RESEARCH OF CONVENIENT ROUTE DESIGN BASED ON SECURE NAVIGATION

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Abstract: Routes are the main paths for shipping activities; the selection of secure and convenient routes is very important in guarantying traffic transportation at sea. To solve the problem, this paper has analyzed all navigation factors, such as soundings, navigation aids and obstruction. With the aid of the shortest route theory, an algorithm to determining navigation-ability and incomplete navigability of grids has been calculated. Additionally,, both network modal theory and geographical information system technologies have been used. Finally, this paper validates the need for precision in route design through some experiments based on the theory route model.

Key words: *route design, secure navigation, the shortest route, grid navigatability*

1 Introduction

Routes are the main paths for shipping transportation, refuge, and rescue at sea. With the development of navigation techniques, the automatic route design of electronic charts plays an important role and gradually becomes the platform for a navigation system. Though civil shipping routes are relatively fixed, secure and convenient routes are the key factors in saving transportation costs. Almost every ship company considers the selection of economical routes as an important element in beating its competition. Therefore, some famous electronic chart systems share the same character of route design function. For example, Navi-Sailor 2400 of England Ship Ltd. and Nucleus2 5000&6000 of Kevin-Hose Ltd. do lots work in route design, which makes route building and revising quite convenient.

So far, less research has been done in along-shore route design by electronic chart systems. For many harbors, anchorages distribute along the seacoast; the seacoast therefore, always plays an important role in traffic transportation. Shallow soundings, reefs, wrecks, submarine cables and pipe lines along seacoast routes, always bring great threats to navigation. Additionally, busy transportation traffic together with various navigation obstructions cause many difficulties in shipping navigations. Therefore, the route design along the seacoast is rather difficult. Compared with seacoast routes, ocean routes have deeper soundings, less dangerous obstructions to navigation and more choices of navigation routes, which makes designing a route relatively easier. In relation to above situation, it is of crucial significance when designing secure and convenient routes to adapt to the needs of coastline navigation.

2 Requirement in Route Design

Route design should fulfill the following requirements: secure, economical and dynamic. First, to assure the dependability of the transportation, a route design must consider security in an important factor. Second, in order for a route to be both economical and fast, the design should shorten navigation time to save cost. Third, routes being designed should be flexible, which means a select route should adapt in case of the need for refuge, rescue or some other special missions. Thus, route design is just as integral as an optimal route selection.

No matter what methods are used in optimal route selection, sailing time is always one of the key decision-making factors. Thus, accurate sailing time directly determines whether an optimal route selection is reasonable. Precise sailing time is based on the calculation of practical navigation speeds under different sea conditions and routes. When sailing in alongshore or offing areas, the calculation of practical navigation speed considers ocean current and the vector speed of both stormy waves and shallow water etc.

Tide current is very important information to acquire; it has significant influence on securing navigation. Considering the length, this paper limits its study to route design based on static factors. Two aspects are introduced in the paper: one refers to research on points (including sounding points, isolated dangers etc.), lines (depth contours, coastlines etc.) and areas (dangerous areas, prohibited areas and islands etc.) to ensure security; the other refers to research on the shortest routes in proportion to time- saving. Remaining dynamics will be specifically addressed in other papers.

3 Algorithm of Optimal Route Selection

3.1 Network Modal of Electronic Chart Data

Divide the Mercator chart into square grids in terms of longitude and latitude. Based on the data of navigation obstruction and navigable areas, grid navigability can be determined. In the grid modal, each grid has eight connecting directions, of which east, south, west and north directions share progressive length S, the other four directions share $\sqrt{2}$S. S represents grid length. See Figure1.

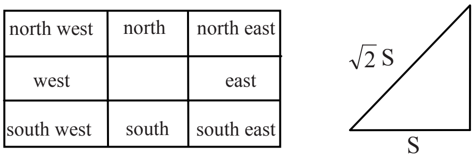

Figure1. Image of grid progressive

According to the model, the paper abstracts each grid as a point in the network. The distance between each point can only be S or $\sqrt{2}$ S; thus, the network figure with added-weight is created. Seeking out the shortest route from jumping-off point to destination becomes the question of analyzing the shortest route with single path.

3.2 Grid Navigability

Based on the intersecting relationship between a single grid and navigable or non- navigable areas, there will be three kinds of grids: complete navigable grids, complete non-navigable grids and incomplete navigable grids. The concept of navigability includes two main factors: (1) the relationship between soundings of charts and shipping sea gauge (2) the relationship between navigation obstruction and shipping security.

Suppose h_1, h_2, h_3, h are respectively the soundings value of a chart, soundings value of sea gauge, depth or height of navigation obstruction, hydrographic data, and depth of charts. Uncovered, drying, submerged reef, riffle and wreck etc. are all included in navigation obstruction. The three kinds of grids are displayed in Figure 2.

(a) Complete navigable grids *(b) Complete non-navigable grids* *(c) Incomplete navigable grids*

Figure 2. Image of navigable grids

Complete navigable grids (Figure 2 (a)): all areas in the grids are navigable for shipping. Namely meets the qualification of $h_1 \succ h_2 \cap h_3 \succ h_2$.

Complete non-navigable grids (Figure 2 (b)): all areas in the grids are not navigable for shipping. Namely they meet the qualification of $h_1 \le h_2 \cup h_3 \le h_2 \cup h_3 \ge h$.

Incomplete navigable grids (Figure 2 (c)): all areas in the grids are incompletely navigable for shipping. Namely they meet the qualification of $h_1 \le h_2 \cup h_3 \le h_2 \cup h_3 \ge h$.

For different navigable grids, the relationship of connectivity between themselves and the surrounding grids are not equal.

3.3 Calculate the Shortest Route by Using Dijkstra Algorithm

The Dijkstra algorithm was first brought forward by the mathematician Dijkstra of Holland in1959. It is the preferred algorithm to calculating the shortest route.

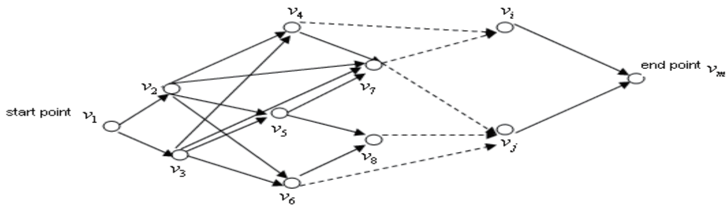

Figure 3. Network of navigable routes

Refer to Figure 3. Suppose start point A (v_1) and end point B (v_m). Navigable points and routes between the start and end points build up a network: $G=(V,E,L)$. Where, V represents the point collection of *m* navigable points; E represents borders collection of *n* routes; L represents weight collection of route weight.

As for the borders (namely routes) of the network, to which corresponding weight can be added according to practical demands. Different route weights can be added together. If there is a route $v_i - v_k - v_j$, there is the following formula: $l(v_i,v_j)=l(V_i,v_k)+l(v_k,v_j)$.

Through endowing route weight, the network figurer can be rebuilt as a directed weight graph. Therefore, optimal route selection is equal to calculation of the shortest route P^* from start point v_1 to end point v_m. The formula of calculating of the shortest route can be described as (Refer to Eq. 1):

$$\min L=\sum_{v_i,v_j\in p^*} l(v_i,v_j) \tag{1}$$

The essence of Dijkstra algorithm is to explore the shortest route step by step from the start point v_s. Assign each point a number (namely symbol), which shows either the shortest route weight (permanent symbol, *P* symbol) from v_s to this point or the max weight of this point (temporary symbol, *T* symbol). Calculation will stop at *P* symbol. To find out the shortest route from start point to each point, N-1 (N represents the number of points) steps need to be calculated.

3.4 Optimal Route Selection for Equal Long Routes

When the border length is either 1 or $\sqrt{2}$, there might be more than one route of equal length in selecting the shortest route when concerning a single source and object.

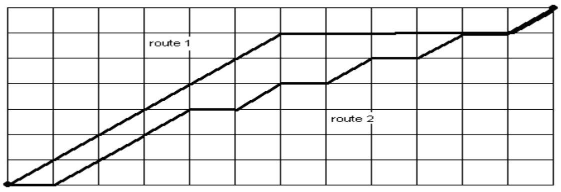

Figure 4. Image of equal long routes

It is easy to find the optimal selection by comparing the two routes in Figure 4.

Route 1 and 2 are equal from the viewpoint of total grid route length. Both Route 1 and 2 are of $5+7\sqrt{2}$ in grid length. $\sqrt{2}$ distributes quite centralized in Route 1, while dispersed in route 2. Look into the content of Route length collection:

Route 1：{$\sqrt{2}$，$\sqrt{2}$，$\sqrt{2}$，$\sqrt{2}$，$\sqrt{2}$，$\sqrt{2}$，1，1，1，1，1，$\sqrt{2}$}；

Route 2：{1，$\sqrt{2}$，$\sqrt{2}$，$\sqrt{2}$，1，$\sqrt{2}$，1，$\sqrt{2}$，1，$\sqrt{2}$，1，$\sqrt{2}$}；

Route 1 and 2 have no difference in the grid model, while Route 2 is more in accordance with real world factors. A Mess degree of $\sqrt{2}$ can be seen in the following way.

There are only 1 and $\sqrt{2}$ elements in route length collection. For the total route length of a route 1 and 2 are equal and the number of element 1 and $\sqrt{2}$ are the same. Suppose the number of element 1 and $\sqrt{2}$ are m and n respectively. Mess degree of $\sqrt{2}$ can be reflected through the maximum number of times of continual appearance of $\sqrt{2}$ or 1. The formula "m > n" means the number of 1 is more, thus, the optimal selection is the route with the minimum value of the maximum times of continual appearance of 1. On the contrary, the formula "n > m" means the number of $\sqrt{2}$ is greater, therefore, the optimal selection is the route with the minimum value of maximum times of the continual appearance of $\sqrt{2}$.

3.5 Process of Changing Routes into Broken Lines

When changing routes into broken lines, the rate of efficiency will be very low. Therefore, an equinoctial finding method is adopted.

(1) Select the first and the last point from the grid list as the first and the last deflection points T_1 and T_2 (temporary).

(2) Determine security in line segment T_1T_2. If T_1T_2 is unsecured, select the middle grid of the first and the last points as the second deflection point T_2, then

determine the its security. The cycle will not stop until a grid with such qualification appears: the line segment from itself to deflection point T_1 is secure, while not secure from the next point to T_1. Here the deflection point T_2 should be selected.

(3) Select the second deflection point T_2 from the grid list; continue the determination of Steps 1 and 2, until the last point of grid list has been determined.

(4) Find out all the deflection points and get its list $\{T_1, T_2, T_3, \ldots, T_n\}$.

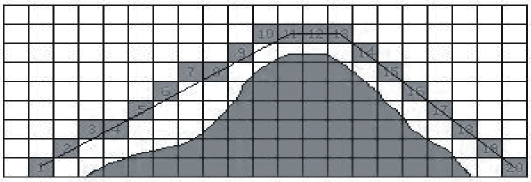

Figure 5. Sketch image of changing routes into broken lines

In Figure 5, the first deflection point is 1; obviously the line segments 1-20 are insecure. After that, select the middle of the grid with deflection point 1 and 10, and determine the security of 1-10, if secure; then select the middle deflection point 15 (of deflection points 10 and 20, …,); continue the cycle. Finally, the second deflection point is 11; Also, the third and forth deflection points are 13 and 20 respectively.

4 Experiments and Conclusions

Some experiments of optimal route selection in the Taiwan Straits of the East China Sea have been conducted using the above algorithm. In order to conveniently analyze and make comparisons, this paper selects two recommended routes from the *Distance Tables for China Coast* and the *Guide to Chinese Ports* , which start at Kaohsiung Harbor (22° 37′.1N，112° 15′.5E) and end at a light buoy (24° 13′.4N，118° 14′.5E) outside the Amoy Harbor. Points 2 and 5 are respectively the 166 and 164 deflection points which are located at (23° 16′.0N，119° 08′.8E) and (23° 17′.0N，119° 46′.0E). Referring to the data, the length of recommended Route 1 (RR1, path 1-2-3) and Route 2 (RR2, path 1-5-3) in Figure 6 are 148 and 149 n miles respectively.

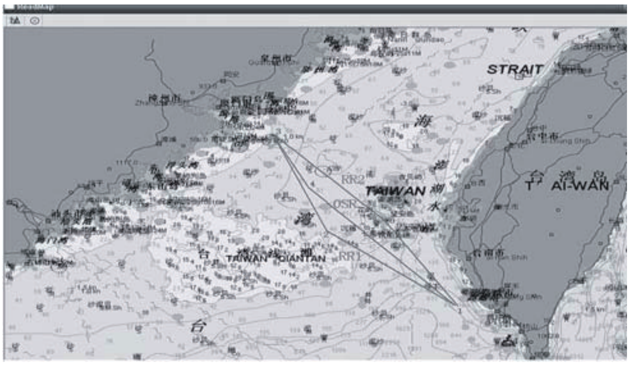

Figure 6. Comparison of recommended routes and optimal selection of route

In Figure 6, the middle route (OSR, path1-4-3) is the optimal selection, which is of 146.67 n miles in length. After comparing these two recommended routes (see Table 1), the paper determines the optimal selection route is the one which is shorter in length. Additionally, analyses about navigation security have been strengthened by system algorithm before the optimal selection route was calculated. Therefore, the routes calculated by the algorithm in this paper are demonstrated to be an optimal theory.

Table 1. Comparison table of route length

Route name	Route length	Shorten voyage	Shorten scale
recommended route 1	148 n miles	1.33 n miles	0.9%
recommended route 2	149 n miles	2.33 n miles	1.6%
optimal selection route	146.67 n miles	/	/

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