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Assessment of the Navigation Safety in the Taiwan Strait during China's Naval Blockade

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1. Introduction

Following Nancy Pelosi's visit to Taiwan in early August 2022, China promptly initiated extensive military exercises and enforced a maritime blockade around Taiwan. Despite the unexpected nature of the drill, China had previously issued notifications regarding restricted areas. The blockade encompassed vital international shipping routes in the Taiwan Strait, compelling vessels to reroute and avoid the restricted zone. This significantly impacted navigation safety in the Taiwan Strait's northeast sea area. To assess this impact, we collected ship data via the Automatic Identification System (AIS) before and after the exercises. Employing technologies such as databases and Geographic Information Systems (GIS), we created Electronic Navigational Charts (ENC) and conducted simulated ship collision risk analyses for the altered routes. The maritime blockade resulting from the military exercise considerably heightened navigation risks in the Taiwan Strait.

Recent events highlight the need to anticipate and prepare for challenges. Assessing vessel responses during military exercises, such as facing blockades, can enhance navigation safety. Simulation and evaluation of risky scenarios allow for the development of better safety regulations. Despite heightened geopolitical risks, these exercises offer valuable opportunities to enhance waterway safety. Figure 1 depicts vigilance areas along Taiwan's northern coast during the exercises. Recent events in the Taiwan Strait, while increasing geopolitical risks, also provide opportunities to improve vessel safety through assessments during military exercises.

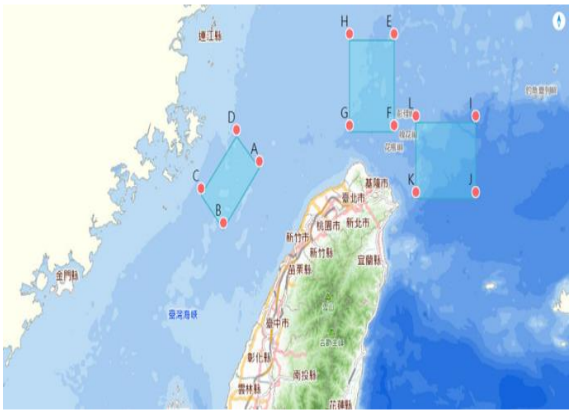

Fig.1 The vigilance areas during the military exercises.

The Automatic Identification System (AIS) is an essential tracking system installed on ships to facilitate vessel identification and positioning for maritime traffic management. AIS enables electronic data exchange between vessels, AIS base stations, and satellites, enhancing naval safety and supporting various applications. AIS serves to improve safety and strengthen territorial defense, address marine environmental issues, and help support maritime big data analyses. AIS data provides real-time information for ship navigation, including identification codes, vessel names, positions, headings, and speeds (Weibin Zhang et al., 2015). The system aids watch officers and maritime authorities in monitoring vessel movements by combining Global Positioning System (GPS) and Very High Frequency (VHF) technology to broadcast dynamic vessel information to nearby AIS-equipped vessels and receive their information in return. AIS data can be integrated with maritime radar, electronic navigational tools, echo sounders, and rudder angle indicators to avert sea collisions. Coastal AIS base

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stations monitor ships equipped with AIS transceivers, while vessels farther from the shore can be pinpointed using dedicated AIS receivers and satellite signals.

Recent research has explored sea collision avoidance (Chiu Bo-Han, 2009; Hsu Che-Ying, 2013; Chen et al., 2022; et al., 2022) and ship route (Xiao et al. 2015) analysis using AIS. We can uncover valuable insights from vast AIS observational data by integrating GIS and data analytic techniques. (Silveira et al. 2013) used historical AIS records from Vessel Traffic Service (VTS) at specific locations. They employed test lines (gate-lines) perpendicular to the trajectories of ships in the channels to sample the vessels' flow and heading statistics along these test lines. (Wu et al. 2016) collected and compiled global AIS records, including plotting the trajectories of individual vessels on a world map to visualize the distribution of high and low traffic density, providing insights into the density of maritime traffic in various major ocean regions. Thus, using maritime traffic AIS data allows us to identify better bottlenecks in marine traffic, which might impact navigational safety.

2. Data collection and analysis

We utilized GIS as the primary tool for developing ENCs. GIS is a comprehensive system integrating diverse data types, including maps, satellite images, terrain data, and population information. For this study, we utilized QGIS, an open-source GIS software tool. Navigators use ENCs for channel navigation and safe vessel operation. ENC provides essential information about the navigational channel, such as water depth, navigational hazards, and buoy positions. Recently, AIS data has been integrated into ENCs to provide real-time information about vessel positions and movements. This technological integration offers an effective way for navigators to navigate congested waterways and avoid collisions. The data collection and analysis processes are described in Figure 2.

The generated ENCs are divided into three periods: before, during, and after the military exercises. We only show the ENCs regarding before and during military drills (Fig. 3 and 4). The gate lines (lanes) shown in Figures 3 and 4 were designated areas in a navigational channel where many vessels enter or exit in that area. The location of gate lanes can be identified by consulting local port authorities, referring to navigation charts, or based on historical navigational trajectories. Once the gate lane positions were identified, their coordinates were determined and planned on the ENCs. This study drew several gate lanes to identify the primary channels near the military exercise area.

Based on the historical AIS records received from Vessel Traffic Service (VTS), (Silveira et al. 2013) used specific locations to establish test lines (gate lines) perpendicular to the vessel trajectories. By sampling and analyzing the vessels' traffic flow and heading statistics along these gate lines, they aimed to calculate the congestion level of ships navigating in the maritime area. As mentioned above, we used the gate-lines from the ENCs to calculate the density of vessels navigating in the area. As shown in Figure. 3, the distances of four gate-lines and the number of ships passing through them were calculated to obtain the density of vessels passing through these gate lines in the specific area. The vessel count and density passing through the gate-lines for the four days before the military exercises (July 31st to August 3rd) are shown in Table I. The vessel count and density passing through the gate-lines for the four days during the military exercises (August 4th to 7th) are shown in Table II. The density of gate-line GLB1 before the military exercises was 3.234165368 vessels per kilometer (ship/km). At the same time, during the military exercises, the density of gate-line GLM1 increased to 5.032583968 vessels per kilometer (ship/km), representing an approximately 1.55-fold increase in density. Similarly, before the military exercises, the density of gate line GLB3 was 1.813433413 vessels per kilometer (ship/km). During the military exercises, the density of gate line GLM3 increased to 5.514667211 vessels per kilometer (ship/km), indicating a roughly 3.04-fold increase in density. These analyses of the gate-lines reveal that due to the forced rerouting of the maritime channel during the military exercises, the density of vessels navigating in the area was higher than before. Additionally, except for gate line GLB3, whose position remained roughly unchanged, the positions of the other three gate lines were significantly altered due to the exercises, particularly gate lines GLB2 and GLB4, indicating a notable impact of the military exercises on the navigational channels in that region.

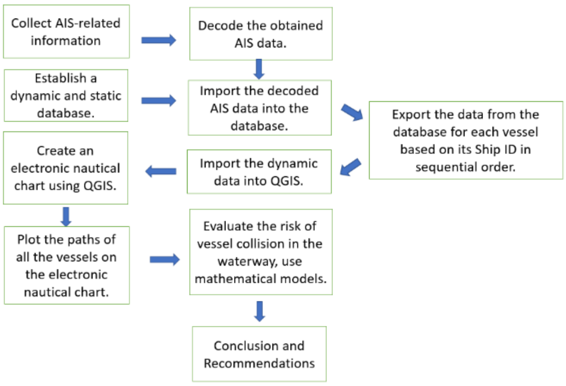

Fig. 2 Data collection and analysis processes

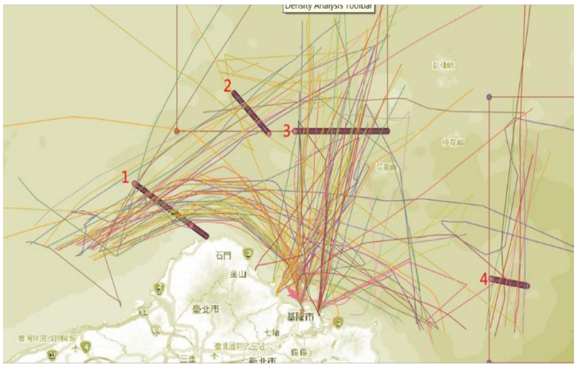

Fig. 3 Four days before the military exercise, from July 31st to August 3rd.

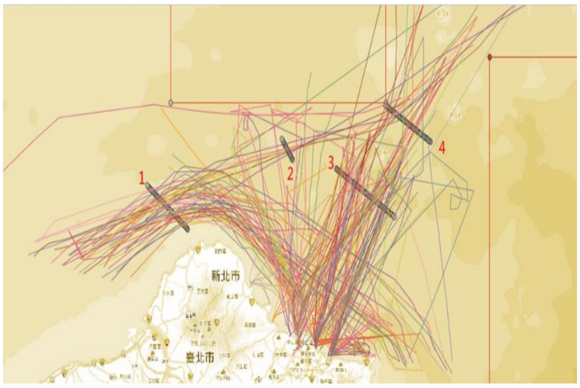

Fig. 4 Four days during a military exercise, from August 4th to 7th.

Table I Gate-line density (GLB1~4)

	distance(meter)	distance(km)	# vessels	ships/km
GLB1	15769.138	15.769138	51	3.234165368
GLB2	9507.552	9.507552	14	1.47251364
GLB3	21506.166	21.506166	39	1.813433413
GLB4	8246.683	8.246683	12	1.455130505

Table II Gate-line density (GLM1~4)

GLM1	9935.254	9.935254	50	5.032583968
GLM2	2349.487	2.349487	6	2.553748967
GLM3	14688.103	14.688103	81	5.514667211
GLM4	9971.973	9.971973	28	2.807869616

3. Ship Collision simulation analysis

Prior research introduced Distance to the Closest Point of Approach (DCPA) and Time to the Closest Point of Approach (TCPA) to assess collision risk. However, they have limitations in describing collision severity accurately. DCPA, for instance, can be misleading when ships sail parallelly. It doesn't consider ship movement direction, resulting in inaccuracies (Weibin Zhang et al., 2015). To address this, the Vessel Conflict Ranking Operator (VCRO) employs a mathematical model suitable for various ship encounter scenarios, rectifying DCPA and TCPA issues. The model has three considerations (Weibin Zhang et al., 2015).

(1) The distance between the two ships

(2) The relative speed of the two ships

(3) The phase difference between the two ships

The three factors discussed above represent the complexity involved when two vessels come into contact, and their values are determined by analyzing how these factors are interrelated in terms of the risk involved in collision-free navigation. The presentation of the VCRO model primarily revolves around collision risk. The VCRO model assesses the collision risk between two vessels without an actual collision and ranks the assessment values. Higher risk levels indicate a greater likelihood of collision between the two vessels, while lower risk levels suggest a higher probability of safe navigation. VCRO was developed based on evaluation criteria formulated by maritime experts, and the mathematical model and AIS data required for the assessment were designed according to their expert definitions (Weibin Zhang et al., 2015). The severity of ship collisions was considered when constructing the mathematical model for VCRO. The model takes into account the three factors mentioned earlier: distance between the two vessels (x), relative speed of the two vessels (y), and phase difference between the two vessels (z). We used the modified VCRO mathematical model from Chen et al. to simulate ship collision patterns and calculate risk values (Chen et al. 2022). The following equation is the VCRO mathematical model used in this study

$$VCRO_{(x,y,z)} = ((3.87x^{-1}y)(\sin z + 0.386\sin(2z))$$

The following figures illustrate ship encounters in a crossing situation involving two intersecting ships passing through GLM1 during a military exercise in the northeast direction of Keelung Port. Vessel_A is the focal point for observation and monitors the dynamic changes between the two ships in this encountering scenario. Figure 5 provides the route map for both ships during the encounter. In contrast, the subsequent figures depict changes in relative distance (Fig. 6), relative speed (Fig. 7), and VCRO value calculated by the model (Fig. 8). When vessels travel at closer distances, leading to higher ship traffic density on the sea, the VCRO value significantly increases.

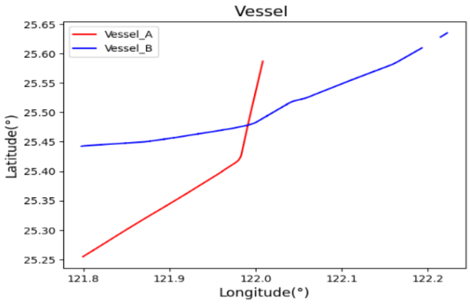

Fig. 5 Path chart of ships A and B.

Fig. 6 Relative distance between ships A and B over time.

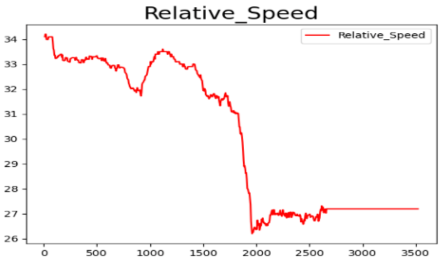

Fig. 7 Relative velocity of ships A and B over time.

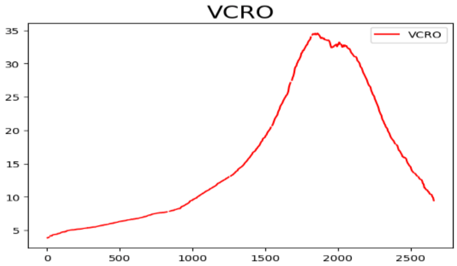

Fig. 8 VCRO values between ships A and B over time.

4. Concluding remarks

The military exercise's area blockade affects ship routes in two ways. First, vessels must divert to avoid restricted zones, causing disruptions and uncertainties. Second, overlapping routes searching for navigational channels increase collision risks and conflicts. A higher VCRO implies safety issues and collision likelihood. Future research should examine sea areas near wind farms, identifying high-risk zones as "risk hotspots." Maps of these areas will aid safety development. Analyzing risk hotspots allows authorities to apply preventive measures for safe navigation. Continued future research and analysis on these topics will give us more comprehensive views regarding sea navigation risk levels, aiding navigational management and safety improvements. Ongoing monitoring and early risk identification enhance safety, route planning, and maritime traffic growth. Since we collected AIS data for only 12 days, from July 31 to August 11, 2022, the dataset is limited, and predictive accuracy may be affected. Route changes should be factored into risk calculations when observed to improve maritime safety. In future gate-lane analyses, using additional test lines in high, medium, and low-density navigational areas for more precise comparisons is advisable. Furthermore, comparing VCRO values in various gate lanes can pinpoint actual risk-prone zones.

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