{12}	C_{12}	C_{16}	C_{12}	C_{17}
7	C_{16}	C_{14}	C_{19}	C_{14}	C_{13}
8	C_{110}	C_{16}	C_{110}	C_{15}	C_{16}
9	C_{13}	C_{18}	C_{13}	C_{19}	C_{19}
10	C_{14}	C_{111}	C_{111}	C_{110}	C_{110}
11	C_{18}	C_{110}	C_{14}	C_{18}	C_{111}
12	C_{112}	C_{112}	C_{112}	C_{112}	C_{112}

Table 5. The descriptive statistical analysis of vessel factors.

Vessel factors (C_2)	Mean (ranking)	Standard deviation
C_{21}: Controlling equipment	4.8036 (1)	0.44393
C_{22}: Auxiliary equipment	4.1964 (4)	0.64441
C_{23}: Communication equipment	4.2143 (3)	0.67995
C_{24}: Ancillary equipment	3.8750 (6)	0.63425
C_{25}: The types of main engine	3.6296 (8)	0.74581
C_{26}: Age of the vessel	3.5185 (9)	0.75656
C_{27}: Cargo loading conditions	4.1071 (5)	0.67900
C_{28}: Cargo content	3.5179 (10)	0.89425
C_{29}: The weight of the vessel	3.7321 (7)	0.88402
C_{210}: Vessel body type	4.3214 (2)	0.66352

properly on time (mean = 4.4286). The vessel management system of the shipping company (C_{112}, with mean = 3.7455) was least important in navigation safety.

We associated each of the respondents to the six highest ranked human factors. The results show that the relative importance of each factor varied by respondent (Table 4). The top three human factors emphasized by the maritime pilots were C_{11}, C_{15}, and C_{17}. For the captains, they were C_{11}, C_{17}, and C_{15}. The deck officers reported that C_{12}, C_{17}, and C_{11} were most important. The academics placed more emphasis on C_{13} (duty officers not fulfilling their responsibilities), C_{17}, and C_{111} (misjudging the effects of the natural environment caused by the lack of navigation experience). The other respondents rated C_{11}, C_{15}, and C_{12} as the most important factors. All the respondents, regardless of type, considered the companies' vessel management system (C_{112}) the factor with the fewest effects on navigation safety.

The pilots, captains, and deck officers considered the factors C_{11}, C_{15}, and C_{17} the most important factors in navigation safety. Within a harbor, the navigational space is limited for the maneuvering of vessels, which complicates the use of the rudder, propeller, thrusters, and the speed required. This is why the steady control of vessels while navigating within the harbor area (C_{11}) was considered the most important human factor. Tomera (2014) derived the same finding.

Collisions occur when a greater number of objects are encountered or cross-encountered, often because of inappropriate responses and conflicted decision-making in steering. This is why the failure in responding safely when encountering or cross-encountering vessels was the second most important factor. Lisowski (2014) and Weng and Xue (2015) have also indicated the navigational risks of encountering other vessels in busy harbor waters.

The third most important factor was violation of the rules of the harbor, either by oneself or by other vessels. The International Regulations for Preventing Collisions at Sea, formulated by the International Maritime Organization, should be considered when steering a ship, both inside the harbor and at sea. The minimum distance required for anti-collision by the give-way ship (under normal situations) and by both the give-way ship and the stand-on ship steering simultaneously (under critical situations) should follow these regulations under all possible encounter situations. Collisions can occur when either vessel violates these regulations or the rules of the harbor. This observation matches the viewpoints of Lin (2007) and Zhang et al. (2012).

As shown in Table 4, the viewpoints of the academics differed from those of the other respondents. The reason may be that some of the academics were young and lacked navigational experience at sea.

2) Vessel Factors

The descriptive statistical analysis of vessel factors that influenced navigation safety in harbor areas is shown in Table 5. The five top ranked factors were: (1) C_{21}: controlling equipment (mean = 4.8036); (2) C_{210}: vessel body type (mean = 4.3214); (3) C_{23}: communication equipment (mean = 4.2143); (4) C_{22}: auxiliary equipment (mean = 4.1964); and (5) C_{27}: cargo loading conditions (mean = 4.1071). These were followed by: (6) C_{24}: ancillary equipment; (7) C_{29}: the weight of the vessel; (8) C_{25}: the type of main engine; (9) C_{26}: the age of the vessel; and (10) C_{28}: the cargo content.

Table 6 ranked vessel factors according to the respondents' rankings. The pilots indicated that the top three factors affecting vessel control were C_{21}, C_{210}, and C_{22}. The captains suggested that C_{21}, C_{23}, and C_{27} were the most important factors, whereas the deck officers emphasized C_{21}, C_{23}, and C_{210}. The academics indicated that C_{21}, C_{23}, and C_{22} were the three most important vessel factors influencing vessel control. The others considered C_{21}, C_{23}, and C_{27} the three most important factors. The bottom-ranked factors were cargo content (C_{28}), the age of the vessel (C_{26}), and the weight of the vessel (C_{29}).

All the respondents considered controlling equipment (C_{21}) the most important factor. Ship maneuvering in harbor waters is one of the most dangerous and complex types of vessel

Table 6. Vessel factors listed by order of importance according to each type of surveyed subjects.

Ranking	Pilot	Captain	Deck officer	Academic	Others
1	C_{21}	C_{21}	C_{21}	C_{21}	C_{21}
2	C_{210}	C_{23}	C_{23}	C_{23}	C_{23}
3	C_{22}	C_{27}	C_{210}	C_{22}	C_{27}
4	C_{25}	C_{210}	C_{22}	C_{29}	C_{22}
5	C_{23}	C_{22}	C_{24}	C_{210}	C_{24}
6	C_{27}	C_{24}	C_{27}	C_{24}	C_{210}
7	C_{26}	C_{25}	C_{29}	C_{27}	C_{25}
8	C_{29}	C_{28}	C_{28}	C_{25}	C_{26}
9	C_{24}	C_{26}	C_{25}	C_{28}	C_{29}
10	C_{28}	C_{29}	C_{26}	C_{26}	C_{28}

motion control. When a ship moves in a harbor, all available controllers and equipment are used, including the rudder, propeller, and thrusters. Because of the low speed, nonlinear ship dynamics, various ship maneuvering movements, and complex harbor environment, ensuring the ship is maneuvering safely in the harbor is critical, especially for large ships. Tomera (2014) indicated the same result in his study.

According to Table 6, the pilots had different viewpoints than those of the captains regarding vessel factors. The pilots are responsible for ship maneuvering and the entering and exiting of harbors. Various vessel body types have different maneuvering characteristics, and power is a major element in ship maneuvering. Therefore, the pilots considered controlling equipment (C_{21}), vessel body type (C_{210}), and auxiliary equipment (C_{22}) the top three vessel factors.

By contrast, when a maneuvering ship is entering or exiting a harbor, the captain is responsible for the communications between his or her vessel and the harbor control station. The traffic flow of ships in a harbor can be typically divided into several groups: container ships, general cargo ships, bulk ships, roll-on roll-off ships, tankers, and passenger ships. Various cargo loading conditions will affect a ship's maneuvering and navigation safety. Weng and Xue (2015) also reported the same findings. Therefore, the captains in our study suggested that controlling equipment (C_{21}), communication equipment (C_{23}), and cargo loading conditions (C_{27}) were the top-ranked vessel factors.

The deck officers also considered the controlling equipment (C_{21}), communication equipment (C_{23}), vessel body type (C_{210}), and auxiliary equipment (C_{22}) the top-ranked vessel factors.

3) Harbor Traffic Factors

A descriptive statistical analysis for harbor traffic factors influencing navigation safety is shown in Table 7. The top three aspects were: (1) C_{31}: the density of vessels navigating through the harbor area (mean = 4.4643); (2) C_{33}: the width and depth of the navigation channel (mean = 4.3571); and (3) C_{34}: the operating conditions of non-berthing and departing vessels (mean = 4.2364). These were followed by: (4) C_{36}: the size of harbor waters; (5) C_{32}: the density of vessels berthing in the harbor area; and (6) C_{35}: the position of buoys or anchorage.

Table 7. The descriptive statistical analysis of harbor traffic factors.

Harbor traffic (C_3)	Mean (ranking)	Standard deviation
C_{31}: The density of vessels navigating through the harbor area	4.4643 (1)	0.57094
C_{32}: The density of vessels berthing in the harbor area	4.1071 (5)	0.77878
C_{33}: The width and depth of the navigation channel	4.3571 (2)	0.61581
C_{34}: Operating conditions of non-berthing and departing vessels	4.2364 (3)	0.80822
C_{35}: The position of buoys or anchorage	3.8571 (6)	0.67227
C_{36}: The size of the harbor waters	4.1429 (4)	0.72434

Table 8. Harbor traffic factors listed by order of importance according to each type of surveyed subjects.

Ranking	Pilot	Captain	Deck officer	Academics	Others
1	C_{34}	C_{33}	C_{31}	C_{33}	C_{31}
2	C_{31}	C_{31}	C_{33}	C_{35}	C_{33}
3	C_{32}	C_{36}	C_{36}	C_{31}	C_{32}
4	C_{33}	C_{34}	C_{34}	C_{32}	C_{35}
5	C_{36}	C_{32}	C_{32}	C_{34}	C_{34}
6	C_{35}	C_{35}	C_{35}	C_{36}	C_{36}

From Table 8, the top three harbor traffic factors reported by the pilots were C_{34}, C_{31}, and C_{32}; for the captains, they were C_{33}, C_{31}, and C_{36}. The deck officers indicated that C_{31}, C_{33}, and C_{36} were the most important harbor traffic factors, whereas the academics reported that C_{33}, C_{35}, and C_{31} were the most important. The others reported that C_{31}, C_{33}, and C_{32} were the key factors. In general, all the respondents agreed that the density of vessels navigating through the harbor area (C_{31}) was one of the key contributing factors influencing navigation safety in harbor areas. The pilots, captains, and deck officers treated the position of buoys or anchorage (C_{35}) as the least important aspect, whereas the academics and others indicated that the least important aspect was the size of the harbor waters (C_{36}).

One of the main missions of a pilot is to maneuver the ship to enter and exit the harbor safely. Therefore, the pilot must account for the operating conditions of non-berthing and departing vessels (C_{34}), the density of vessels navigating through harbor areas (C_{31}), and the density of vessels berthing in the harbor area (C_{32}) to avoid collisions. This observation matches the viewpoint proposed by Cockcroft (1983). In addition, the

Table 9. The descriptive statistical analysis of climatic and environmental factors.

Climate and environment (C_4)	Mean (ranking)	Standard deviation
C_{41}: Strong or monsoonal winds	4.8036 (1)	0.40089
C_{42}: Fog and thunderstorms	4.7143 (2)	0.52964
C_{43}: Tides	4.2143 (5)	0.62419
C_{44}: Water currents	4.4643 (4)	0.57094
C_{45}: Geology of the sea bed	3.8393 (6)	0.78107
C_{46}: Typhoons	4.6607 (3)	0.51440

Table 10. Climatic and environmental factors listed by order of importance according to each type of surveyed subjects.

Ranking	Pilot	Captain	Deck officer	Academics	Others
1	C_{42}	C_{41}	C_{41}	C_{46}	C_{42}
2	C_{41}	C_{42}	C_{42}	C_{44}	C_{41}
3	C_{46}	C_{44}	C_{44}	C_{45}	C_{46}
4	C_{44}	C_{46}	C_{46}	C_{41}	C_{43}
5	C_{43}	C_{43}	C_{43}	C_{42}	C_{44}
6	C_{45}	C_{45}	C_{45}	C_{43}	C_{45}

pilot also must focus on the width and depth of the navigation channel (C_{33}) to avoid grounding.

Whereas a local pilot is generally familiar with the width and depth of a navigation channel, a captain entering or exiting a harbor for the first time is not. The captain must particularly focus on the width and depth of the navigation channel (C_{33}) to avoid grounding. Because the captain has the pilot's assistance and command for maneuvering a ship upon entering or exiting a harbor, the density of vessels navigating through the harbor area (C_{31}), and the operating conditions of non-berthing and departing vessels (C_{34}) were only the second and the fourth most important factors in safety navigation for captains.

The main mission of the deck officer is to steadily and safely steer the ship's wheel. It is very difficult for a deck officer to steer the ship's wheel in busy or small harbor waters. Therefore, deck officers considered the density of vessels navigating through the harbor area (C_{31}) the most important factor in safety navigation, followed by the width and depth of the navigation channel (C_{33}), and the size of the harbor waters (C_{36}).

4) Climatic and Environmental Factors

A descriptive statistical analysis of the climatic and environmental factors influencing navigation safety is shown in Table 9. The top three aspects were: (1) C_{41}: strong or monsoonal winds (mean = 4.8036), (2) C_{42}: fog and thunderstorms (mean = 4.7143), and (3) C_{46}: typhoons (mean = 4.6607). This was followed by: (4) C_{44}: water currents, (5) C_{43}: tides, and (6) C_{45}: geology of the sea bed.

The climatic and environmental factors were ranked according to respondents' relative emphasis, as shown in Table 10. The pilots were more concerned about the effects of C_{42}, C_{41}, and C_{46}, whereas the captains emphasized C_{41}, C_{42}, and C_{44}. The deck officers reported that C_{41}, C_{42}, and C_{44} were the most influential factors, whereas the academics were more concerned about C_{46}, C_{44}, and C_{45}; the others chose C_{42}, C_{41}, and C_{46} as the most important factors. Observations of the rankings revealed that most of the respondents agreed that fog and thunderstorms (C_{42}), strong or monsoonal winds (C_{41}), and typhoons (C_{46}) were the most important factors. They also agreed that the geology of the sea bed (C_{45}) and tides (C_{43}) were the least influential climatic and environmental factors for vessel control.

Strong winds, monsoonal winds, fog, and thunderstorms occur year-round in Taiwan, whereas typhoons occur only from July to October. All these weather phenomena heavily influence vessel navigation, especially when entering or exiting the harbor. All the pilots, captains, and deck officers considered the strong or monsoonal winds (C_{41}), fog and thunderstorms (C_{42}), and typhoons (C_{46}) the most important factors in navigation safety. They also agreed that the geology of the sea bed (C_{45}) and tides (C_{43}) were the least influential climatic and environmental factors on vessel control.

2. Factor Analysis

A factor analysis method was applied to design a systematic hierarchical structure for clustering the influencing factors in navigation safety. The Kaiser-Meyer-Olkin (KMO) measure was used to determine whether the data were suitable for factor analysis, and a principal components method was applied in the analysis after setting the rotation to varimax and the eigenvalues to be larger than 1.

1) Human Factors

The KMO value for the human factor was 0.770, passing the test. Four components were extracted: (a) the suitability of personnel, (b) the lack of experience and ability of personnel to take on the job, (c) the mastering ability of personnel to the working environment, and (d) the capability of personnel to control the vessel.

2) Vessel Factors

The KMO value for the vessel factor was 0.679, which was just acceptable for factor analysis. Three common components were extracted with a cumulative explained variance of 64.147%. We renamed the three common components of the vessel factor as: (a) vessel structure and cargo type, (b) ancillary equipment of cargo loading and communication, and (c) control and auxiliary equipment.

3) Harbor Traffic Factors

The KMO value of the harbor traffic factor affecting navigation safety was middling at 0.745. Two common components were extracted with a cumulative explained variance of 69.248%. The two common components were renamed as: (a) harbor waters and navigation density and (b) berthing conditions and port operations.

4) Climatic and Environmental Factors

The KMO value of the climatic and environmental factors influencing navigation safety in harbors was 0.648, which is acceptable for factor analysis. From a principal components analysis, two common components were extracted with a cumulative explained variance of 62.460%. We renamed the two common components as (a) environmental conditions and (b) climatic conditions.

V. CONCLUSIONS

1. Conclusions

This study investigated the navigation safety in Taiwanese harbors and its surrounding waters. A review of the literature and interviews with experts resulted in the identification of four key factors influencing navigation safety: human, vessel, harbor traffic, and climatic and environmental factors. A questionnaire was administered to assess the degree of importance for each navigation safety factor. A detailed discussion on the influencing factors for navigation safety was presented. In addition, a factor analysis was applied to design a systematic hierarchical structure for clustering the influencing factors.

The results of the survey showed that the three most important human factors influencing navigation safety in harbors were: (1) the steady control of the vessel while navigating within the harbor areas, (2) the failure to respond safely when encountering or cross-encountering vessels, and (3) the violation of the rules of the harbor, either by oneself or by other vessels. Research related to maritime incidents has shown that the risk of collision is highest in harbor waters. This indicates that within harbor areas, the key conditions for collision were whether the movement of the vessel was within the control of the crew, whether vessels complied with regulations to avoid emergency situations, whether there was enough time and ability to avoid collision in an emergency, and whether the behavior of vessels was too difficult for navigators to determine.

The vessel factors influencing harbor navigation safety were ranked in importance as: (1) controlling equipment, (2) vessel body type, and (3) communication equipment. The three most important aspects of harbor traffic factor were: (1) the density of vessels navigating through the harbor area, (2) the width and depth of the navigation channel, and (3) the operating conditions of non-berthing and departing vessels. This indicates that the frequency of vessels entering and leaving the port or the size of the vessel body type were key factors in influencing navigation safety around harbor areas. Therefore, as vessels become larger, more specialized, and more efficient in loading and unloading cargo, the frequency of vessels entering and exiting the harbor, the traffic density within the harbor area, and a demand on channel width and depth would all increase. With such complex factors, ensuring traffic safety in harbor areas is a greater challenge than ever before. With vessel navigation through restricted waters and the difficulties of vessel control, a highly technical and artistic discipline is required. Consequently, navigating vessels and maritime traffic management departments face greater risks than before.

From the analysis of climatic and environmental factors, their order of importance was: (1) strong or monsoonal winds, (2) fog and thunderstorms, and (3) typhoons. Our study found that the main environmental influence on vessels navigating within harbors or surrounding waters was wind, because strong winds greatly influence vessel control. The offsetting effects of strong winds considerably influence navigation safety. Other factors such as fog and thunderstorms influence visibility, and strong winds and waves caused by typhoons could also cause navigational difficulty and increased risks.

2. Suggestions and Future Studies

The findings of this study indicate that duty officers should be able to prevent maritime incidents from occurring by taking precautions against the various key factors identified in this paper. International and domestic regulations stipulate that people working at sea obtain relevant certificates to show prevocational education. Technical and safety training are requirements to being an effective crew member. Nevertheless, technological progress and corporate cost considerations have led to decreased crew quotas, thereby increasing the workload of duty officers. Consequently, some officers may encounter difficulty performing normal vessel control operations and assessing dangerous situations accurately. This substantially increases the risks of navigation safety. Therefore, this study suggests that a reasonable personnel quota be another solution in reducing maritime incidents caused by human factors.

Because climatic and environmental factors are difficult to predict, compiling a suitable data record of maritime incidents and a complete maritime incident database would be useful for analyzing and comparing how often certain climatic, environmental, and other factors have occurred in past incidents. This could help reduce the degree of uncertainty in climatic and environmental factors, and increase the navigation safety of ships in harbors and surrounding waters. A limitation of this study was that there were no maritime incident or climatic and environmental databases. Future studies should integrate and address vessel traffic service management, electronic chart display and information systems, geographic information systems, and the observation of vessel traffic flow.

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