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Improving Sea Transport Efficiency through Simulations

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Abstract

This paper seeks to improve traffic management through simulations so as to get the highest transport efficiency in a given area. The simulation used in this paper is a dynamic mass simulation. Due to a large data set, various simplified methods are used in organizing the environmental data. Vessels are generated according to given distribution and then move along designated routes. When a vessel moves along a route and meets some an abnormal situation through the detection of nearby vessels, it will adopt certain measures automatically according to the model. So the influence of traffic turbulence can be simulated and this makes the simulation more realistic. Based on this simulation method, several adjustable parameters, and the sailing rules, the best traffic management measures can be obtained, and the transport efficiency in a given area can be globally improved.

Key Words: transportation, simulation, traffic engineering, shipping.

Introduction

Improving transport efficiency is one effective way to improve logistics efficiency. With globalization, the demand for shipping has increased quickly. In international trade, more than 80 percent of trade cargo is carried by vessels. As ships become larger and production tends to become large-scale and centralized, the traffic at many large ports has become more congested and the risk of traffic accidents has risen. So, scientific traffic management has become much more important for improving sea transport efficiency.

Traditionally, traffic management is based on traffic observation. By using the statistical data, some management measures are adopted. Due to the limitation of budget and staff, traffic surveys can only present the data at certain times and places, thus this statistical data can only reflect one facet of actual traffic conditions. Traffic management plans and strategies based on this static data are not optimal because it is difficult to test these under different conditions. Because of the limitations of the methodology, this kind of method is out of sync with reality, especially when there is turbulence. Moreover, this kind of method is also difficult to apply in new fairway design due to the shortage of data during the design stage. Thus, the chance of success in improving transport efficiency when applying this traditional method is slim.

A dynamic traffic simulation simulates real vessel movements in a given area as time elapses. Based on vessel arrival distribution and the sailing environment, the model continu-

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ously simulates vessels movements by using a mathematical model based on vessel movement. Since the model is adjustable and various management rules can be applied in the simulation, this kind of method is more scientific and realistic, and can be applied to improve transport efficiency and make management measures the best possible.

1. Simulation Objects

The simulation selection method is determined using the following considerations: which objects should be simulated, the level of detail in which they should be simulated, and the simulation goal. The goal of the simulation in this paper is to improve the whole traffic management system in a given area. Thus, a mass simulation is used which simulates all vessel movements in a given area based on fairway conditions, sailing rules, vessel arrival distribution, and vessel movement using real time or simulated time series equations. A single ship can not be maneuvered or controlled separately in order to get its best performance. What the paper considers is the traffic flow in the whole area. So, from the methodology, this simulation is a macro-simulation, not micro-simulation. Each ship in the simulated area is maneuvered automatically by a mathematical model that encompasses sailing conditions and existing rules. The traffic performance of the whole system can be obtained by aggregating the performance of every ship.

The simulation is computer-based and takes into account the sailing environment, vessel movement, and maneuvering decision-making. The sailing environment simulation includes the sea environment and sailing rules and real sailing conditions. The precision of the movement simulation represents the precision of the whole simulation. The maneuvering decision-making simulation imitates the mariner's decision-making in practice. These aspects are keys in creating an overall simulation that is more realistic and applicable. The paper will discuss the details below.

In order to make the simulation more vivid, perceivable, and easily used in assessing, comparing and improving traffic management, it uses a computer-generated graphics interface that includes electronic charts, visuals of vessel movement, and other pertinent data.

2. Sailing Environment Simulation

The sailing environment simulation is based on charts that cover the simulated area. In order to make the environment more flexible and make it easy to set up different traffic rules as well as increase display speeds, the simulated environment uses a specially-made simplified chart rather than a standard electronic chart. The difference between the standard chart and the simplified chart is mainly the way that the data is organized. In reflecting real environmental conditions, it is essentially the same.

The simulation is a computer-based numeric simulation. The environmental data is not only used in the display but also in detecting each vessel's nearby conditions. Since there are so many vessels in the simulated area, completely representing the detection task of all the vessels is a huge burden. So, the environment needs to be simplified and the environmental data must 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 simulation runs. So, simplification is important. The simplification of the environment is helpful not only in processing data but also in the detection of nearby vessels. This helps make vessel movement more realistic. Among all the simplification methods used, the simplification of the fairway or channel network is vital.

2.1 *Fairway network*

The fairway network is based on a real or planned one. Figure 1 is a simple fairway network. Such a fairway network is further divided into lines and points according to the features of traffic flow.

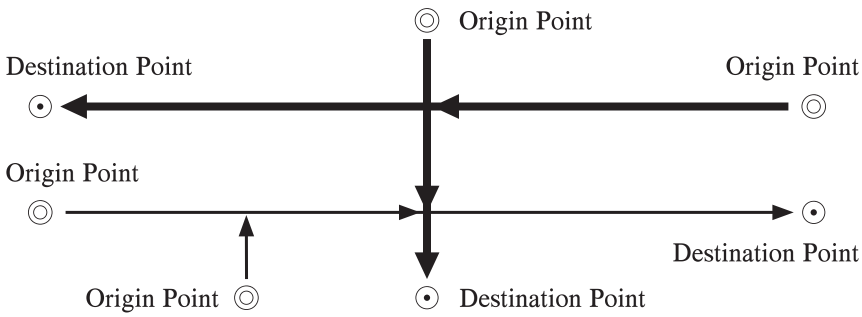

Figure 1 A Simple Fairway Network

2.1.1 Single direction fairway

A fairway network consists of line segments. In each line segment, only one sailing direction is permitted, so each of these is called a segment branch. So, in a branch its direction is determined and the vessel is only permitted to go along that direction. This rule obviously comes from traffic separation regulations. 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 a fairway network, there are only three kinds of points: origin points, termination points and cross points. Origin points, termination points (or destination points) and cross points are different points in the branches.

An origin point uses the symbol ◎. In a simulation process, vessels are generated at origin points and then they go along branches. This represents a vessel entering the simulation area. These points are deployed in the edge of the simulation area. If there are ports and anchorages in the simulated area, these points are placed at these positions.

A termination point uses the symbol ⊙. Since the simulation area is limited, a vessel is removed when it leaves the simulation area. The point the vessel is removed is called the termination point. These points are also placed on the edge of the simulation area and at ports and anchorages in the simulation area.

A cross point uses the symbol •. A cross point is a common point where two or more branches intersect. Cross points exist on both land and water; however, land cross points can be eliminated by the use of an overpass. Since a cross point is a traffic conflict point, it is also corresponds to a high accident rate and is a focus of transportation management focus. In the simulation, these points are key points for controlling movement.

A cross point has some of the attributes of origin and termination points. It is a termination point for incoming branches and an origin point for outgoing branches. However, vessels from the incoming branches do not exit the simulation but merely continue on outgoing branches. Vessels on outgoing branches are not newly generated but have come from incoming branches.

2.1.3 Branch grids

If the length of the branch is *S, ds* is used to make it discrete. Then, the branch can be divided into *n* segments:

$$P_0,\ P_1,\ P_2,\ \cdots\cdots P_n \qquad \left(n = \text{int}\left(\frac{S}{ds}\right)\right)$$

We call these sorted segments branch grids. For each grid the position is known if the number of the grid is known. As a 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. Moreover, the branch grids further simplify 1D movement into a 1D array. This 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 seriously vary. If 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) is used to define the size of the array, it is not only a waste of memory, but also inconvenient to process. Sometimes, it is even impossible due to memory limitations. 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 at origin points and then entered into the simulated area. Vessel generation is based on the survey of the real traffic situation and a distribution function. In the simulation, an exponential distribution is mostly used. The function is as follows:

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

where *E* is the mean interval time, *r* is random data in [0, 1], and *ta* is the random interval time. If at time t_0 there is a vessel generated at the origin point, the next vessel will be generated at $t_1 = t_0 + t_a$.

Other distribution functions in addition to this exponential function are used to model the various factors in the simulation. For example, a uniform distribution is used for tidal effects. Vessels will enter or leave one by one in a given period because they wait for the time when the tide is high enough. In another example, a pulse distribution is be used to describe vessels awaiting the opening of a ship lock gate. When the gate is opened, the smaller vessels will rush to pass. Under a pulse distribution, the volume of passing vessels is highest at the very beginning and then gradually decreases.

In addition to the random generation of vessels, the vessel generator is also responsible for generating a vessel's particulars, such as ship type, tonnage, speed, draft, etc. By controlling the range, the number generated can be controlled. Thus, one can control the ship type by fixing the range, and a percentage of each type can be obtained:

$[0, a_1]$: general cargo ship;
$[a_1, a_2]$: oil carrier;
$[a_2, a_3]$: passenger ship;

⋮

[a_n, 1] : Roro ship °

Here, $0 < a_1 < a_2 < a_3 < \cdots\cdots < a_n < 1$ °

A vessel's particulars are interrelated. For example, the length of the ship is related to ship's tonnage. In order to avoid conflict, some particulars can be omitted. Some parameters have little meaning in the simulation, so 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 the dynamic sorting function is for the ease of detecting nearby vessels, and the objective of the detection function is for the control of movement of the vessel according to real conditions. All data of the movements of ships is recorded on disk periodically during the simulation run.

3.1.1 Time sorting

Since a particular vessel is generated at an origin point and then enters into a branch, sorting according to generation time is natural. However, as time goes by, this kind of sorting demands very large arrays which are beyond a typical computer's processing capacity. Also, vessels generated early in the simulation still occupy these data arrays even though they have already entered into the next branch, and some of them have already arrived at the termination points and have exited the simulation. Because of this, reverse sorting is used. 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 accomplish this, the array is shifted when a new vessel is generated ($m \rightarrow m+1$, $m-1 \rightarrow m$, ..., $2 \rightarrow 3$, $1 \rightarrow 2$, $0 \rightarrow 1$. The size of the array depends upon the branch that has the most vessels. When a vessel exits the simulation, the data in the array for this ship is replaced by next ship.

3.1.2 Distance sorting

Distance sorting is sorting vessels according to the distances they are from their origin points. This means that vessels are sorted according to the distance they sail, not the amount of time they are in the simulation. From the detection viewpoint, distance sorting is more convenient than time sorting because it is very easy to know in which grid the ship is located. If the overtake is not permitted in the branch, distance sorting is the same as time sorting. However, if the overtake is permitted and number k vessel overtakes number $k+1$ 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 based on 1, the position of the vessel can be identified by the number. A cross point has two roles as both a termination point and an origin point. So, two numbers are 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 between them. When a vessel arrives at a cross point, it will exit the incoming branch and enter outgoing branch and get a new number of 0 in this branch. When there are more than one outgoing branches, the one that the ship enters is determined randomly or according to a rule.

Because the vessels are controlled, when one grid is occupied by a vessel another vessel cannot occupy it. So, it is impossible to have a situation where vessels from different branches occupy the same grid.

3.2 *Velocity control*

The movement control used in the simulation is a 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 a polynomial of velocity.

This type of velocity control model has enough precision to model traffic flow in a macro-simulation.

The parameters in the equation can be estimated from the inertial experimental data. The usual stopping distance is 8 to 11times the ship's overall length. However, the stopping distance of VLCC or ULCC is 20 to 22times of the ship's overall length. The velocity control can use different parameters in accordance with different operational modes such as going forward, reversing, and stopping.

3.3 *Vessel dynamic detection*

Vessel dynamic detection is the detection of the positions and movements of nearby vessels in the simulation area. All vessel data, including vessel particulars and movement data in the simulated area, are stored in a corresponding array. Since the sailing area has been changed into branch grids, the detection of nearby vessels is actually the detection of the grid array data. This improves the detection efficiency to large extent.

In the simulation, there may be many vessels near one particular vessel. If the vessel were to check all the other vessels, it would incur a huge cost. The discrete grid array actually makes this unnecessary because each vessel only needs to detect its nearest lead ship. When a vessel goes into a cross point, it should detect the vessels from all other branches so as to determine if it can enter or whether it should reduce its speed. Similarly, when a vessel in the cross point wants to enter new branch, it should also check the vessel numbered 0 in this branch so as to determine how to proceed.

3.4 *Vessel dynamic control*

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

Control behaviors should not only be consistent with the principle of collision avoidance;

they should also obey given regulations as well. For example, when overtaking is prohibited in a certain segment, the distance between two vessels should be more than a determined safe value, the speed should be controlled below a given value, and the ship should always check its status to find out whether it is in compliance or not. If a vessel finds that its speed is too high and/or the distance between it and its lead ship is not large enough, it should decrease its speed. When the distance between the ships is enough, it can return to a normal speed. Another example of this point is when the headings of two or more vessels cross near the cross point, the vessels should obey traffic rules. A yielding vessel should decrease its speed and give the right-of-way to the proper vessel, a vessel in the main fairway should go first if different level fairways cross, and so on. In addition to conventional rules, special rules can also be applied in the simulation. Obviously, the control of vessels near a cross point is a focus of control and management.

4. Using Statistics Data to Improve Traffic Efficiency

The system will become stable after a significant running period. When the system is stable, all data will be periodically recorded on the disk. After the simulation, this 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, entire sailing routes and course change points can be adjusted to get the best channel design.

There are many statistical criteria that can be used. The criteria used in this paper to illustrate the traffic efficiency include fairway (branch) mean traffic density, vessel volume per unit length, mean traffic density at a cross point, number of passing vessels at a cross point per time unit, mean speed in a fairway (branch), and total traffic capacity in the study area. All the vessels in the simulation can be changed to standard vessels according to their overall length. By using different combinations of parameters and sailing rules, the best traffic management measures can be obtained.

Also by using this method, a ports allocation problem can also be solved for given area, such as East Asia. Port cooperation rather than port competition may be strengthened in order to get the highest efficiency for the whole shipping system.

5. The Framework of Dynamic Traffic Simulation System

According to the above model and algorithm, a design of a dynamic traffic simulation system was completed and is included in this paper. Vessel generation, sorting, detection, control, display, output, and statistical data were designed as independent modules. A vessel's particulars and environmental data were inputted using data files. The procedure of the simulation and running interface are illustrated in Figure 2 and Figure 3.

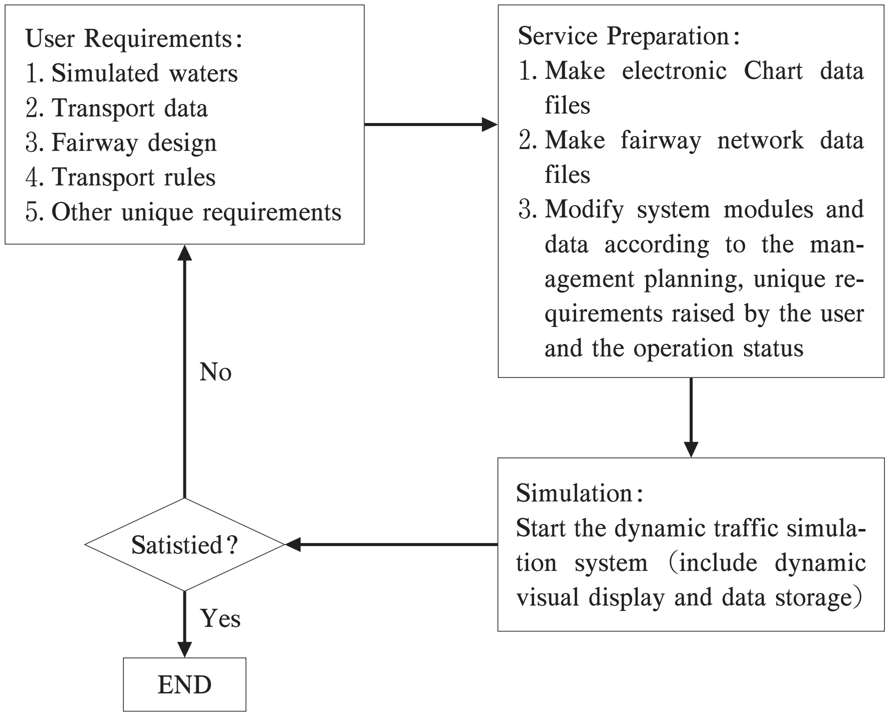

Figure 2　The Procedure of the Simulation

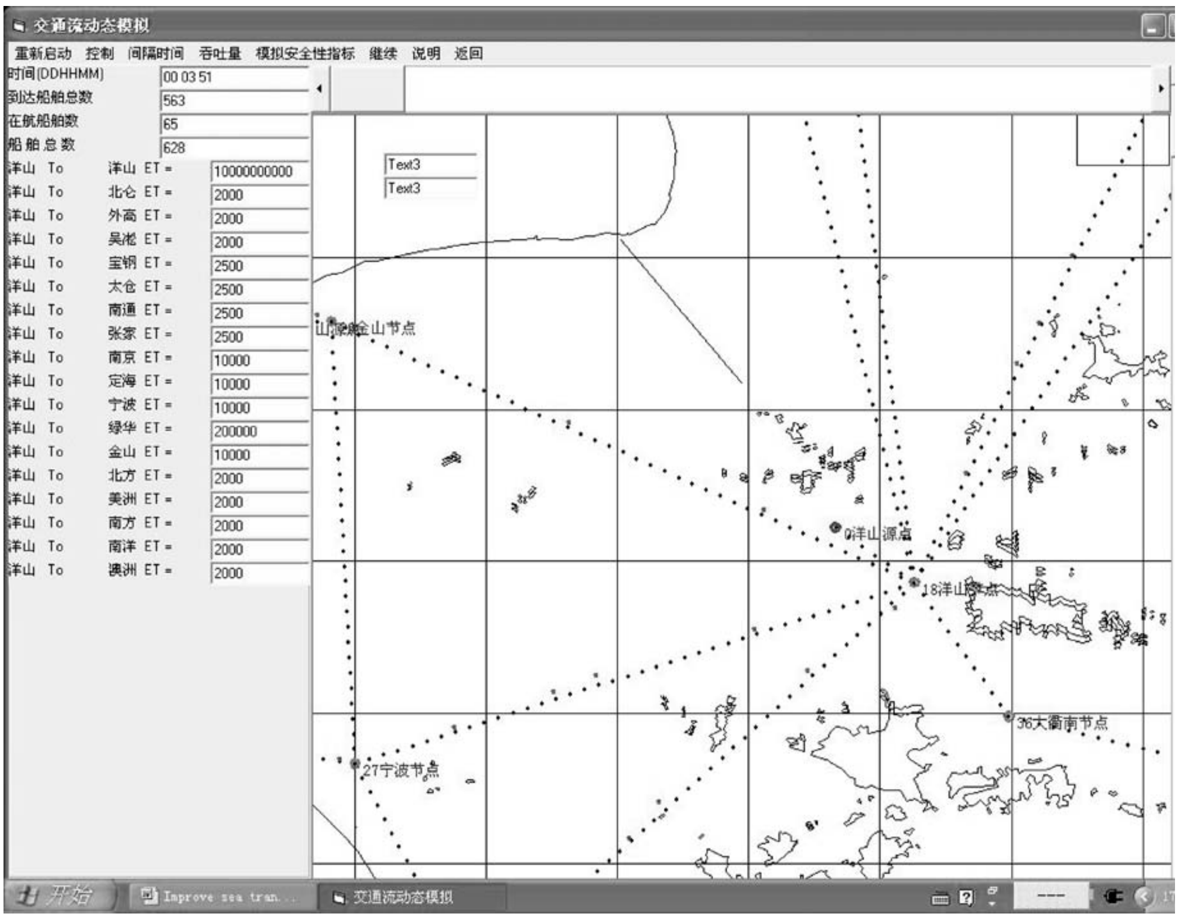

Figure 3　The Running Interface

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, pp. 59–64.

[3] Le, Meilong, Shi Zhibiao (1995), Design Method of Simulation System of Automatic Collision Prevention, *The Discussion of Chinese Communications by Cross-century Intellectuals*, pp. 391–395, 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, pp. 58–65.

[5] Le, Meilong, Wang, Xiling, Lu, Huisheng (1998), The Application of TMS 340xx 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, pp. 33–39.