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Improve Sea Transport Efficiency through Simulation

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Abstract

This paper aims at improvement of the traffic management through simulation so as to get the highest transport efficiency in certain area. The simulation in this paper is dynamic mass simulation. Because a large quantity of data should be processed, various simplified methods are used in organizing environment data. Vessels are generated according to certain distribution, and then move along the routes. When one vessel moves along the route and meets some abnormal situation through detecting nearby vessels, it will adopt certain measures automatically according to the model. So the influence of traffic turbulence can be simulated and it makes the simulation more realistic. Based on this simulation method and adjustable parameters and sailing rules, the best traffic management measures can be gotten, and the whole transport efficiency in certain area can be improved.

Keyword : Transportation, simulation, traffic engineering, shipping.

To improve transport efficiency is one of effective ways to improve logistics efficiency. With the economical globalization, the demand of shipping increases quickly. In international trade, more than 80 percents of trade cargos is carried by vessels. Meanwhile, as the ship becomes larger and larger and the production tends to be large-scale and centralized, the traffic to some large ports in the world becomes more congested and the risk of traffic accidents rises. So, scientific traffic management becomes much more important to improve sea transport efficiency.

Traditionally, the traffic management is based on traffic observation. By using the statistical data, some management measures are adopted. Due to the limitation of budget and hands, traffic surveys can only present the data at certain times and places, thus these statistical data can only reflect one facet of the real traffic condition. Traffic management accordingly bases on these static data is not optimal management since they are difficult to test too much management solutions under different conditions. Therefore, from the methodology, this kind of methods is difficult to be accordance with the reality, especially under some turbulence. Meanwhile, due to the shortage of data during design stage, this kind of methods is also difficult to apply in new fairway design. Thus, the chance of applying this traditional method to improve transport efficiency is slim. These kinds of management are reasonable rather than scientific or optimal.

Vessels dynamic traffic simulation simulates real vessels movements in certain area as the time elapses. Based on vessels arrival distribution and sailing environment, it continuously simulates vessels movements by using vessels movement mathematical model. Because the model is adjustable and various management rules can be applied in the simulation, this kind of methods is more scientific and realistic, and can be applied in seeking for best management measures and improve transport efficiency.

1. Simulation Objects

Using simulation method to seek for best traffic management, firstly, it should be determined which objects should be simulated. And which objects should be simulated and how detail they should be simulated depends on the simulation goal. The simulation goal of the paper is to improve the whole traffic management in certain area, so the mass simulation is used. It simulates all the vessels' movements in certain area based on fairway condition, sailing rules, vessels arrival distribution and vessel movement equation according to real time or simulated time series. The single ship can not be maneuvered or controlled separately in order to get its best performance. What the paper cares about is the whole traffic flow. Each ship in the simulated area maneuvers itself automatically by computing mathematical model according to sailing conditions and existed rules. From every ship's performance, the whole traffic performance can be gotten. So, from the methodology, this simulation is macro simulation, not micro simulation.

The simulation is computer-based simulation. The objects which should be simulated include sailing environment, vessel movement and maneuvering decision-making. Sailing environment simulation simulates sea environment and sailing rules. It reflects real sailing condition. Vessel movement simulation simulates various vessels movements by using mathematical model. The precision of the movement simulation mainly represents the whole simulation precision. Maneuvering decision-making simulation simulates mariner's decision-making in practice. These simulations are keys to achieve the simulation and make the simulation more realistic and applicable. The paper will discuss it in detail below.

In order to make the simulation more vividly, perceivably and be easily used in assessing, comparing and improving traffic management solution, the simulation uses computer generated graphics interface, which includes electronic Chart, visual vessels' movement, etc.

2. Sailing Environment Simulation

Sailing environment simulation bases on the Charts which cover the simulated area. In order to make the environment more adjustable and be easy to set up different traffic rules as well as to increase the display speed, the simulated environment does not use standard Electronic Chart but specially-made simplified Chart. The difference between the standard Chart and the simplified Chart is mainly the data organization method. In reflecting the real environmental condition, it is the same.

The simulation is computer-based numeric simulation. The environment data is not only used in display, but also used in each vessel's detecting nearby condition. Since there are so many vessels in the simulated area, to finish all vessels' detecting task is a huge burden. So, the environment should be simplified and environmental data should be carefully organized. Meanwhile, the larger the simulated area is, the more realistic the result is. In order to be realistic, more data should be processed during running. So, the simplification is important. The simplification of the environment is helpful not only to process data but also to detect nearby vessels in order to make vessels movement more realistic. Among all the simplification methods used, the simplification of fairway or channel network is vital.

2.1. Fairway network

Fairway network bases on the real or planned one. Figure 1 is a simple fairway network. According to the feature of traffic flow, the fairway network is further divided into lines and points.

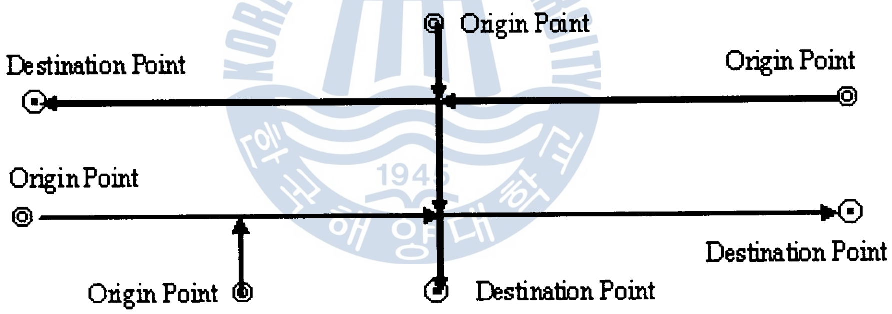

Fig. 1 A Simple Fairway Network

2.1.1. Single direction fairway

Fairway network consists of line segments. In each line segment, there is only single sailing direction is permitted. We called such a line segment branch. So, in a branch, the direction is determined and the vessel is only permitted to go along the direction. The rule obviously comes from traffic separation scheme regulation. For a single fairway, dual directions can be set up, but vessels cannot move along the way in two directions simultaneously.

2.1.2. Origin point, termination point and cross point

In fairway network, there are only three kinds of points existed, which are origin point, termination point and cross point. Origin point, termination point (or destination point) and cross point are different points in branches.

Origin point (use symbol ◎): In simulation process, vessels are generated in origin points and then go along branches. It represents vessel's entering the simulated area. These points are deployed in the edge of the simulated area. If there are ports and anchorages in the simulated area, these points are also deployed at these positions.

Termination point (use symbol ⊙): Because simulation area is limited, when a vessel leaves this limited area, it will be canceled. The point the vessel is canceled is called termination point. These points are also deployed in the edge of the simulated area and ports and anchorages in the simulated area.

Cross point (use symbol ·): Common point of two and more than two branches cross. Cross point exists in both land and water communication. But in land communication, cross point can be avoided by use of overpass. Because cross point is traffic concentrated point, it is also high accidental point and management focus. In simulation, these points are key points of control of movement.

Cross point has both attribute of origin and termination point. For the branch it comes, it is termination point, but it will not exit the simulation. For the branch it will go, it is origin point, but it is not newly generated but comes from come branch.

2.1.3. Branch grids

If the length of the branch is S, use ds to discrete it, the branch can be divided into n segments, $P_0, P_1, P_2, \ldots\ldots P_n$ $\left(n = int(\frac{S}{ds})\right)$. We call these sorted segments branch grids. For each grid, if the number of the grid is known, the position is known. For the vessel moves along the branch, the branch grid can be deduced from the sailing distance.

By using the fairway network instead of 2D sailing waters, 2D movement is simplified into 1D movement. And branch grids further simplify 1D movement into 1D array. The simplification facilitates the detection of nearby vessels during the simulation.

2.1.4. Sub-branch

In real fairway network, the lengths of branches may vary largely. Meanwhile, volume of traffic flow may also vary from branch to branch. So, the vessels in each branch may vary seriously. Since all the vessels data in one branch are stored and processed in the same size high dimension arrays, and the largest volume of the branch (most often, the longest one) should be used to define the size of the array, it is not only waste of memory, but also inconvenient to process. Sometimes, it is even impossible to the memory. Therefore, a long branch should be divided into some sub-branches. It is also helpful to balance processing workload of each branch or sub-branch.

2.2. Vessels generator

Vessels are generated in origin points, then enter into the simulated area. Vessels generation bases on the survey of the real traffic situation and some distribution function. In the simulation, the exponential distribution is mostly used. The function is as follows,

$$ta = -E \cdot \ln(r)$$

Here, E is the mean interval time, r is random data in [0,1], ta is random interval time.

If at the time t0, there is one vessel generated at the origin point, the next vessel will be generated at t1=t0+ta in this point.

Except exponential function, the other distribution functions can be used. For example, for the vessels awaiting the tide, when the tide height is enough, the vessels will enter or leave one by one in certain period. At this situation, the uniform distribution is used. In addition, for the vessels awaiting open of ship lock gate, when the gate is opened, the small vessels will rush to pass. At this situation, the pulse distribution can be used to describe it. Under pulse distribution, the volume of passing vessels is the highest at the very beginning,, then gradually decreases down.

Except random generation of vessels, the vessel generator is also responsible for generating vessel's particulars such as ship type, tonnage, speed, draft, etc. By controlling the range, the number it generates can be controlled. E.g. Control ship type, by fixing the range, the percentage of each type can be achieved.

[0,a1) ~ general cargo ship;

[a1,a2) ~oil carrier;

[a2,a3) ~passenger ship;

....

[an,1] ~Roro ship。

Here, $0<a1<a2<a3<\cdots<an<1$。

Vessel's particulars have interrelations. For example, the length of the ship is related to ship's tonnage. In order to avoid collision, some particulars can be omitted. Some parameters have little meaning in simulation, they can also be omitted in order to improve access and processing performance.

3. Processing of Data

3.1. Vessels dynamic sorting

The objective of vessels dynamic sorting is for convenience of detecting nearby vessels, and the objective of the detection is for control of movement of the vessel according to real movement. All data of movements of ships is recorded on the disk periodically during its running.

3.1.1. Time sorting

At the origin point, the vessel is generated accordingly and enters into the branch. So, sorting according to generation time is natural. However, as the time goes by, this kind of sorting wants very large arrays, even excess of the computer memory. In fact, early generated vessels have already entered into next branch, and some of them have already arrived at the termination points and exited the simulation, but the data array is still occupied by them. So, we use reverse sorting. The number of the most recently generated vessel is 0. The earlier the vessel is generated, the larger the number it has. In order to achieve it, the array should be shifted when a new vessel is generated. m→m+1,m-1→m,......,2→3,1→2,0→1. The size of the array depends on the branch which has the most vessels. When a vessel exits the simulation, the data of this ship in the array is covered by next ship.

3.2.2. Distance sorting

Distance sorting is this kind of sorting that vessels are sorted according to the distance they leave the origin point. That means vessels are sorted according to the distance they sail not the life time they exist. From the detection viewpoint, distance sorting is more convenient than time sorting because it is very easy for the ship to know which grid it locates. If the overtake is not permitted in the branch, the distance sorting is the same to the time sorting. However, if the overtake is permitted and No. K vessel overtakes No. K+1 vessel, they will swap data when distance sorting is used.

Because the branch grids are numbered from the origin point to the termination point or cross point accordingly based on 1, the position of the vessel can be identified by the number. At the cross point, the termination point and the origin point is the same point in fact. But it should act as two roles. So, two numbers should be given to the cross point. One number is for termination, another is for origin. The difference between two numbers should be big enough to distinguish. When a vessel arrives at the cross point, it will exit the come branch and enter will-go branch and get the new number 0 in this branch. When there are more than one will-go branches, which one it will enter is determined randomly or according to the rule.

Since the vessel is controlled, when one grid is occupied by a vessel, another vessel can not occupy it. So, the situation that the vessels from different branches occupy the same grid will not happen.

3.2. Velocity control

The movement control used in the simulation is velocity control equation. The equation is as follows,

$$M\frac{dv}{dt}=N-f(v)$$

Here, M ~ ship's mass

v ~ ship's velocity

$\frac{dv}{dt}$ ~ accelerator

N ~ main engine thrust

$f(v)$ ~ ship's resistance. It is polynomial of velocity.

For traffic flow macro simulation, this kind of velocity control model has enough precision.

The parameters in the equation can be estimated from the inertia test result. The usual stopping distance is 8 to 11 times of ship's length overall. However, the stopping distance of VLCC or ULCC is 20 to 22 times of ship's length overall. The velocity control can use different parameters according to different operation modes such as forwarding, reversing and stopping.

3.3. Vessels dynamic detection

Vessels dynamic detection is detection of nearby vessels positions and movements in the simulated area.

All the vessels data including vessel's particulars and movement data in the simulated area are stored in the according array. Because the sailing water has changed into the branch grids, the detection of nearby vessels is actually detection of the grid array data. This improves the detection efficiency to large extent.

In the simulated area, there may be many vessels nearby one vessel. If the vessel should check all the vessels, it will be a huge cost and actually unnecessary. Due to the discrete grid arrays environment, each vessel should only detect his nearest lead ship. When a vessel will go into the cross point, it should detect the vessels from all other branches so as to determine it can enter or should reduce speed. Similarly, when a vessel in the cross point wants to enter new branch, it should also check No. 0 vessel in this branch so as to determine how it should control itself.

3.4. Vessels dynamic control

The vessel dynamic control is achieved through maneuvering of the vessel. It usually includes alter course and/or speed. The vessel control is collision avoidance behavior in effect. In simulation, since the sailing water is changed into fairway network, and only one way movement is permitted in the branch at certain time, the vessel control can actually only be achieved through velocity control, which includes keeping, increasing and decreasing speed. In the branch, prohibition of altering course actually reflects the modern traffic separation rule, that is when a vessel sails in the traffic lane, the course of the vessel should be consistent with the whole traffic flow, and free sailing is not permitted.

Control behaviors should not only be consistent with the rules of collision avoidance, it should also obey given regulations as well. For example, in certain segment, given overtaking is prohibited; the distance between two vessels should be more than a fixed safe value; the speed should be controlled below a certain value, the ship should always check its status to find it obeys or not. If a vessel finds the distance between it and its lead ship is not big enough or its speed is too high, it should decrease speed. When the distance is enough, it can restore to normal speed. Another example in this point is when the heading of two or more vessels crosses nearby the cross point, the vessels should obey the rules, that is the give-way vessel should decrease speed and give way to the right vessel; or the vessel in the main fairway can go first if different level fairways cross. Except the conventional rules, special rules can also be applied in the simulation.

Obviously, the control of vessels nearby the cross point is control focus and management focus.

4. Using Statistics Data to Improve Traffic Efficiency

The system will become stable after a certain period of running. When the system is stable, all the data will be recorded on the disk periodically. After the simulation, these data can be used in various statistics.

In order to find out the best traffic management measures, many parameters in the program can be adjusted. These parameters include time interval, safe distance, sailing speed and sailing rules. Furthermore, the whole sailing routes and alter course points can be adjusted to get the best channel design.

There are so many statistical criteria we can use. The criteria used in this paper to illustrate the traffic efficiency include

- Fairway (branch) mean traffic density. Vessel volume per length unit;
- Mean traffic density at the cross point. Passing vessels at the cross point per time unit.
- Mean speed in fairway(branch).
- Total traffic capacity in certain waters

Before statistics, all the vessels can be changed to standard vessels according to their length overall.

By using different combination of parameters and sailing rules, the best traffic management measures can be gotten.

By using this method, ports allocation problem can also be solved in certain area, for example, in our East Asia. Ports cooperation rather than ports competition may be strengthened in order to get the highest efficiency of the whole shipping system.

5. The Framework of Dynamic Traffic Simulation System

According to above mentioned model and algorithm, this paper finished the design of dynamic traffic simulation system. Vessels generator, sorting, detection, control, display, output, statistics, etc., all were designed into independent modules. The vessel's particulars and environmental data were inputted through data files. The procedure of the simulation and running interface are illustrated in Figure 2 and Figure 3.

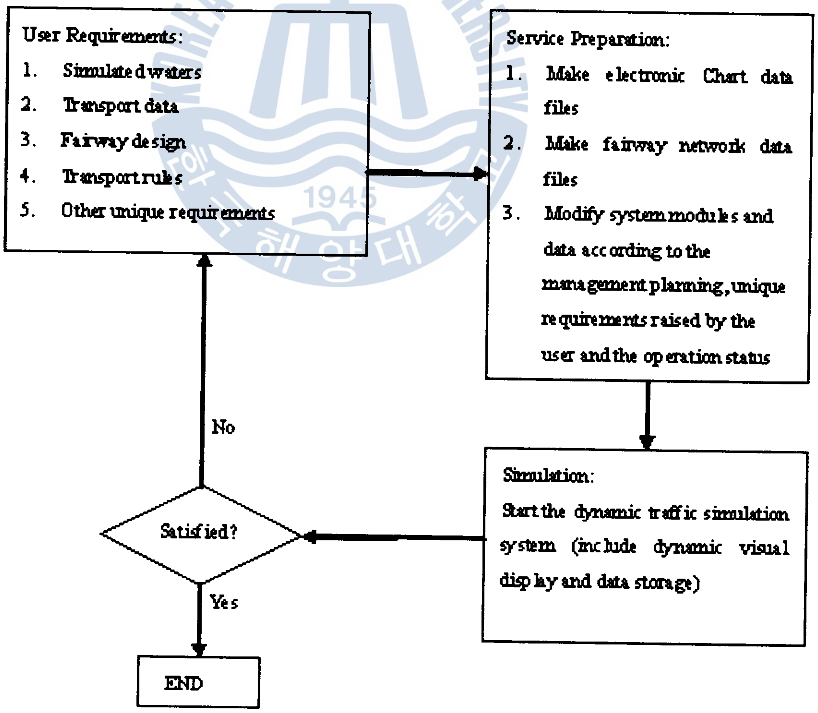

Fig. 2 The Procedure of the Simulation

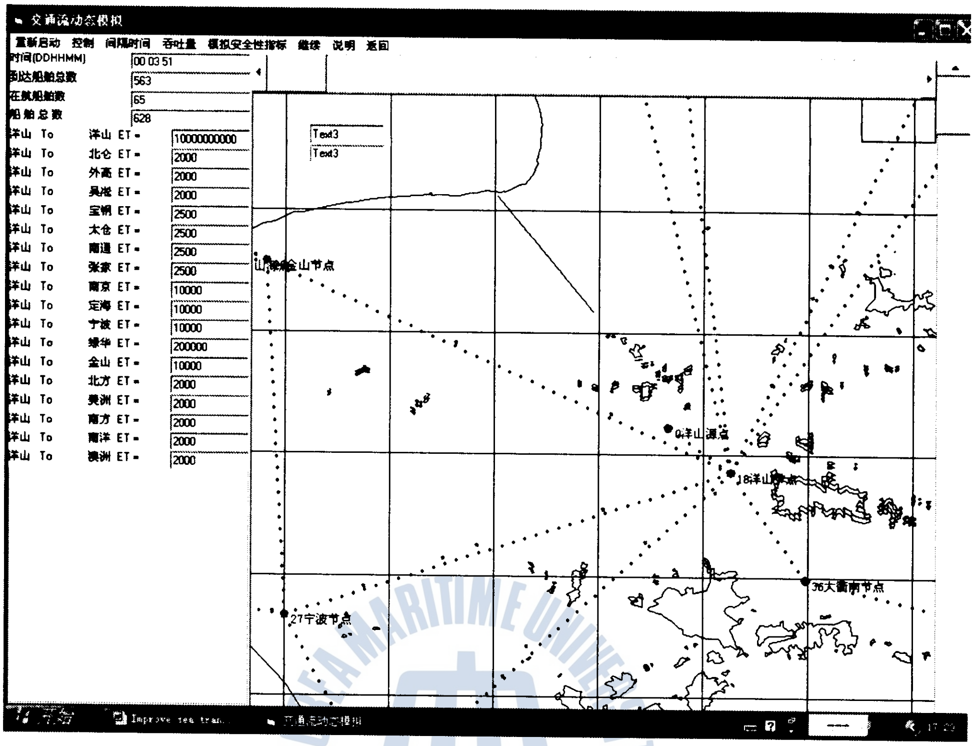

Fig. 3 The Running Interface

References

1. LE, Meilong(2004), *Ship's Maneuverability Forecasting and Maneuvering Simulation in Coastal and Harbor Waters,* first edition, Shanghai Jiao Tong University Press, Shanghai.
2. Le, Meilong(1996), The Algorithm of Searching of 3D Discrete Data of Chart, *Journal of Shanghai Maritime University,* Vol. 17, No. 3, pp59-64
3. Le, Meilong, Shi Zhibiao(1995), Design Method of Simulation System of Automatic Collision Prevention, *The Discussion of Chinese Communications by Cross-century Intellectuals*, pp391-395, December, 1995, Chongqing University Press, Chongqing.
4. Le, Meilong, Shi, Zhibiao, Ni, Xueyi(1994), The Simulation System of Special Automation, *Journal of Shanghai Maritime University,* Vol. 15, No. 3, pp58-P65

5. Le, Meilong, Wang, Xiling, Lu, Huisheng(1998), The Application of TMS340xx to Simulation System of Ship's Sailing Automation, *Proceedings of the 9th National Conference on Image and Graphics,* pp, May, 1998, Xi'an, China.
6. Ni Xueyi, Le, Meilong(1995), The Matrix Unit Array Structure of Plan Discrete Data, *Journal of Shanghai Maritime University,* Special Issue in Commemoration of the Founding of College of Mercantile Marine, September, 1995, pp33-39