Integrating AIS, GIS and E-Chart to Analyze the Shipping Traffic and Marine Accidents at the Kaohsiung Port

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Abstract: In the past, case study and questionnaire survey methodologies have often been used to analyze the causes of marine accidents. One of the disadvantages of these two methods is that they can only interpret the specific causes of one particular marine accident at a time. They cannot analyze and find the common causes of most marine accidents. Therefore, this study integrates the Automatic Identification System, Geographic Information System, and an e-chart to explore the relationship between environmental factors (wind, wave, tide, and current), locations, and significant common causes of marine accidents. Firstly, an Automatic Identification System is used to collect the traffic flows of vessels entering/exiting the port. The locations of maritime accidents were then plotted on an e-chart, after which we can quickly analyze the locations of marine accidents on the e-chart. Furthermore, environmental data are displayed using Geographic Information System. Subsequently, all data, including traffic flows of vessels, locations of marine accidents, and environmental data, are integrated into the e-chart simultaneously. As a result, the information related to factors affecting the probability of marine accidents could be displayed clearly on the e-chart. Finally, findings and conclusions are given to port authorities to help manage the ship traffic flow and reduce the probability of the occurrence of marine accidents around the port efficiently.

Keywords: Vessel Traffic Service; big data analysis; intelligent port; navigational safety; port management

1. Introduction

Ship navigational safety is one of the important issues faced by governmental marine departments, port managers, and port authorities. Academic researchers also consider the ship navigational safety problem an essential research topic (Darbra and Casal [1], Yip [2], Dobbins and Abkowitz [3], Wang and Lee [4], Wang and Lee [5], Chou et al. [6], Kao et al. [7], Chou [8], Chou et al. [9]).

The major causes of maritime casualties are usually separated into two categories: human factors and environmental factors (Chou [8], Hetherington et al. [10]). The human factors include fatigue, pressure, health condition, situation awareness, teamwork, decision making, communications, safety culture, and so on. The natural environmental factors include wind, waves, tide, and current.
In the past, case study and questionnaire survey methodologies have been often used to analyze the causes of marine accidents. Few studies have applied integrated approaches combined with various advanced information technologies to investigate and display the relationship between the causes and the locations of marine accidents (Dobbins and Abkowitz [3], Konstantinos and Ernestini [11], Jensen et al. [12]). One of the disadvantages of the case study and questionnaire survey methodologies is that it can only analyze the specific causes for one specific marine accident case at a time (Ceylan et al. [13], Zaib et al. [14]). They cannot analyze and find the common causes of most marine accidents. Therefore, this study proposes an integrated approach combining Automatic Identification System (AIS), Geographic Information System (GIS), and an e-chart to analyze the relationship between the locations and the common causes of marine accidents. Firstly, AIS is used to collect the traffic flows of merchant vessels which enter/exit the Kaohsiung port in Taiwan. Then, GIS is applied to analyze the location of marine accidents and the environmental data such as wind, waves, tide, and current. Finally, all data including the traffic flow of merchant vessels, locations of marine accidents, wind, waves, tide, and sea current are integrated into the e-chart simultaneously. This integrated approach enables information related to factors that may affect the probability of marine accidents (traffic flow, wind, waves, tide, current, etc.) to be displayed clearly on the e-chart.

The rest of this paper is organized as follows. Section 2 includes a literature review. In Section 3, AIS is used to collect the traffic flows of vessels entering/exiting the port of Kaohsiung. The locations of marine accidents surrounding the harbors are plotted on an e-chart. In addition, the wind, wave, tide, and current data are displayed on GIS. An analysis of locations and common causes of most marine accidents is presented in Section 4, followed by conclusions and suggestions in Section 5.

2. Literature Review

2.1. Human Factors

Hetherington et al. [10] found the eight main human factors which caused maritime accidents are fatigue, stress, health condition, situation awareness, teamwork, decision making, communication, and safety culture.

Yip [2] pointed out that few papers have discussed the causes of marine accidents in port waters. He found that port traffic risks are of certain pattern, and collision is the most frequent accident in the busy port. Chin and Debnath [15] constructed a Probit regression model and made a simulation study to investigate the collision risk when navigating within port waters with heavy traffic. Some recommendations were provided to navigators to decrease the collision risks when navigating within port waters with heavy traffic.

Tzeng [16] found that most grounding accidents were caused by human factors, and that natural environmental factors increase the degree of vessel damage while grounding. The rate of vessel grounding will increase when entering/exiting a port in bad weather.

Chou et al. [17] found the the important factors influencing navigational safety in ports include human, vessel, port traffic, and environment factors. The human aspect includes: (a) the steady control of the vessel while navigating within the harbor areas, (b) failure to respond safely when encountering or cross-encountering vessels, and (c) violation of the rules of the harbor, whether by oneself or by other vessels. The vessel aspect includes: (a) controlling equipment, (b) vessel body type, and (c) communication equipment. The three most important aspects of harbor traffic factors were: (a) the density of vessels navigating through the harbor area, (b) the width and depth of the navigation channel, and (c) the operating conditions of non-berthing and departing vessels. The environmental aspect includes: (a) strong wind, (b) fog and thunderstorms, and (c) typhoons.

Debnath and Chin [18] indicated that, although some previous studies focused on navigational safety in port channels, few focused on safety at port anchorages. They measured and identified the collision risks in anchorages.

Chou et al. [6] analyzed the marine accidents in the waters surrounding Taiwan. The historical records of marine accidents involving fishing boats and merchant ships were
collected from Taiwanese maritime bureaus. The merchant ship accidents were ranked in
order of occurrence frequency as collision, grounding, and mechanical failure.

Zhang et al. [19] analyzed the relationship between ship accident consequences and
related contributing factors based on actual ship accident investigation reports. The results
showed that (1) vessel speed is the most significant factor contributing to fatality and injury
in collision accidents; (2) crew number shows a strong association with injury and fatality;
and (3) the consequence of an oil spill is strongly related to collision position, especially in
head-on and crossing collisions.

Ceylan et al. [13] analyzed the case of a main engine failure accident of one ship
in heavy conditions. Due to heavy weather, the ship anchors were dropped and then
ineffectual attempts were made to start the main engine. Finally, the ship was rescued and
towed to a repair factory in Rotterdam. The analysis results showed that the causes of the
accident were 80% human factor, 13% hardware and software, and 7% external factors.

Zaib et al. [14] applied the case study and the questionnaire survey methods to the
causes of a grounding accident of a chemical tanker. The grounding accident caused
flooding and serious hull damage to the ship. According to the case study analysis and
the questionnaire survey results, the major causes of this grounding accident were human
factors including misinformation and lack of experience.

As mentioned above, several reports in the literature (Ceylan et al. [13], Zaib et al. [14])
used the case study and the questionnaire survey methods which can only analyze the
causes for a single specific marine accident. The analysis results cannot be applied to other
marine accidents.

2.2. Natural Environment Factors

Liu [20] analyzed the geographical distribution of marine accidents. He pointed out
that many accidents happened in waters with complex natural climates, including strong
wind, fog at sea, and rain.

Toffoli et al. [21] explored the relationship between marine accidents and sea conditions.
They found that waters with quickly changing sea conditions have higher navigational
risks. Finally, they suggested that it is very important to pay more attention to the weather
conditions at sea.

Dobbins and Abkowitz [3] investigated the place of shipwrecks in American inland
rivers by using Google Earth and Geographic Information System (GIS). They pointed out
the 25 shipwreck sites where the frequency of marine accident occurrence is the highest.

Arslan and Turan [22] explored the navigation risks in narrow waters. They found
that ship traffic flow and sea conditions including visibility, wind, waves, and current
significantly affect navigation safety.

Chou et al. [23] analyzed that the key environment causes of maritime accident includ-
ing wind, waves, tide, and sea current. However, their research only focused on analyzing
the natural environment factors. Therefore, they recommended that the human factors in
navigational safety should be considered in future studies.

Chou [8] used a ship maneuvering simulator to analyze ship encounters and collisions
with environmental effects such as wind, waves, tide and current conditions. The simulation
results showed that wind and current are critical influencing factors in ship maneuvering.

2.3. Application of AIS

The processing and use of AIS data has been a very popular area of research on
maritime transportation recently. For example, Zhang et al. [24] developed a big data
analysis approach to evaluating grounding risk. The big data were collected by AIS. The
results showed that the developed approach could estimate the grounding probabilistic
risk. In addition, the grounding probabilistic risk estimation may be extremely diverse and
it depends on voyage routes and operational conditions.

Xu et al. [25] presented a big data method for estimating the time of arrival of ships
by collecting AIS data. They presented integrated trajectory clustering and Support Vec-
tor Regressor methods. An historical AIS dataset was used to evaluate the presented method. The result showed that the presented method was more accurate than previous estimation approaches.

Silveira et al. [26] applied AIS data to developing a modified ship domain, which results in better fitting to the empirical domain, and provides important information for monitoring and controlling traffic flows.

Feng et al. [27] proposed an information entropy approach based on AIS data to evaluate collision risks in the waters of shipping routes, especially in busy waters. Based on historical AIS data, the information entropy approach was applied to evaluate the highest risk and medium-high risk areas in the Ningbo-Zhoushan Port.

3. Methodology

It is necessary to consider both human and environment factors simultaneously while analyzing the causes of marine accidents. Thus, this paper integrates ship traffic flow and environment factors to analyze the locations and the causes of marine accidents by combining AIS, GIS, and an e-chart. AIS, GIS, and the e-chart are the main three research tools used in this study. This paper uses the Visual Basic programming language to develop an interface for combining the three systems together.

In recent years, some maritime researchers studied navigational safety by using GIS. Others analyzed the causes of maritime accidents by using both AIS and GIS. Still others have investigated navigational safety by using both AIS and chart. Few studies have investigated the navigational safety issue by using AIS, GIS, and an e-chart together [7]. AIS and GIS will be introduced in this section. The research frame of this study is shown in Figure 1. Each of the steps in Figure 1 is described as follows:

Figure 1. Diagram of research framework.

1. The collected data
   (a). Traffic flow of vessels entering/exiting the port
   (b). Locations of marine accidents
   (c). Data of wind, wave, tide, and sea current

2. Collect the traffic flow of vessels by using AIS

3. Plot the locations of marine accidents on e-chart

4. Analyze the data of wind, wave, tide and current by using GIS

(5). Integrate all data onto e-chart, and then analyze the relationship between the marine accidents and all data.
(All data including: traffic flows of vessels, locations of marine accidents, wind, wave, tide and sea current)

Data collected in this project include: (a) traffic flows of vessels entering/exiting the port, (b) locations of marine accidents, and (c) data for wind, waves, tide, and sea current.

2. Collect the traffic flows of vessels by using AIS
This study used AIS to collect the traffic flows of vessels which enter/exit the Kaohsiung port of Taiwan and then displayed and analyzed the traffic flows on an e-chart. The e-chart used in the study was produced by the authors. For example, in Figure 2 the red lines represent the tracks of the vessels which are entering the port and the green lines represent the tracks of the vessels which are exiting the port. The traffic flow of vessels was collected during the period from 2011 through 2015. Figure 3 shows the traffic flow of vessels which enter/exit the port. The collected five years of original AIS data were decoded and plotted on an e-chart by using the Visual Basic computer language. Original AIS data include the time and the position of ships; therefore, we can decode AIS and then obtain the daily traffic flow of vessels entering/exiting the Kaohsiung port in Figure 3.

(3) Plot the locations of marine accidents on the e-chart

This study crosschecked and collected the location data of marine accidents from the port authority, Taiwanese Coast Guard, and the Annual Report published by the Ministry of Transportation and Communications in Taiwan. Then the locations of marine accidents were displayed on the e-chart. This paper collected the marine accidents in the port and surrounding waters from 2011 to 2015. In recent years, the Taiwanese government department has only reported the number and types of marine accidents, and it no longer reports the detailed positions (longitude and latitude) of marine accidents.

(4) Analyze the data of sea conditions by GIS

This study collected the data of sea conditions including wind, waves, tide, and current from the Center for Harbor Technology Research in Taiwan, the port in Taiwan, and the report published by the Weather Bureau in Taiwan. Figures 4–7 represent the levels of the data of the sea conditions. Finally, the collected data of sea conditions were integrated and then displayed in Figure 8. The data of sea conditions were collected during the period from 2011 to 2015.

(5) Integrate all data onto the e-chart to analyze the relationship between accidents and data

Finally, all data including the traffic flows of vessels in Figure 2, the locations of marine accidents, and environment data such as wind, waves, tide, and sea current in Figure 8, are integrated onto the e-chart in Figure 9. Based on Figure 9, the study analyzed the relationship between accidents, traffic flows of vessels, locations of marine accidents, and environment data such as wind, waves, tide and sea current.

3.1. Automatic Identification System

Traditional maritime traffic survey methods are complicated and time-consuming. Nowadays, Automatic Identification System (AIS) is applied to improve navigational safety and efficiency in the maritime transportation system (Høye et al. [28], Mou et al. [29], Kao and Chang [30], Huang et al. [31]).

AIS is based on radio communications technology and is a system which receives and transmits the dynamic and static data of vessels. The system collects data including ship type, ship name, navigation status, length and width, draught, call sign, maritime mobile service identities (MMSI), longitude, latitude, speed, course, destination, and other information. According to international conventions, all vessels must be equipped with AIS. Nowadays, AIS has been comprehensively used in related maritime fields such as maritime traffic investigation (Bai et al. [32]), collision prevention at sea (Li and Hu [33]), maritime management (Wu et al. [34]), navigation buoy system management (Li et al. [35]), and large cruise ship traffic management (Webb and Gende [36]).
Figure 2. The traffic flows of vessels entering/exiting the Kaohsiung port. Note: the red line means ship track (enter); the green line means ship track (exit); the yellow area means land; the light blue area means coastal line.
This study crosschecked and collected the location data of marine accidents from the port authority, Taiwanese Coast Guard, and the Annual Report published by the Ministry of Transportation and Communications in Taiwan. Then the locations of marine accidents were displayed on the e-chart. This paper collected the marine accidents in the port and surrounding waters from 2011 to 2015. In recent years, the Taiwanese government department has only reported the number and types of marine accidents, and it no longer reports the detailed positions (longitude and latitude) of marine accidents.

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Integrate all data onto the e-chart to analyze the relationship between accidents and data
Finally, all data including the traffic flows of vessels in Figure 2, the locations of marine accidents, and environment data such as wind, waves, tide and sea current in Figure 8, are integrated onto the e-chart in Figure 9. Based on Figure 9, the study analyzed the relationship between accidents, traffic flows of vessels, locations of marine accidents, and environment data such as wind, waves, tide and sea current.
This study used the AIS to collect the data of vessels which entered/exited the port during the period of 2011–2015. The collected data were then plotted on the e-chart shown in Figure 2. In Figure 2, the red lines represent the tracks of the vessels which are entering the port, and the green lines represent the tracks of the vessels which are exiting the port. Figure 3 shows the daily traffic flow of all vessels which enter/exit the port and that the average hourly number of vessels which enter/exit the port during the period from 07:00 to 08:00 A.M. is the highest (average 5.5 vessels per hour), followed by 08:00~09:00 A.M. and 09:00~10:00 A.M. The average hourly number of vessels entering/exiting the port during the time period from 04:00 to 05:00 A.M. is the lowest (average two vessels per hour), followed by 05:00~06:00 A.M. and 03:00~4:00 A.M.

3.2. Geographic Information System

Geographic Information System (GIS) has been applied comprehensively to various fields such as planning for land use, resource utilization, environmental detection and conservation, operation and management of water resources, transportation network planning, national defense and military applications, automotive navigation, applications in civil engineering, public facilities management and planning, location selection decision, 3D space applications, and water conservation.

One of the most powerful functions in GIS is the map overlay. Thus, this study first scanned the chart of the Kaohsiung port to be the first tier of figure in the GIS (ArcGIS 10). Secondly, we collected AIS data and then plotted them on the first tier of figure using the Visual Basic computer language. These then become the second tier of figure in GIS, i.e., Figure 2. Thirdly, we collected wind, wave, tide, and current data and used Visual Basic to integrate these and form the third tier of figure in GIS, i.e., Figure 8. Finally, we combined Figures 2 and 8 into one figure, i.e., Figure 9. In other words, Figure 9 consists of four tiers of figures.

After collecting the data for wind, waves, tide and current in Table 1, this study classified the wind, wave, tide, and sea current data into three categories: small, middle, and large, as shown in Figures 4–7. In order to clearly display all the data on the e-chart, this paper simplified and classified the wind, wave, tide, and current data into different ranges with symbols of different colors and sizes for distinction. The color of the symbols for wind speed is blue and the unit is meters per second. The wind speed is classified into 12 ranges (1 m/s~12 m/s) and displayed with diagrams as shown in Figure 4. The color of the symbols for wave height is red and the unit is meters. The wave height is classified into 24 ranges (0.1 m~2.4 m) and displayed with diagrams as shown in Figure 5.

The color of the symbols for tide height is green and the unit is meters. The tide height is classified into 9 ranges (0.1 m~0.9 m) and displayed with diagrams as shown in Figure 6. The color of the symbols for current speed is purple and the unit is knots. The current speed is classified into 18 ranges (0.1 knot~1.8 knot) and displayed with diagrams as shown in Figure 7.
Figure 8. The locations of marine accidents and the levels of wind, wave, tide, and current in the port of Kaohsiung. Note: a blue circle is wind speed and the number inside a blue circle is level of wind speed; a red circle is wave height and the number inside a red circle is level of wave height; a green circle is tide height and the number inside a green circle is level of tide height; a purple circle is current speed and the number inside a purple circle is level of current speed; a set of data (four circles including blue, red, green, and purple circles) means one marine accident, and the position of the blue circle is the location of that marine accident.
Figure 9. All data for the port of Kaohsiung are integrated on the e-chart. Note: lines A, A₁, B, and B₁ are traffic flows; points C₁, C₂, ..., Cₙ are marine accidents within the port; points D₁ and D₂ are marine accidents in the channel; point E is the marine accident in the anchorage; a set of data (four circles including blue, red, green, and purple circles) means one marine accident, and the position of the blue circle is the location of that marine accident.
Table 1. The data of wind, waves, tide, and current.

| Observation | Wind | Wave | Tide | Current |
|-------------|------|------|------|---------|
| 1           | 2    | 0.8  | 0.4  | 0.5     |
| 2           | 2    | 0.8  | 0.4  | 0.4     |
| 3           | 2    | 1.1  | 0.6  | 0.9     |
| 4           | 2    | 0.8  | 0.2  | 0.6     |
| 5           | 2    | 0.3  | 0.6  | 0.6     |
| 6           | 1    | 1.1  | 0.7  | 0.3     |
| 7           | 5    | 1.6  | 0.5  | 0.9     |
| 8           | 3    | 1.9  | 0.5  | 0.8     |
| 9           | 9    | 1.8  | 0.5  | 0.9     |
| 10          | 2    | 0.4  | 0.3  | 0.5     |
| 11          | 3    | 0.5  | 0.4  | 1       |
| 12          | 3    | 0.7  | 0.3  | 0.5     |
| 13          | 1    | 0.7  | 0.6  | 0.3     |
| 14          | 2    | 0.7  | 0.7  | 0.7     |
| 15          | 3    | 0.8  | 0.6  | 0.3     |
| 16          | 3    | 0.7  | 0.4  | 0.4     |
| 17          | 2    | 0.7  | 0.4  | 0.8     |
| 18          | 2    | 0.4  | 0.6  | 0.5     |
| 19          | 3    | 1    | 0.3  | 0.2     |
| 20          | 2    | 0.5  | 0.4  | 0.5     |
| 21          | 1    | 0.7  | 0.7  | 0.5     |
| 22          | 3    | 0.8  | 0.3  | 0.6     |
| 23          | 2    | 0.1  | 0.4  | 0.2     |
| 24          | 3    | 0.5  | 0.4  | 0.5     |
| 25          | 2    | 0.5  | 0.4  | 0.6     |
| 26          | 3    | 0.7  | 0.6  | 0.6     |
| 27          | 3    | 0.2  | 0.4  | 0.2     |
| 28          | 2    | 0.9  | 0.2  | 0.5     |
| 29          | 2    | 0.6  | 0.3  | 0.4     |
| 30          | 7    | 1.9  | 0.6  | 1.1     |
| 31          | 2    | 1.2  | 0.5  | 0.4     |
| 32          | 2    | 0.5  | 0.4  | 0.6     |
| 33          | 1    | 0.6  | 0.6  | 0.5     |
| 34          | 2    | 0.7  | 0.6  | 0.4     |
| 35          | 3    | 0.7  | 0.5  | 0.4     |
| 36          | 3    | 1    | 0.7  | 0.5     |
| 37          | 5    | 1.2  | 0.6  | 0.9     |
| 38          | 2    | 0.6  | 0.4  | 0.7     |
| **Average** | **3** | **0.8** | **0.5** | **0.6** |
| **STDEV**   | **1.56** | **0.43** | **0.14** | **0.23** |
Then, according to the location and date of each maritime accident, this study displayed the diagrams of wind speed, wave height, tide height, and current speed on the e-chart as shown in Figure 8. In order to clearly display the levels of wind, waves, tide, and current on the screen, different sizes of diagrams are used, i.e., large, medium, and small diagrams. For example, the wind speed is classified into three categories (small: 0~4 m/s, medium: 5~8 m/s, and large: 9~ m/s). The wave height is classified into three categories (small: 0~0.6 m, medium: 0.7~1.6 m, and large: 1.7~ m); the wave height is the significant wave height. The tide height is classified into three categories (small: 0~0.3 m, medium: 0.4~0.6 m, and large: 0.7~ m). The current speed is classified into three categories (small: 0~0.4 knot, medium: 0.5~0.9 knot, and large: 1.0~ knot). The values of these data increase from low to high, corresponding to small to large diagrams. In this way, different levels of sea conditions as well as the locations of maritime accidents can be clearly displayed on the e-chart. Wind, wave, current, and tide data are independent, and any sea conditions could be displayed on an e-chart.

The location of each set of wind, wave, tide, and current diagrams in Figure 9 is the location for one marine accident. For example, we determined that the marine accident D in Figure 9 occurred on 9 September 2015, as reported by the Ministry of Transportation and Communications of Taiwan. We then obtained the wind, wave, tide, and current data from the Center for Harbor Technology Research of Taiwan and the Weather Bureau of Taiwan. The wind speed was 9 m/s, wave height was 1.8 m, tide height was 0.5 m, and sea current speed was 0.9 m for 9 September 2015.

4. Results Analysis and Discussion

Figure 9 shows the integrated results on the e-chart, including traffic flows of vessels from Figure 2, locations of maritime accidents, and the data for wind, waves, tide, and current from Figure 8. The 38 collected marine accidents occurred surrounding the port of Kaohsiung. Most of the 38 marine accidents are visible in Figure 9, except for those which happened far away from the Kaohsiung port, e.g., one of these was the one in the upper left corner of Figure 9, i.e., point F. Most mechanical failure accidents occurred in the waters far away from the port of Kaohsiung; therefore, they are missing in Figure 9. The descriptions of the elements/symbols shown in Figure 9 are as follows. The red lines are the tracks of vessels entering the port. The green lines are the tracks of vessels exiting the port. The blue circles with number are the levels of wind speed. The red circles with number are the levels of waves. The green circles with number are the levels of tide. The purple circles with number are the levels of current speed. Lines A, A1, B, and B1 are traffic flows; points C1, C2, . . . , Cn are marine accidents within the port; points D1, D2 are marine accidents in the channel; point E is the marine accident in the anchorage; and point F is a marine accident far away from the port and almost missing in the e-chart. This study then analyzed the shipping traffic and marine accidents shown in Figure 9. Some major findings are listed as follows.

(1) The Traffic Separation Scheme works well

The Traffic Separation Scheme (TSS) is one traffic management system suggested by the International Maritime Organization. The traffic lane indicates the general direction of the vessels, which enter/exit the port. In other words, vessels sailing within TSS waters always navigate in the same direction. Usually, there are specific waters where a lane splits into two channels: one for exiting and the other for entering into the port. These two channels of a TSS are shown on the Electronic Chart Display and Information System (ECDIS) so that navigators on vessels entering/exiting can understand clearly where the TSS zone is. The waters between two opposite lanes should be avoided by vessels entering/exiting the ports as far as possible. The Vessel Traffic Service (VTS) operators in the port also watch and control the tracks of the vessels by AIS to decide if a vessel is following the TSS or not. The TSS is applied to regulate the traffic flow of vessels surrounding the waters of ports, especially in busy ports or waterways. The occurrence of marine accidents could be reduced if all vessels entering/exiting the port follow the TSS. Thus, the TSS is an important
system for port safety management. A marine accident will probably occur when vessels disobey the TSS.

According to the red track lines of the vessels which are entering the port and the green track lines of vessels which are exiting the port in Figure 9, it seems that most of the vessels which enter/exit the port followed the rules of TSS. TSS refers to the two light purple lines in Figure 9. One is between points A1 and B1. The other is close to point F. Almost all the red lines A are within the waters of the TSS channel for entering and almost all the green lines B are within the waters of the TSS channel for exiting. Only a few ships disobeyed the rules of the Traffic Separation Scheme, e.g., the green line B1 is in the waters of the TSS channel for entering and the red line A1 is in the waters of the TSS channel for exiting.

(2) Most marine accidents occurred inside port waters

In Figure 9, it is noted that most of the marine accidents occurred inside port waters, e.g., marine accidents C1, C2, C3, C4, …, Cn. According to the locations of marine accidents shown in Figure 9, Figure 10 shows the percentages for different locations of marine accidents. Figure 10 illustrates that 61% of all marine accidents occurred inside port waters, while 16% occurred in the channel of the port, e.g., the marine accidents D1 and D2 in Figure 9. In addition, 13% of all marine accidents occurred in the anchorage area, e.g., the marine accident E in Figure 9. Only 10% of all marine accidents occurred outside port waters, e.g., the marine accident F in Figure 9.

Figure 10. The locations of marine accidents.

(3) Discussion on the causes of marine accidents that occurred inside port waters

Marine accidents were separated into eight categories: collision, grounding, mechanical malfunction, fire, sinking, capsizing, leakage, and others. The causes of the marine accidents were reported in the Annual Report published by the Ministry of Transportation and Communications of Taiwan. The definition of each type of marine accident is described as follows. Collision means ships striking or being struck by another ship, regardless of whether the ships are underway, anchored, or moored. Contact (allision) means ships striking or being struck by an external object. The objects can be cargo, ice, other, or unknown, but not the sea bottom. Grounding means a moving navigating ship, either under command, under power, or not under command, drifting, striking the sea bottom, shore, or underwater wrecks. Mechanical malfunction refers to damage to equipment, systems, or machines. Fire is the uncontrolled process of combustion characterized by heat or smoke or flame, or any combination of these. Sinking means one vessel goes down below the surface of the sea water. Capsizing means the ship no longer floats in the rightside-up mode due to negative metacentric height, or transversal shift of the center of gravity, or the impact of external forces. Leakage means the escape of liquids such as water, oil, etc., out of pipes, boilers, tanks, etc., or an inflow of seawater into the vessel due to damage to the hull. Other accidents means marine accidents which did not belong to any of the abovementioned casualty types.
A total of 61% of all marine accidents occurred inside port waters. These marine accidents were mainly caused by allisions between the vessels and the wharfs. The others were caused by fire, explosion, and grounding. The reason why the vessel collided with the wharf was mainly inappropriate operation by operators. Some collision accidents were caused by environment factors including typhoon and monsoon. A few collisions were caused by mechanical failures. Figure 9 also shows that most marine accidents happened inside port waters when wind, current, and waves are weak. This means that the major causes of marine accidents which occurred inside port waters are human errors rather than natural environment factors.

(4) Discussion on the causes of accidents that occurred in the channel of the port

A total of 16% of all marine accidents occurred in the channel with heavy traffic. Nearly half of these marine accidents that occurred in the channel were caused by vessel collision, the others were extraordinary events.

Two thirds of the collision accidents were caused by inappropriate navigational operation, i.e., human errors, and one third of the collision accidents were caused by strong winds and currents while a typhoon was approaching Taiwan. In Figure 9, it is noted that some marine accidents located in the channel of the port occurred when wind, current, and wave levels were strong. This means that the natural environment factor is one of the major causes of marine accidents which occurred in the channel of the port.

(5) Discussion on the causes of accidents that occurred in the anchorage area

A total of 13% of the marine accidents occurred in the anchorage area attached to the shoreline and the fairway. In other words, some anchored vessels did not anchor exactly inside anchorage waters. Almost one half of the marine accidents that occurred in the anchorage area were caused by a collision between the navigating vessel and an anchored vessel. Sometimes vessels entering/exiting a port have to sail through other anchored ships. These movements generate more interactions or conflicts between ships, resulting in a higher probability of collision. Another half of the marine accidents that occurred in the anchorage area were caused by grounding, mainly due to inappropriate navigational operation, i.e., human errors, or bad weather such as typhoon, strong winds, and strong currents. Few marine accidents in the anchorage waters were caused by mechanical failure.

(6) Discussion on the causes of marine accidents that occurred outside port waters

Only 10% of the marine accidents occurred outside port waters. Most of the marine accidents that occurred outside port waters were caused by collision between merchant vessels and fishing boats. Interestingly, it is noted that most of these collisions occurred in good weather. Few marine accidents were caused by bad weather. Some of the marine accidents that occurred outside port waters were caused by mechanical failures.

(7) Discussion on the differences between previous studies and this paper

Chou et al. [6] used GIS to analyze the location of marine accidents. The environmental data, such as wind, waves, tide, and current, were not involved in their study. They only found that almost half of marine accidents happened within the port waters. In our study, we used AIS, GIS, and an e-chart to analyze the relationship between the locations of accidents and environmental factors. The results showed that the major causes of marine accidents that occurred inside port waters were human errors rather than natural environment factors. However, the main causes of marine accidents that occurred in the channel, anchorage area, or outside port waters, were environmental factors, such as strong winds, typhoons, and strong currents.

5. Conclusions

In the past, few studies have integrated AIS, GIS, and an e-chart simultaneously to analyze the relationship between the traffic flows of ships and the locations and causes of marine accidents around a port. To improve analysis methodologies, this paper first used
AIS to collect the traffic flows of vessels entering/exiting the port, and then used GIS to analyze environmental data, including wind, waves, tide, and current. Finally, this study integrated these relevant data, i.e., traffic flows of vessels, locations of marine accidents, and wind, wave, tide, and current data, and then displayed them on the e-chart to analyze the relationship between the traffic flows and the locations and causes of marine accidents. Some major findings are shown below.

(1) At present, the Traffic Separation Scheme in the Kaohsiung port works well. Most vessels entering/exiting the port obeyed the Traffic Separation Scheme.

(2) Most marine accidents occurred inside port waters, followed by in the channels, the anchorage areas, and outside port waters.

(3) Marine accidents that occurred inside port waters were mainly caused by allision between the vessel and the wharf. Therefore, this paper suggests that port authorities should initiate some strategies to improve the management and communications between the seafarers on merchant vessels and the workers at the wharfs, as well as the cooperation and communications between tugs and merchant vessels when berthing. In addition, slower navigation speed usually can reduce allision and collision potentials. Therefore, the port authority should enforce low-speed or safe-speed navigation inside port waters.

(4) The channels are used by all vessels to enter/exit the port; therefore, they usually have heavy traffic. The marine accidents that occurred in the channels were basically navigational accidents due to human errors or environmental factors.

(5) Some marine accidents occurred in the anchorage areas attached to the shoreline and the fairway. In other words, some anchored vessels did not anchor exactly inside anchorage waters. The port managers, e.g., the Vessel Traffic Service (VTS) in the port, should command the vessels to anchor exactly inside anchorage waters to lower the probabilities of potential collisions. Anchorages bounded by confined waters will lower the probability of potential collisions. In addition, the number of danger markers is associated with reduction in the collision potential.

(6) The integrated AIS, GIS, and e-chart system is an initial work. Based on the integrated AIS, GIS, and e-chart system, we will continue to further develop a monitoring system for automatically monitoring the real-time traffic flows of all ships around the port (in the future tier II project), and to develop a pre-alarm system for real-time collision avoidance (in the future tier III project). The major difference between the integrated pre-alarm system and the ECDIS is that the integrated system is suitable for multiple-ship to multiple-ship and is set up in one port, and the ECDIS is suitable for one-ship to multiple-ship and is set up on one ship. The integrated pre-alarm system for real-time collision avoidance could be the basis for developing an intelligent port in the future. Additionally, this study also recommends that future studies should focus on how ship traffic movements resulted in individual accidents when using such an integrated pre-alarm system.

(7) Sometimes, government marine departments do not report detailed information on marine accidents. It is understandable that there are national security and marine insurance reasons for keeping accident information secret. This paper suggests that accident information could be made public for academic research only.

Author Contributions: Conceptualization, C.-C.C.; data curation, C.-C.C., C.-N.W., H.-P.H., J.-F.D. and W.-J.T.; formal analysis, C.-C.C.; funding acquisition, C.-C.C.; investigation, C.-C.C., C.-N.W., H.-P.H., J.-F.D. and W.-J.T.; methodology, C.-C.C., C.-N.W., J.-F.D. and W.-J.T.; project administration, C.-C.C.; resources, C.-C.C.; software, C.-C.C., H.-P.H. and C.-Y.Y.; supervision, C.-C.C.; writing—original draft, C.-C.C.; writing—review and editing, C.-C.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research work was partially supported by the Ministry of Science and Technology, R.O.C., under Grant No.: MOST 109-2410-H-992-012-MY2.
Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.
Data Availability Statement: Not applicable.
Conflicts of Interest: The authors declare no conflict of interest.

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