Particle swarm optimization algorithm-based siting and design of fishing vessels concentrating on crossing the precautionary area

Kaiqiang Wang, Zhongzhou Fan*, Yuqing Wang, Yuchi Han
Navigation College, Dalian Maritime University, Dalian 116026, Liaoning, China

ABSTRACT

In order to avoid the safety hazards of fishing vessels dispersing and crossing the precautionary area in a disorderly manner, reducing collisions between commercial and fishing vessels and ensuring the safe and efficient operation of neighboring ports, it is crucial to select the area where fishing vessels are concentrated to cross the large precautionary area. Based on the advantages and disadvantages of the particle swarm algorithm and the path planning principles outlined in the General Provisions on Ships' Routeing, we conducted a site selection study focused on the waters within the large cordoned-off area where fishing vessels frequently cross. As a practical example, we planned a recommended route for fishing vessels navigating the densely trafficked area in the southeast of Shidao. The recommended route for fishing vessels described in this plan is the optimal crossing of waters under the condition of non-closed fishing season, which was verified to be feasible by examples and announced on April 9, 2024, for implementation.

Keywords: Precautionary area, particle swarm algorithms, general provisions, recommended routes for fishing vessels

1. INTRODUCTION

1.1 Regulations

The guiding document for ship routeing, the *General Provisions on Ships' Routeing*[1], originated from the 1977 International Maritime Organization Assembly. This document offers several key recommendations for the creation and implementation of ship routeing systems, significantly enhancing their role in ensuring navigational safety, regulating passage, and standardizing design practices across different countries. The *Law of the People's Republic of China on Safety of Maritime Traffic*[2], which took effect on September 1, 2021, further empowers maritime safety authorities with greater authority and responsibility to manage activities related to the safety of maritime traffic, particularly concerning fishing vessels. According to the *General Provisions on Ships' Routeing*, onepurposes of the ship routeing measures is to guide traffic away from fishing grounds or to organize traffic through these areas., and there are more routeing measures for merchant ships, while there are no routeing measures for fishing vessels in waters outside the port as the target of regulation.

1.2 Precautionary areas

Precaution is a warning on the behavior of ships, i.e., ships navigating in the precautionary area should maintain a high degree of alertness to the navigational situation of the ship and the surrounding ships, the encounter situation, and the natural environment that affects the safety of the ship's navigation. While maintaining safe navigation by all effective means such as strengthening lookout and using safe speed, the ship is highly sensitive to changes in the surrounding natural and traffic environment, and improves its ability to respond to any situation that may arise in the precautionary area. Once a situation that jeopardizes the navigation safety of the ship appears, the ship can take timely and effective measures to avoid accidents[3]. In other words, in order to cope with navigational risks that may arise at any time, ships in the precautionary area must take higher-than-normal alert measures, and at the same time ensure that their response speed and effectiveness are sufficient to cope with potential dangers. As the default target of the ship's routeing system, such as the precautionary area, is the merchant ships, the alertness of the fishing vessels using the precautionary area is weaker than that of the merchant ships, which makes the collision of merchant vessels and fishing vessels in the waters of the precautionary area and other ships' routeing system high, and strengthens the safety control of the navigation of the fishing vessels in the high-risk waters has become an urgent task. We take the Shidao Southeast Navigable Intensive Area as an example, the precautionary area was established in 2015, which undertakes the north-south vessel traffic flow

*ffzz101@163.com

International Conference on Optics, Electronics, and Communication Engineering (OECE 2024), edited by Yang Yue, Proc. of SPIE Vol. 13395, 133951W · © 2024 SPIE · 0277-786X · Published
 · doi: 10.1117/12.3048593

of 66,213 (2023) vessel trips of the navigable sub-channels within the navigation system of Chengshanjiao Sub-channel, and meanwhile, there are 115,016 vessel trips of east-west traversing the precautionary area during the non-closed seasons (Jan.-Apr. and Sep.-Dec., 2023), and the disorganized and dispersing of the vessels traversing the precautionary area, which is dominated by the fishing vessels, constitutes a major potential hazard for the navigational safety of this area of the water. As shown in Figure 1, the vessel trajectories for all vessels and fishing vessels in the Shidao Southeast Navigable Intensive Area in December 2023 clearly depict the high density of vessel distribution and the complexity of their navigational paths. This illustrates the challenges and urgency of managing navigational safety in this area.

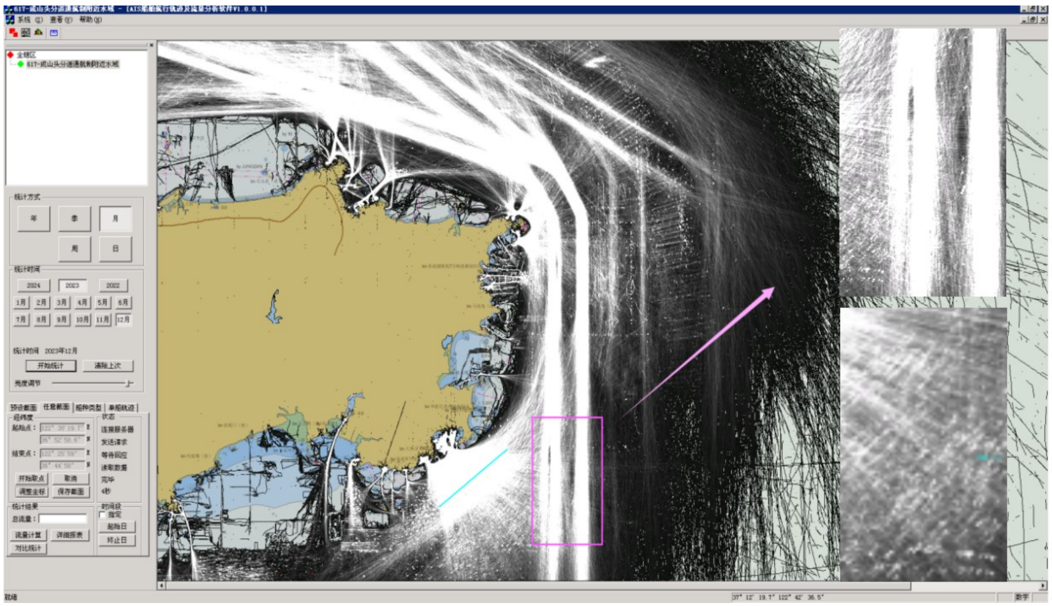

Figure 1. Vessel trajectories (all vessels and fishing vessels) in Shidao Southeast Navigable Intensive Area, December 2023.

1.3 Swarm intelligence optimization algorithm

The purpose of the path planning technique is to select an optimal route plan with the shortest possible path length to minimize travel time and ensure safe arrival at the destination while avoiding all possible obstacles, provided that the start and end points have been determined[4]. Some of the swarm intelligence optimization algorithms proposed so far are particle swarm algorithm[5], sparrow search algorithm[6], ant colony algorithm[7] and so on. Particle swarm optimization (PSO) is a meta-heuristic algorithm for swarm intelligence proposed by researchers Kennedy and Eberhart[5], inspired by the natural foraging behavior of birds. The algorithm simulates a group of birds searching for food within a defined search space. Initially, each bird's position and search direction are generated randomly. As the birds search, they adjust their flight direction based on the distance between their current position and the food source. Once a bird locates the food, it communicates this information to the nearest bird. This information then spreads progressively from bird to bird, guiding the entire flock toward the food source. Each bird represents a solution and its fitness value is determined by the objective function. These individuals determine their respective flight speeds and directions based on the information between the individuals themselves and other companions during the feeding process, and ultimately determine the updating method of the position. PSO has the advantages of fewer parameters, simpler operation, and higher resilience, however, a significant disadvantage of this approach is its tendency to get trapped in local optima.

2. METHODOLOGY

2.1 Formulas

The Particle Swarm Optimization (PSO) algorithm models each particle in the swarm as a potential solution to a given problem. The problem-solving intelligence is achieved through the simple behaviors of individual particles and the exchange of information within the swarm. Due to its simplicity and fast convergence speed, PSO has been widely applied in various fields such as function optimization, image processing, and geodesy. The algorithm begins by initializing a group of random particles (random solutions) and iterates to search for the optimal solution. During each iteration, particles update their status by tracking two "extreme values"—the personal best (Pbest) and the global best (Gbest). After identifying these optimal values, each particle adjusts its velocity and position according to the following formula. The PSO algorithm enables all particles in the population to modify their speed and position based on the best solutions they have individually found and the global best solution identified by the entire population.

$$v_i = v_i + c_i \times rand() \times (pbest_i - x_i) + c_2 \times rand() \times (gbest_i - x_i) \tag{1}$$

$$x_i = x_i + v_i \tag{2}$$

$$v_i = \omega \times v_i + c_i \times rand() \times (pbest_i - x_i) + c_2 \times rand() \times (gbest_i - x_i) \tag{3}$$

$$\omega = \frac{(\omega_{\text{ini}} - \omega_{\text{end}})(\text{G}_{\text{k}} - \text{g})}{\text{G}_{\text{k}} + \omega_{\text{end}}} \tag{4}$$

Equations (1) and (2) describe how to update the velocity and position of particle, respectively. Where, $i = 1, 2, ..., N$, N represents the particle number. v_i is the particle's velocity, x_i is the particle's position, $rand()$ is a random number between (0, 1), c_1 and c_2 are learning factors. In equation (1), t the first component is the memory term, reflecting the influence of the previous velocity on the current update. The second component, known as the self-cognition term, is a vector pointing from the current position to the particle's personal best, representing the impact of the particle's own experience on the update. The third component is the population-cognition term, a vector pointing from the current position to the global best, indicating the influence of the swarm's collective experience on the update. Equations (1) and (2) form the standard model of the particle swarm optimization algorithm.

Equation (3) represents the standard particle swarm optimization algorithm, where ω is known as the inertia factor. A larger inertia factor enhances the algorithm's global optimization capability but weakens its local optimization ability. Conversely, a smaller inertia factor strengthens local optimization but reduces global optimization effectiveness. Since the algorithm starts with a group of random particles distributed over a broad range, the inertia factor should be set to a larger value at the beginning to promote strong global optimization. As the algorithm progresses and particles begin to converge toward one or more optimal solutions, the inertia factor should be gradually reduced to enhance local optimization in a more confined search space.

Equation (4) for the commonly used linear decreasing weights strategy, ω_{ini} denotes the initial value and ω_{end} denotes the final updated value.

2.2 Iterative algorithm

The initial position, speed and the position of starting fishing operation (Weidong fishing ground and Shidao fishing ground) of 115,016 vessels were selected, and the plus and minus coefficients were determined according to the maneuvering performance of the fishing vessels, and simulated by using Python, and the distribution of optimal solutions is illustrated in Figures 2 and 3. These figures depict the results from the particle swarm optimization simulations conducted to assess the navigational strategies of fishing vessels in the Shidao waters.

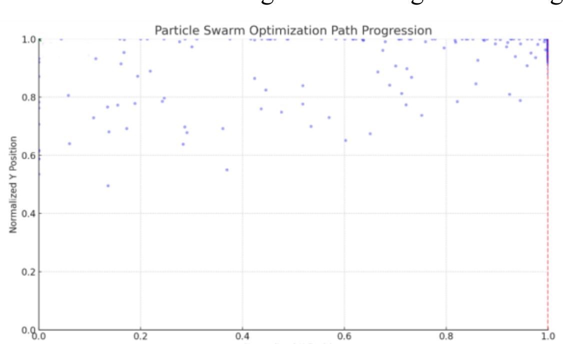

Figure 2. Particle swarm optimization path progression in Shidao waters for fishing vessels.

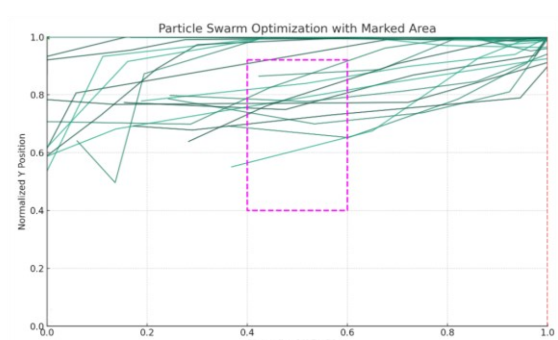

Figure 3. Particle swarm optimization path progression with lines in Shidao southeast navigable intensive area (marked).

3. OPTIMIZATION BASED ON THE GENERAL PROVISIONS ON SHIPS' ROUTEING

The purpose of ships' routeing is to enhance navigational safety in areas where traffic converges, where traffic density is high, or where shipping movement is restricted due to limited sea-room, navigational obstructions, shallow depths, or adverse weather conditions. Additionally, ships' routeing aims to prevent or mitigate the risk of pollution or other environmental harm that could result from ships colliding, grounding, or anchoring in or near environmentally sensitive areas. In this section, based on the optimal solution, the width, direction, and position of the fishing vessels' passageway from the northern and southern ends of the precautionary area are optimized.

3.1 Width of fishing vessel passageways

According to 6.10 of the *General Provisions on Ships' Routeing* adopted by IMO, the width of a route should consider factors such as navigational density, general usage of the area, and the available sea space. Passage capacity is the ability of a shipping route to handle ship traffic, typically expressed as the maximum number of ships that can pass through the route within a given time frame. When the passage capacity is insufficient to meet the actual traffic demands, it can lead to congestion in the waterway, thereby reducing the efficiency of ship passage.

From theoretical research and practical application, traffic capacity is often categorized into basic traffic capacity, possible traffic capacity and practical traffic capacity. Japanese scholars Fujii[8] has 1 nautical mile-wide unidirectional waterway corresponding to different scales and speeds of the ship's basic traffic capacity to do theoretical research. For the average length of 33 m, the average speed of 9.1 kn 100-500 gross tons of ships, 1 nautical mile wide waterway basic traffic capacity of 1500 /h, 24 h traffic capacity of 36000, obviously, if the width of unidirectional waterway to 1 nautical mile, in the ability to pass through the more than enough.

Because of the abundant water available in this precautionary area, and the traffic flow of fishing vessels is affected by the fishing ban and typhoons, which often show the characteristics of concentrating on going out and returning to port, the width of this water area is selected as 3 nautical miles in one direction to address the unique characteristics of fishing vessel traffic and to ensure the smooth flow of the channel during peak times, specific measures need to be implemented. Figure 4, which presents the daily fishing flow through the precautionary area monthly in 2023, vividly illustrates these variations. The graph shows how environmental and regulatory conditions significantly influence the traffic patterns, justifying the need for a wider navigational passage to manage these peak flows effectively.

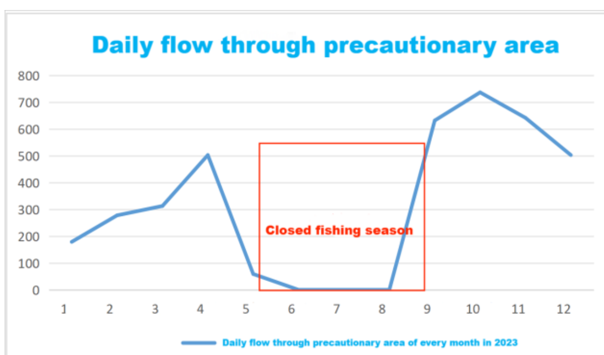

Figure 4. Daily fishing flow through precautionary area monthly in 2023.

3.2 Direction of fishing vessel passageways

A ship navigates through an area where traffic flow is characterized by randomly distributed vessels, as illustrated in Figure 5:

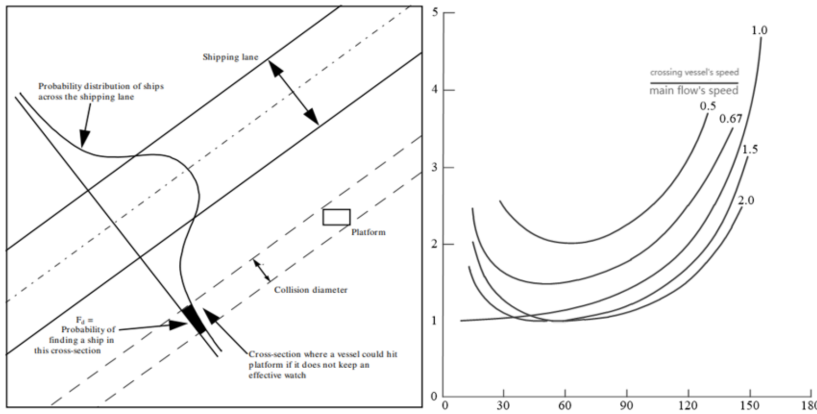

Figure 5. Theoretical modeling of ships crossing traffic streams and encounter rates.

We apply equation (5) for the calculation of the encounter rate[9]:

$$\text{encounterg rate}=\{1+(\frac{V_M}{V})^2-\frac{2V_M}{V}\cos\theta\}^{\frac{1}{2}}\sin^{-1}\theta \tag{5}$$

where V is the velocity of the single vessel; V_M is the velocity of the main traffic; and θ is the angle between the single vessel and the direction of the main flow.

However, the approach to handling this encounter scenario is still based on the assumption that all ships in the main traffic stream are traveling at the same speed. Despite this assumption, calculations of the assumed speed distribution indicate that the crossing angle should be accurate to within 10%. To ensure safety and efficiency, vessels should cross the main traffic stream at angles as close to 60°-90° as possible. There are two main traffic streams from north to south in the precautionary area, so the channel is divided into two parts with reference to the above conclusion, i.e. 60°-90° for the west section and 90°-120° for the east section. Therefore, to minimize the number of waypoints and adhere to the principles of good seamanship, which recommend crossing the main traffic flow at right angles, the channel direction is selected to be 90° and 270°, i.e. east-west direction.

3.3 Position of fishing vessel passageways

Based on the optimal route generated by the particle swarm optimization algorithm, while referring to the conclusion above according to the *General Provisions on Ships' Routeing*, the space of 30% (6.6 nautical miles) or more of the span of the precautionary area is set aside in the north side. In order to facilitate the release of the maritime department and the navigational personnel to mark on the chart, the area as A (36°50' N, 122°42'42" E), B (36°50' N, 122°56'36" E), C (36°44' N, 122°56'36" E), and D (36°44' N, 122°42'42" E) enclosing the area as the commended routes for fishing vessels (see Figure 6).

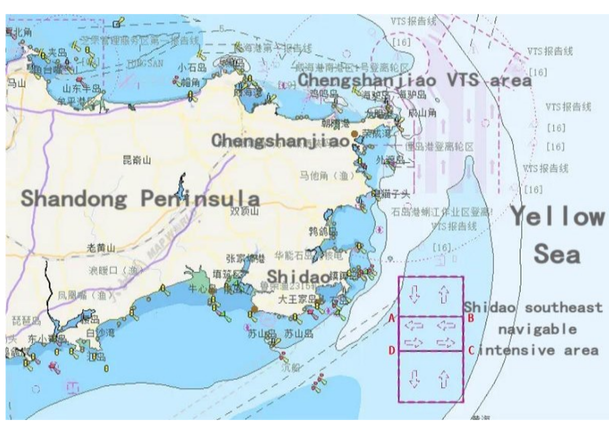

Figure 6. Diagram of recommended routes for fishing vessels in Shidao southeast navigable intensive area.

4. CONCLUSION

In order to protect the navigation safety of fishing vessels crossing the precautionary area and other vessels in the surrounding waters, this paper proposes and designs a recommended route for fishing vessels in the precautionary area based on the existing traffic flow, through particle swarm optimization algorithm, combining with the *General Provisions on Ships' Routeing* and other nautical norms, and taking the southeast waters of Shidao as an example.

The implementation of this route will significantly reduce the scope of the intersection areas of ships in the water, thereby lowering the risk of collisions within and around the precautionary area. It will also enhance the safety of ship navigation while balancing the development of fisheries in the region and the protection of the marine environment. It is a positive attempt and exploration to set up the fishing vessel routeing measures by using a group intelligent optimization algorithm and referring to the *General Provisions on Ships' Routeing* of merchant ships. The conclusion has been adopted by the Shandong Maritime Safety Administration and Shandong Provincial Department of Agriculture and Rural Affairs, announced on April 9, 2024 (https://www.sd.msa.gov.cn/art/2024/4/15/art_1443_1814615.html) for implementation.

REFERENCES

[1] International Maritime Organization, [General Provisions on Ships' Routeing], London, (2008).

[2] Lin, W., "Revision of the Maritime Transportation Safety Law through six keywords," China Maritime Affairs, 2021(10), 26-27+54, (2021).

[3] Shi, Y. J., "Meaning of warning area in the regulations of ship routeing system," Navigation Technology, (2), 8-9 (2008).

[4] Deng, M. J., [Research on Group Intelligent Optimization Algorithm for Path Planning], Ganzhou, Jiangxi University of Technology, Master's Thesis, (2023).

[5] Kennedy, J. and Russell, E., "Particle swarm optimization," Proceedings of ICNN'95-International Conference on Neural Networks, (1995).

[6] Xue, J. and Shen, B., "A novel swarm intelligence optimization approach: sparrow search algorithm," Systems Science & Control Engineering, 8(1), 22-34 (2020).

[7] Li, X. W., Li, Q. and Zhang, J. H., "Research on global path planning of unmanned vehicles based on improved ant colony algorithm in the complex road environment," Measurement and Control, 55(9-10), 945-959 (2022).

[8] Fujii, Y. P., [Marine Transportation Engineering], Tokyo: Kai Bundo, (1981).

[9] Guo, T. T., [Study on the Collision Risk of Ships in 3rd Precautionary Area of the Qiongzhou Strait Separate Channel Navigation System], Dalian, Dalian Maritime University, Master's Thesis, (2020).