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Navigation Safety Analysis in Taiwanese Ports

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Many researchers have studied vessel systems to enhance navigation safety at sea, or analysed the statistics of marine casualties of different flagged vessels as well as the fatalities and injuries in ferry accidents. However, little research has been devoted to port safety and especially navigation safety within Taiwanese territorial waters where over a 10-year period there have been 3428 marine accidents with 548 deaths and 524 vessels sunk. In this paper, we use the Grey Relational Analysis (GRA) to analyse the marine accident records of each of Taiwan's commercial ports from 1992–2003. Then, after interviewing the port authority managers and marine specialists, we discover the concerns felt by these professionals about Taiwanese commercial ports. We provide suggestions to strengthen port navigation safety.

KEY WORDS

1. Marine Navigation. 2. Safety of Navigation. 3. Port Safety.

1. INTRODUCTION. As indicated by Kopacz et al., (2004), the safe and efficient navigation of a ship depends on factors of the navigational features of the ship, the ship's geographical environment, the ship's navigation process, and the Maritime Navigation Safety and Efficiency System. Many researchers have studied the ship's navigation process (Kopacz et al., 2003), navigation in narrow waterways (Ince and Topuz, 2004), problems of Vessel Traffic Control (Filipowicz, 2004) and Global Maritime Distress and Safety System (Tzannatos, 2004). However, little research has been devoted to port navigation safety, despite Kopacz et al. (2003) revealing that one of the causes of poor safety of ships at sea is the presence of unknown shipping traffic in confined and constrained waters.

The IMO has advocated analysing the cause and effects of marine accidents in order to help authorities create marine policies and regulations to enhance navigation safety and ocean environmental protection. Accordingly, much research has been done on the safety records of different flags (Li and Wonham, 1999; Alderton and Winchester, 2002), seamen fatalities, and/or injuries in ferry accidents (Li and Wonham, 2001; Talley, 2002). But, little research has been devoted to analysis of port marine accident records, while past records show that marine accidents occur mostly in or near port territorial waters. Hence, a navigation safety analysis of the territorial waters of ports is essential to reduce marine casualties.

In this paper, we introduce Taiwan's commercial ports as a case study for navigation safety within the territorial waters of ports. Taiwan has four busy commercial ports, Kaohsiung, Keelung, Taichung, and Hualien. Kaohsiung is the largest port in Taiwan and the sixth-largest port in the world in terms of container throughput handled. From 1992–2003, within Taiwanese territorial waters there were 3,428 marine accidents, with an annual average of 271 events and a 0·3455% casualty rate. Records also reveal that most marine casualties occurred less than 10 nautical miles from commercial ports, which increased the need to investigate and analyse navigation safety within the waters of each port.

To achieve the objectives of this study, we first analyse the marine accident records of each of Taiwan's commercial ports from 1992–2003 and identify relevant indicators that reveal the safety of their waters. The Grey Relational Analysis (GRA) methodology is applied to rank the navigation safety of each commercial port. By thoroughly reviewing accident reports, and interviewing managers of port authorities and marine specialists, we discover concerns about Taiwanese commercial ports and offer suggestions to strengthen port navigation safety.

2. GREY RELATIONAL ANALYSIS.

Most marine safety researchers apply descriptive statistical analysis to investigate accident records, while others use regression to analyse determinants of injuries. However, marine accidents do not occur in normal or regular manners and incomplete marine casualty records exacerbate this indeterminacy. Traditional data analysis methodologies are not suitable for the comparison of navigation safety among ports. Accordingly, we chose GRA as the tool for the study of navigation safety in this paper.

The GRA is one of the foundations in Grey System Theory (Deng, 1982, 1984a, 1984b). Through a relationship comparison among parameters, the GRA can indicate the relationship between parameters and ideal variables. Additionally, it locates necessary messages from uncertain conditions and infers the interaction among parameters.

Based on the Grey System Theory, the Grey Relational Factor Space (GRFS) X can be defined as

$$X=\{x_i|x_i=(x_i(1),\ x_i(2),\ \ldots,x_i(k),\ \ldots,\ x_i(n)),\ n\geqslant 3,\ 0\leqslant i\leqslant m,\ m\geqslant 2\} \tag{1}$$

Where n and m denote the number of message (criteria) and message series, respectively. And x_i is the i^{th} message series.

Let $x_0=(x_0(1),\ x_0(2),\ \ldots,\ x_0(k),\ \ldots,\ x_0(n))$ and $x_i=(x_i(1),\ x_i(2),\ \ldots,\ x_i(k),\ \ldots,\ x_i(n))$, $x_0,\ x_i\in X$. x_0 is the reference series and x_i the compared series. In addition, allow $\Delta_{0i}(k)$ to be the absolute difference between the reference pattern $x_0(k)$ and a compared pattern $x_i(k)$, where $x_0(k)$ and $x_i(k)$ are the observation values of x_0 and x_i at the k^{th} message, respectively. Define $\Delta_{0i}(k)$ as

$$\Delta_{0i}(k)=|x_0(k)-x_i(k)| \tag{2}$$

Define the Grey Relational Coefficient (GRC) of x_0 and x_i at the k^{th} message as

$$\gamma(x_0(k),\ x_i(k))=\frac{\min\limits_i\ \min\limits_k \Delta_{0i}(k)+\zeta\max\limits_i\ \max\limits_k \Delta_{0i}(k)}{\Delta_{0i}(k)+\zeta\max\limits_i\ \max\limits_k \Delta_{0i}(k)} \tag{3}$$

The GRC can be utilized to reflect the grey relational coefficient of x_i compared to x_0 at point k.

In equation (3), $\max_i \max_k \Delta_{0i}(k)$ and $\min_i \min_k \Delta_{0i}(k)$ denote the maximum and the minimum elements of the $\Delta_{0i}(k)$, respectively. The coefficient ζ, ranging from 0 to 1, can be used to change the dimension of relative values of $\gamma(x_0(k), x_i(k))$ (Wong and Lai, 2000; Wen and Wu, 1996). In general, $\zeta = 0{\cdot}5$ provides better results when the relative conditions among series and elements are uncertain (Deng, 1989).

Define the Grey Rational Grade (GRG) of x_i compared with x_0 as

$$\gamma(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n} \gamma(x_0(k), x_i(k)) \tag{4}$$

When the number of message series is large and the observed values of messages are highly diverse, the GRG $\gamma(x_0, x_i)$ is used to characterize the GRG of x_i compared to x_0. The GRG approaching 1 indicates that the series x_i and x_0 are closely related but these two series have a weaker relationship when the GRG is approaching 0.

Let X be the GRFS, and γ be the Grey Relation reflecting from x_i, x_0 to $\gamma(x_0, x_i)$. Γ is a map set of γ. Then, (X, Γ) is called the Grey Relational Space (GRS).

In GRFS X and GRS (X, Γ), let x_0 be the reference series, and x_j, x_p, …, x_q the compared series, if there exists $\gamma(x_0, x_j)$, $\gamma(x_0, x_p)$, …, and $\gamma(x_0, x_q)$ satisfying $\gamma(x_0, x_j) > \gamma(x_0, x_p) > \ldots > \gamma(x_0, x_q)$, then $x_j \succ x_p \succ \ldots \succ x_q$.

This is called the Grey Relational Order. Noted as $(j, p, \ldots, q: \succ)$.

3. INDICATORS AND DATA.

In the past, most researchers used accidental total loss rates, casualty rates, fatality rates, and/or number of injuries and fatalities to analyse marine accidents for pertinent issues. These indicators are all considered in our study. Furthermore, in the process of formulating our indicators, we were also interested in other indicators, such as the flag of the ship, degree of injury, degree of cargo damage, degree of ship damage, claims for people injured or killed, claims for cargo loss, claims on ship damage, and weather conditions during each casualty. However, some pertinent data indicators are not available because they are not recorded (such as flag of ship and degree of each injury), or kept secret (such as claims on injuries and claims on damage of cargo and ships).

The only statistical data available is the annual number of marine accidents at each port. Marine accidents defined in this study include collision/contact, stranding/grounding, foundering/sinking, fire/explosion, capsizing/listing, structural failure, machinery/equipment damage, heavy weather damage, missing vessels, damage to port facilities/goods, and/or loss of human life caused by vessels. After collecting the marine accident data, we divided it by the number of incoming vessels to obtain the casualty rate. To gather more relevant data, we reviewed each registered casualty investigation report, and summarized the number of people killed and missing, the number of people injured, the number of ships damaged, and the number of ships sunk. Table 1 shows the 12-year aggregate data for each port from 1992–2003 for the six indicators mentioned above. The second row of the table, the reference series (x_0), shows the least number or rate among four commercial ports in each category of indicators.

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Table 1. Original navigation safety data for Taiwan's commercial ports.

Ports \ Indicators	Number of Marine Accidents (Events)	Casualty Rate (%)	Number of People Dead and Missing (Persons)	Number of People Injured (Persons)	Number of Ships Damaged (Vessels)	Number of Ships Sunk (Vessels)
Reference (x_0)	178	0·1748%	30	10	133	10
Keelung (x_1)	1292	0·5694%	166	47	858	141
Kaohsiung (x_2)	1573	0·2829%	284	57	388	332
Taichung (x_3)	205	0·1748%	68	35	133	41
Hualien (x_4)	178	0·4453%	30	10	147	10

Table 2. Standardized navigation safety data for Taiwan's commercial ports.

Ports \ Indicators	Number of Marine Accidents	Casualty Rate	Number of People Dead and Missing	Number of People Injured	Number of Ships Damaged	Number of Ships Sunk
Reference (x_0)	0·1132	0·3070	0·1056	0·1754	0·1550	0·0301
Keelung (x_1)	0·8214	1·0000	0·5845	0·8246	1·0000	0·4247
Kaohsiung (x_2)	1·0000	0·4970	1·0000	1·0000	0·4522	1·0000
Taichung (x_3)	0·1303	0·3070	0·2394	0·6140	0·1550	0·1235
Hualien (x_4)	0·1132	0·7821	0·1056	0·1754	0·1713	0·0301

4. COMPARISON OF PORT NAVIGATION SAFETY. Each indicator can be used simultaneously to compare the navigation safety among ports. All data should be standardised. The formula used for standardising data can be defined as

$$x_i^*(k) = \frac{x_i(k)}{\max_i \{x_i(k)\}} \tag{5}$$

where k denotes the indicator, x_i the original data, and x_i^* the standardized data. Table 2 displays the standardised navigation safety data of each indicator.

By Equation (2), the absolute distance between the compared pattern ($x_1(k)$, $x_2(k)$, $x_3(k)$, $x_4(k)$) and the reference pattern ($x_0(k)$) at point k can be calculated. For example, for the casualty rate criteria, $\Delta_{02}(2) = |x_0(2) - x_2(2)| = |0{\cdot}3070 - 0{\cdot}4970| = 0{\cdot}1900$. The results are shown in Table 3, from which we obtain $\min_i \min_k \Delta_{0i}(k) = 0{\cdot}0000$ (the minimal value in Table 3) and $\max_i \max_k \Delta_{0i}(k) = 0{\cdot}9699$ (the maximal value in Table 3).

After selecting the coefficient $\zeta = 0{\cdot}5$ and substituting into Equation (3), we can obtain the GRC of all navigation safety indicators for the four international ports. For example, for the casualty rate criteria, $\gamma(x_0(2), x_2(2)) = (0 + 0{\cdot}5 \times 0{\cdot}9699)/(0{\cdot}1900 + 0{\cdot}5 \times 0{\cdot}9699) = 0{\cdot}7185$. The results are shown in Table 4.

Finally, by Equation (4), the GRG $\gamma(x_0, x_i)$ of these four ports can be calculated. For example, $\gamma(x_0, x_2) = (0{\cdot}3535 + 0{\cdot}7185 + 0{\cdot}3516 + 0{\cdot}3703 + 0{\cdot}6200 + 0{\cdot}333)/6 = 0{\cdot}4579$. The results are also shown on the right hand column of Table 4.

Table 3. Absolute differences between reference and compared patterns.

$\Delta_{0i}(k)$	Number of Marine Accidents	Casualty Rate	Number of People Dead and Missing	Number of People Injured	Number of Ships Damaged	Number of Ships Sunk
$\Delta_{01}(k)$	0·7082	0·6930	0·4789	0·6491	0·8450	0·3946
$\Delta_{02}(k)$	0·8868	0·1900	0·8944	0·8246	0·2972	0·9699
$\Delta_{03}(k)$	0·0172	0·0000	0·1338	0·4386	0·0000	0·0934
$\Delta_{04}(k)$	0·0000	0·4751	0·0000	0·0000	0·0163	0·0000

Note: (0) denotes the reference series, (1) denotes compared series of port of Keelung, (2) denotes compared series of port of Kaohsiung, (3) denotes compared series of port of Taichung, (4) denotes compared series of port of Hualien.

Table 4. GRC and GRG of all navigation safety indicators of the four commercial ports.

$\gamma(x_0(k), x_i(k))$	Number of Marine Accidents	Casualty Rate	Number of People Dead and Missing	Number of People Injured	Number of Ships Damaged	Number of Ships Sunk	$\gamma(x_0, x_i)$
$\gamma(x_0(k), x_1(k))$	0·4064	0·4117	0·5031	0·4276	0·3646	0·5514	0·4441
$\gamma(x_0(k), x_2(k))$	0·3535	0·7185	0·3516	0·3703	0·6200	0·3333	0·4579
$\gamma(x_0(k), x_3(k))$	0·9658	1·0000	0·7838	0·5251	1·0000	0·8385	0·8522
$\gamma(x_0(k), x_4(k))$	1·0000	0·5051	1·0000	1·0000	0·9674	1·0000	0·9121

Note: $\zeta = 0{\cdot}5$.

Table 5. GRG of the four commercial ports with different ζ values.

$\gamma(x_0, x_i)$	$\zeta=0{\cdot}1$	$\zeta=0{\cdot}2$	$\zeta=0{\cdot}3$	$\zeta=0{\cdot}4$	$\zeta=0{\cdot}5$	$\zeta=0{\cdot}6$	$\zeta=0{\cdot}7$	$\zeta=0{\cdot}8$	$\zeta=0{\cdot}9$	$\zeta=1{\cdot}0$
$\gamma(x_0, x_1)$	0·1403	0·2447	0·3258	0·3908	0·4441	0·4888	0·5266	0·5592	0·5876	0·6125
$\gamma(x_0, x_2)$	0·1628	0·2692	0·3473	0·4083	0·4579	0·4992	0·5342	0·5645	0·5909	0·6141
$\gamma(x_0, x_3)$	0·6601	0·7487	0·7975	0·8294	0·8522	0·8694	0·8829	0·8938	0·9028	0·9104
$\gamma(x_0, x_4)$	0·8376	0·8687	0·8878	0·9015	0·9121	0·9205	0·9275	0·9333	0·9382	0·9424

Based on the principle of the Grey Relational Order, the order of these four ports is Hualien $\succ$Taichung $\succ$Kaohsiung $\succ$Keelung, that is, Taiwan's safest port for navigation is Hualien, followed in descending order by Taichung, Kaohsiung, and Keelung.

In order to test whether a different coefficient ζ would change the order, we tested different ζ, and results of the GRE are shown in Table 5, which reveals that a different coefficient ζ does not change the ranking order.

As shown in Table 4, the value of the GRC $\gamma(x_0(k), x_i(k))$ of each navigation safety indicator is positively related to the safety reference row. The higher the GRC value, the better is port safety. Moreover, the GRC can also reveal directions to improve port navigation safety. For example, the GRC value of the third row is $\gamma(x_0(k), x_2(k)) = (0{\cdot}3535, 0{\cdot}7185, 0{\cdot}3516, 0{\cdot}3703, 0{\cdot}6200, 0{\cdot}3333)$. Although the second GRC value – $\gamma(x_0(2), x_2(2)) = 0{\cdot}7185$ casualty rate – is high, the remaining GRC values are low, indicating that there is a need for the port authorities to

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Table 6. Causes of marine accidents of each commercial port in Taiwan.

Types/Causes of Marine accidents	**Keelung**	**Kaohsiung**	**Taichung**	**Hualien**	**Total**
Collision/Contact	341	262	92	63	**758**
Stranding/Grounding	84	114	27	13	**238**
Leaking/Foundering	63	62	5	10	**140**
Fire/Explosion	69	190	18	2	**279**
Capsizing/Listing	8	26	11	0	**45**
Structural damage	86	25	0	9	**120**
Machinery failure	268	642	5	14	**929**
Intertwisting	47	26	3	6	**82**
Heavy weather damage	122	89	4	14	**229**
Missing vessels	4	10	1	1	**16**
Other	200	127	39	46	**412**
Total	**1292**	**1573**	**205**	**178**	**3248**
Average per year	108	131	17	15	271

improve in these areas. Using the above analysis, the management of Kaohsiung port can put more effort into finding the causes of marine accidents; injuries, deaths and missing persons; and sunken ships, in order to find ways to mitigate damage and casualties.

In the right hand column of Table 4, the higher GRG value, ($r(x_0, x_1) = 0{\cdot}4441 < r(x_0, x_2) = 0{\cdot}4579 < r(x_0, x_3) = 0{\cdot}8522 < r(x_0, x_4) = 0{\cdot}9121$), indicates higher navigation safety in the port's territorial waters. As maintaining safe navigation waters is the duty of port authorities, the results of the GRG not only provide one criteria to evaluate the operating performance of each port, but can also help port authorities to understand and enhance navigation safety in each port.

5. NAVIGATION CONCERNS.

After comparing the navigation safety of each port with the six indicators, we reviewed 3,248 marine accident reports from 1992–2003 provided by each port to analyse the causes of each casualty. Table 6 lists the types and causes of casualties and the number of events that occurred in each port. The category "Other" includes passengers who fell into the sea or are missing, seamen injured or dead on board, cargo fallen into the sea, etc. With a yearly average of 271 marine accidents reported, the main causes of casualties are collision/contact and machinery failure, which should attract the attention of port authorities and ship owners seeking to mitigate this type of event.

We also positioned the location of the marine accidents on the chart of each port, visited some territorial waters, and then delivered our findings with the Grey Relationship results to the managers of port authorities and marine specialists. The people we interviewed included seven port managers in charge of marine accidents, five senior seamen (pilot, captain, chief officer), five senior managers of marine insurance companies, and four navigation scholars. Table 7 reveals the number of interviews with each type of specialist in each port. Since the people interviewed do not have experience with every port, the total number of interviews of each port is less than the total number of specialists.

Table 7. Interviews with specialists in each port.

Types of Specialists	**Keelung**	**Kaohsiung**	**Taichung**	**Hualien**
Port managers in charge of marine accidents	3*	3	3	2
Senior seamen	5	5	5	3
Senior managers of marine insurance companies	4	3	4	1
Navigation scholars	4	4	4	4
Total	**16**	**15**	**16**	**10**

Note: * denotes three out of seven port managers in charge of marine accidents provided information related to the port of Keelung.

Table 8. Navigation safety concerns for each commercial port in Taiwan.

Factors Affecting Navigation Safety		**Keelung**	**Kaohsiung**	**Taichung**	**Hualien**
Concerns about Mooring Vessels	Arbitrary anchoring of vessels	V	V		
	Grounding and collision of heavily-loaded vessels in complicated channels	V	V		
	Berthing and unberthing at wharfs	V	V		
	Unseaworthy vessels	V	V	V	V
Concerns about Navigation Waters	Navigation aids	V	V	V	V
	Coastal aquaculture		V		
	Water annexes	V	V	V	
Other Concerns	Motor fishing boats	V	V	V	V
	Cargo loading	V	V		V
	Contention from fishermen	V	V	V	V

Note: V denotes the concerns faced by ports.

After the interviews 10 safety concerns about Taiwanese commercial ports were identified; they are listed in Table 8. Descriptions of the concerns and improvement strategies follow.

5.1. *Concerns about Mooring Vessels.*

5.1.1. *Arbitrary anchoring of vessels.* Vessels should anchor within assigned anchorages whilst waiting for a berth. However, some vessels anchor arbitrarily when there are too many vessels in the anchorages. This condition usually occurs in busy ports such as Kaohsiung and Keelung, especially among vessels with clear boarding schedules, which tend to anchor near the channel in order to enter the channel directly. The heavy density of anchored vessels in anchorages can cause collision/contact between ships, as a result of dragging affected by heavy weather.

5.1.2. *Grounding and collision of heavily loaded vessels in complicated channels.* Lacking capital and integrated plans in the early stages of port development, local authorities drew up channels based on the historical needs. With rapid changes in the global economy and current needs, the channels have now become more complicated. Therefore, ships may ground and collide easily when they are inbound and outbound through complicated channels. For example, some wharfs in the port of Keelung and the exit of the fishing wharfs of He-Ping Isle are connected, with both sharing the main channel. Furthermore, the inner channel, the linked branch channel, and the outer channel are narrow (the width of the linked channel is merely 100 metres) and the channels have a "Z" shape. Thus, bow cushion and bank suction occur constantly. Due to the lack of bounded landmarks next to the exit of the port, helmsmen have difficulty grasping the advance angle of turn required while vessels are entering or leaving, so that vessels often ground.

5.1.3. *Berthing and unberthing in wharfs.*

5.1.3.1. *Failure to keep safe distance between neighbouring berths.* In general, the length of a wharf is 1·2 times that of a vessel waiting to berth, so that there is adequate space for manoeuvring for safe ship berthing and unberthing. Concerns arise when vessels fail to keep a safe distance between neighbouring berths, especially when two large vessels simultaneously berth at "L" type connected berths.

5.1.3.2. *Inappropriate berths.* During economic recessions in the shipping industry, port management may permit small ships that do not conform to the standard of the wharf to load and unload. During these situations, the height of the freeboard for the vessel is usually lower than that of the wharf apron. The vessel's berthing side may strike strongly against the dock wall during gales and surges. At the same time, the gangway between the vessel and wharf may snap or fall off.

5.1.4. *Unseaworthy vessels.* Unseaworthy vessels frequently cause marine accidents. Therefore, the vessels will not be considered seaworthy if the following conditions are in effect prior to departure, and will be regarded as dangerous both inside and outside the port.

- Hull integrity of the vessel is insufficient, or there are defects within the hull or machinery. This condition is especially true in old ships with lower class certification.
- Equipment is deficient, including: blemishes to the pipeline; unqualified navigational apparatus on board; lack or inoperability of anchors, rudders, propellers, compasses, necessary lifesaving appliances, communication facilities and sidelights; inappropriate position of portholes; and so forth.
- Master and officers are incompetent and crew members are insufficient.
- Fuel and stores of the ship are not adequate for any delay in the voyage.
- Vessel is improperly loaded with goods.

5.2. *Concerns about Navigation Waters*

5.2.1. *Navigation aids.*

5.2.1.1. *Reduced visibility of landmarks.* The positions of tall cranes can affect the visibility of landmarks. Also, the light from tall buildings close to the navigation lights is confusing at night. These conditions can make the correct identification of landmarks and lights difficult and thus safety is compromised.

5.2.1.2. *Decrease of the utility of navigation aids.* During the monsoons that occur from the end of winter to the beginning of spring in northern Taiwan and during the typhoons in summer, strong winds usually damage or reposition the maritime buoys, especially the lights-piles and the range-lights. When this is combined with the violations of some fishermen destroying buoys, the utility of navigation aids is sharply reduced.

5.2.2. *Coastal aquaculture*. Currently, coastal aquatic farms in western Taiwan commonly illegally occupy such navigation waters as channels, anchorages, and traffic density zones. Taking the port of Kaohsiung as an example, illegal private aquatic farms near the port of An-Ping and on the shores of Kaohsiung and Ping-Dong counties seriously influence the safety of incoming and outgoing vessels. According to statistical data in the Fishery Administration annual report, aquatic farms within anchorage waters frequently cause marine accidents between merchant ships and fishing boats.

5.2.3. *Water annexes*.

- Construction sites that occupy the main channels inside ports reduce the valid area for safe navigation. Thus, apprehension arises from vessels entering construction waters, such as in the port of Keelung, where reconstruction of wharfs is taking place.
- The high-frequency traffic of construction ships affects the safe passage of vessels. Various types of ships such as dredgers and tugs come and go in the docks, pass through channels, and cross traffic density zones. Most of them are under the command of different construction organizations, which lack unity and discipline.
- Irregular operation of construction ships is seen in the lack of proper watch keeping. Some construction ships at work are not equipped with ultra high frequency radiophones. These actions violate the code of safe navigation, and bring about great apprehension of navigation safety for other ships.

5.3. *Other Concerns*.

5.3.1. *Motor fishing boats*. During the fishing seasons, a large number of motorised fishing boats crowd into basins, channels, and anchorages for fishing. In peak tourist seasons, high-speed fishing boats and yachts seek surgeless positions near wharfs for sightseeing passengers. They often interfere with the regular traffic of vessels by passing near merchant ships and sailing across channels.

5.3.2. *Cargo loading*. Improper cargo loading conditions may result in marine accidents. Such conditions include disproportionate disposition of weight causing destruction or instability to the hull, cargo collapse or displacement, wet cargo seeping or floating, spontaneous combustion of chemical cargo, and so forth.

5.3.3. *Contention from fishermen*. Merchant ships and fishing boats have long shared the main channels of Taiwanese territorial waters. When there is a conflict in interest, fishermen sometimes take an extreme stand, such as besieging ports and endangering the incoming and outgoing merchant ships.

6. SUGGESTED STRATEGIES.

To mitigate those concerns, we provide the following seven strategies for improved navigation safety.

6.1. *Enhanced Vessel Traffic Management Systems*. Each port should enhance the vessel traffic management system of its own environment, including the rules for assigning anchorages under special weather conditions, position reporting, marine traffic information, punishment for violations, etc. Port authorities should also seriously punish vessels anchoring arbitrarily, or unregistered boats crossing basins.

6.2. *Reinforcement of Navigation Signals Visibility*. Gathering marine societies to form the Navigation Mark Ordinance will be helpful for maintaining the coast and navigation aids. Visible navigation landmarks obstructed by tall container cranes or coastal buildings should be remedied. For example, in order to reduce the danger of collision, stranding or grounding, coastal ranges could be installed in Kaohsiung and Keelung ports to help seamen locate and direct during night or poor weather conditions. Moreover, short-range navigation facilities and buoyage systems in commercial ports and navigation aids in fishing ports should be enhanced.

6.3. *Maintenance of Maritime Buoyage at Sea.* In addition to the supply and repair of lighthouses, coastal patrol ships can assist ports in replacing and re-positioning buoys or floating piles at sea during the periods of monsoon, typhoon and heavy weather. This could ensure the clarity and accuracy of channels.

6.4. *Compulsory Piloting of Complicated Channels.* For complicated channels, it is necessary to compulsorily assign tugs and pilots to help vessels navigate safely. Nautical charts should be renewed periodically, especially when wharfs, docks, or channels are newly built. Other information pertaining to navigation should also be provided in order to decrease the probability of marine accidents caused by vessels sailing in dangerous waters.

6.5. *Regulation of Aquaculture.* Port authorities should actively negotiate with the local government for the creation of marine function areas for the installation of aquatic farms at sea. Illegal aquatic farms affecting navigation waters, especially those near channels and basins, should be dismantled.

6.6. *Control of Construction.* The approval and inspection of construction on waters, relay systems of construction ships, notice systems of navigation information, and delimitation of navigation blocking areas should be further standardised and regularised. Additionally, port agents should be encouraged to deliver construction information to vessels for navigation safety.

6.7. *Regular Navigation Safety Sessions.* Many marine accidents result from the improper coordination of steering among the pilots, tugmen, and seamen. Therefore we suggest that a regular session for better communications among pilots, tugmen, and seamen be initiated.

7. CONCLUSION.

In order to reduce fatalities, property loss and ocean contamination resulting from marine accidents, the investigation and analysis of casualties that occur within the territorial waters of ports is essential. After referencing previous research, and reviewing the 1992–2003 recorded casualty reports of Taiwan's four commercial ports, we propose six indicators of port safety: number of marine accidents; casualty rate; number of people dead and missing; number of people injured; number of ships damaged; and number of ships sunk.

The indicators can further be used to compare navigation safety among ports. Using the methodology of the Grey Relationship Analysis, we found that Taiwan's safest port for navigation is Hualien, followed in descending order by Taichung, Kaohsiung, and Keelung.

After discussing navigation safety with the managers of port authorities and marine specialists, we find three aspects of concern encountered by Taiwanese commercial ports. The first concern is about the mooring of vessels, which includes arbitrary anchoring of vessels, grounding and colliding of heavily loaded vessels in complicated channels, berthing and unberthing in wharfs, and unseaworthy vessels. The second concern is about navigation waters, including problems with navigation aids, coastal aquaculture, and water annexes. The final area of concern includes motor fishing boats, cargo loading, and contention from fishermen. To mitigate those concerns, we provide seven strategies for strengthening navigation safety.

The principal problem confronted by most researchers is that no relevant data is available. This problem also occurred during our study. Thus, we strongly recommend that detailed information regarding marine accidents be recorded in a statistical database, which will allow the public to supervise governors maintaining maritime environments. As for future research, a comparison of port navigation safety among different countries and their associated strategies for improvement should be extended from this study.

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