Study on Shipping Safety Strategy Based on Accident Forecast Model

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ABSTRACT: The factors which would cause shipping accidents are analyzed in detail and a model which can forecast shipping accidents is studied in this paper. During navigation, all the factors are integrated and calculated in this model which then estimate and speculate on the risk degree of collision for the own ship. Finally, the risk level and the possibility of shipping accidents can be forecasted in real-time. The proposed accident forecast model can estimate the possibility of collision with other ships or objects in a specific domain. Meanwhile, the external environment such as weather, stream, *etc.* is taken into account in the model. Besides, the validity of navigators' orders can also be evaluated in the model which consequently can forecast different kinds of shipping accidents effectively in that most of the factors which cause shipping accidents have been involved in the proposed model. With the accident forecast model, the shipping safety would be improved greatly. A practical example demonstrates the effectiveness and superiority of the proposed strategy.

1 INTRODUCTION

Although modern watercrafts have been equipped with advanced facilities, such as satellite navigators, anti-collision radars, electronic charts, and automatic cabins, *etc.*, the occurrence of shipping accidents is still frequent. Therefore, the IMO organization and many other organizations pay more attention to the shipping safety. According to IMO organization's analysis results, there are three main reasons resulting in shipping accidents in recent years:

1 the failure of equipments on watercrafts;
2 the influence of navigation environments and conditions;
3 and, human factors.

The proportion of these three factors to the whole is shown in Fig.1, from which it can be seen that up to eighty percent of shipping accidents are directly or indirectly caused by human error. Under the complicated circumstance, navigators lacking of watch have poor capability of dealing with emergency, poor qualities and little sense of duty, as well as cannot master traffic rules on the sea well. Hence, misoperation will occur. In order to guarantee the safety of shipping, we should pay more attention to human factors where not only the quality of navigators and their ability of dealing with emergency would be developed, but also the latest modern technology for prediction of shipping accidents and blocking the wrong order or misoperation would be adopted. Consequently, a shipping accident forecast model is developed in this paper. Furthermore, a method of the shipping accident prediction and control is studied based on the proposed model.

2 ANALYSIS OF THE REASONS IN SHIPPING ACCIDENTS

The shipping system is comprised of watercrafts, human and the navigation circumstance. Due to the particularity of carriers and conditions, the characteristic of shipping systems which are complicated systems is multi-category, multi-layer, multi-attribute and multi-rule. Shipping accidents can be classified into the following types, collision, grounding, striking, heavy weather, fire & explosion, foundering, missing, and engine failure, *etc.* Risk during navigation mainly results from three factors: a) collisions with other objects (static or moving), b) the change of external environments (such as typhoons, tidal waves, fogs, and other disasters), and c) wrong orders sent by navigators (including misoperations). These three factors of the system also have many components which are shown in Fig.1. In recent years, new challenges encountered in shipping systems are mainly as follows:
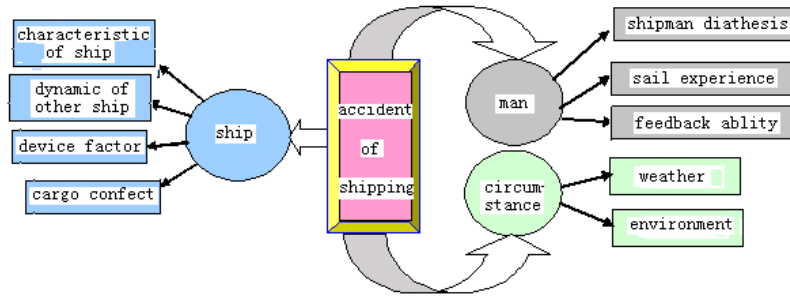
Figure.1 The influence factors of shipping accident

1) With the trend that ships become larger and larger, as well as more and more rapid, the inertia of a ship becomes larger, and therefore it is more difficult to manipulate the ship.

2) With the world economy incorporating and increasing, the quantity of ships proliferates. Together with the progress of ocean oil field exploring and sea culture, the navigation density inshore becomes higher. Hence, high risk would be taken when a ship navigates in the inshore area or on dense lane.

3) The abnormal change of the weather such as fogs and typhoons, etc., critically influences the navigation condition.

In order to cope with these problems, the technology and techniques for shipping safety are required to be studied and developed urgently. Especially, the human factor should be highlighted. In this paper, a shipping accident forecast model is proposed to avoid and control various accidents.

3 THE SHIPPING ACCIDENT FORECAST MODEL

3.1 *Structure of the model*

Nowadays, there are many kinds of models describing the ship motion. Among them, models correlated to the shipping safety are mainly: 1) OD traffic flow model (Fuji J. *et al.* 1971), 2) ship field model (Davis P V. *et al.* 1982, Goodwin E.M. 1975), and 3) DCPA (distance of close point of approaching) and TCPA (time of close point of approaching) model (Zheng Zhongyi *et al.* 2000). These models describe various characteristics of the shipping safety from different points of view. They have some advantages and are applied to large scales of areas. However, they cannot essentially solve the problems of the shipping safety. In this paper, a shipping accident forecast model which integrates each kind of factors influencing the shipping safety is proposed. As the output of the model, the risk degree is the concept of the possibility that accident will occur.

The shipping accident forecast model can be expressed as follows:

$$W(n) = U_T(U_{dT}, U_{tT}) \bigcap M_{i,j} \bigcap H_n \qquad (1)$$

where,

$W(n)$——the output of the forecast model which is defined as risk degree;

H_n——the evaluated influence degree of navigation environments;

U_T——the risk degree of collision with encountering targets;

$M_{i,j}$——evaluation results of the operation instruction (telegraph orders and rudder orders).

The output of the accident forecast model is determined by three items which correlates to three main aspects causing shipping accidents respectively. The first item in the model is $U_T(U_{dT}, U_{tT})$, which interprets the encounter probability and the risk degree of collision. The second item is the evaluation to the validity of orders sent by navigators. The third item is the degree of influence on the shipping safety while external conditions vary. The output $W(n) \in [0, 1]$ suggests that the ship has no danger while $W(n)=0$ and the ship is in danger while $W(n) \neq 0$. The larger the output $W(n)$ is, the higher the risk degree is.

The inputs of the model mainly come from the scanning information of the ARPA, other navigation operation instructions, parameters of velocity and course, and other related information from sensors (wind velocity and ship draft, *etc.*). Integrating this information, the forecast model evaluates the risk degree in real time.

3.2 *Risk degree of collision*

The risk degree of collision with encounter targets U_T involves the space collision risk U_{dT} and the time collision risk U_{tT}. The space collision risk mainly includes the $DCPA$, ship fields, the fuzziness of domain boundary, the orientation of encounter targets, observation errors in the $DCPA$, *etc.* According to the velocity and course of the own ship

and encounter objects, the shortest encounter distance between them is $DCPA = R_T \bullet \sin(\varphi_R - \alpha_T - \pi)$. After the safety encounter domain d_1 and the safety passing distance d_2 are determined, the fuzzy set U_{dT} of the space collision risk can be obtained. The membership function u_{dT} of U_{dT} is defined as follows:

$$u_{dT}(DCPA) = \begin{cases} 1, \text{if} \mid DCPA \mid < d_1 \\ \left(\dfrac{d_2 - \mid DCPA \mid}{d_2 - d_1} \right)^2, \text{if } d_1 \leq \mid DCPA \mid \leq d_2 \\ 0, \text{if} \mid DCPA \mid > d_2 \end{cases}$$

The time collision risk mainly expresses the relative velocity, distance, velocity ratio between two ships, the length of own ship, and maneuvering performance, *etc.* According to the relationship between encounter and movement of ships, the encounter time between the own ship and targets is given by

$$TCPA = R_T \bullet \cos(\varphi_R - \alpha_T - \pi)/v_R \qquad (2)$$

After the extreme time t_1 for sending a rudder order and the time t_2 for ensuring the relative safety distance between two ships are determined, the verifying domain of $TCPA$ is U_t and the fuzzy set of the time collision risk is U_{tT}, of which the corresponding membership function u_{tT} is defined as follows:

$$u_{tT}(DCPA) = \begin{cases} 1, \text{if } TCPA \leq t_1 \\ \left(\dfrac{t_2 - TCPA}{t_2 - t_1} \right)^2, \text{if } t_1 < TCPA \leq t_2 \\ 0, \text{if } TCPA > t_2 \end{cases}.$$

The collision risk between ships is the synthesis of the space collision risk and the time collision risk. In the domain U, the ship collision risk is a set of U_T, and we have

$$u_T = u_{dT} \oplus u_{iT} \qquad (3)$$

The above-mentioned synthesis operator "$\oplus$" means that,

So long as u_{dT}=0 or u_{iT}=0, we have $u_T = 0$. Otherwise, if $u_{dT} \neq 0$ and $u_{iT} \neq 0$, $u_T = \max(u_{dT}, u_{iT})$.

3.3 *Determination of the impact item of environment conditions*

The navigation environment factors involve the weather, hydrology and lane conditions. For the sake of simple computations, the environment influence parameter H_n (influence degree of navigation environment) is mainly determined by the wind velocity and the wind direction measured by wind gauges, and determined by rocking parameters which are derived from the ship's draft of each shipboard. The function is given by

$$H_n = (\frac{f_n}{f_{\max}} \otimes \frac{l_n}{l_{\max}})$$

Where f_n is the wind velocity, $f_{\max}$ is the maximal wind power, l_n is the rocking height, $l_{\max}$ is the maximal rocking height. $f_{\max}$ and $l_{\max}$ can be approximately set according to actual navigation conditions.

The value of $H_n \in [0, 1]$ is the maximum of $\dfrac{f_n}{f_{\max n}}$ and $\dfrac{l_n}{l_{\max n}}$, which means that the worse the environment is, the more the value of H_n is close to 1. It is obvious that the environment influence parameter H_n makes a great impact on the risk degree $W(n)$.

3.4 *Assessment of navigators' orders*

Most shipping accidents are caused by improper orders sent by navigators. Hence, as the term for assessing the validity of orders, $M_{i,j}$ is included in the forecast model. The principle of how to get the value of $M_{i,j}$ is shown in Fig. 2.
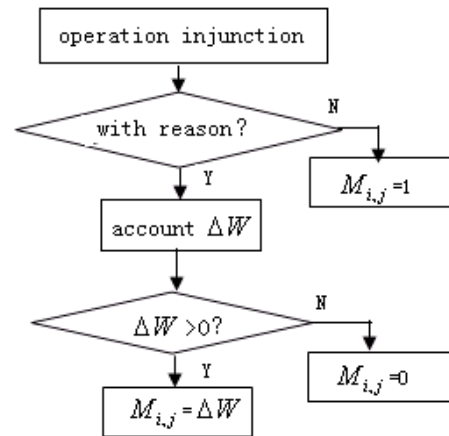

Figure.2 The choice of value $M_{i,j}$

① Expert system of the order assessment is stored in the system. Each order sent by navigators will be analyzed whether it is reasonable according to basic operation rules and emergency operation rules. If the order violates the rules, then $M_{i,j}$=1. Fig.2 The choice of the value $M_{i,j}$ output $W(n)$ equals to zero.

② If the order is evaluated to be valid by the expert system, the output $W(n+1)$, which is the output on the time of $n+1$ after the order is sent, should be calculated and compared with the output $W(n)$ on the time of n. The variety of $W(n)$ will be obtained through the function $\Delta W = W(n+1) - W(n)$. If ΔW is positive, it implies that the risk degree is increasing, then $M_{i,j} = \Delta W$. Otherwise, $M_{i,j} = 0$.

4 PRACTICAL EXAMPLE

A practical example of the shipping accident forecast model will be illustrated as follows. A ship is navigating with the course of 60° and the velocity of 14Kn, as shown in Fig. 3.
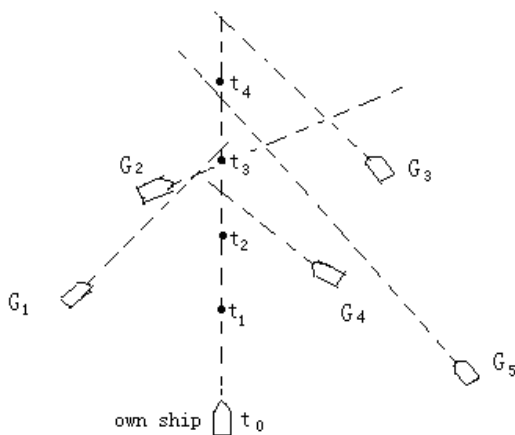

Figure.3. The navigating condition of own ship

In the definite domain, the own ship may encounter with other five ships which are marked as G_1, G_2, G_3, G_4 and G_5. The moving condition of ships is listed in Table 1.

Table 1. The moving condition of other ships in the domain of the own ship

object	G_1	G_2	G_3	G_4	G_5
course (C_0)	120	136	36	24	30
velocity (V)	16	11	10	14	12
distance (D)	3.85	2.75	5.60	3.20	4.15
angle of bow (Q)	335	010	035	065	121

Here, DCPA, TCPA and the collision membership function between the own ship and other ships at the moment t0 can be deduced, it is shown in Table 2, from which it can be seen that the collision risk degree between the own ship and G_4 is the highest at the moment t_0, U_T = 0.437. Provided that H_n =0 and $M_{ij} = 0$, we have $W(n)$ =0.437. Similarly, the output $W(n)$ of the forecasting model at the time of t_1, t_2, t_3, t_4 can be calculated respectively. According to the output of the model, navigators can take proper actions to avoid shipping accidents.

Table 2. Collision membership function between the own ship and other ships at the moment t_0.

object	G_1	G_2	G_3	G_4	G_5
DCPA	1.188	1.732	0.947	1.339	1.676
TCPA	0.220	0.184	0.660	0.286	0.359
u_{dT}	0.018	0.078	0	0.437	0.206
u_{tT}	0.015	0.071	0.057	0.375	0.146
U_T	0.018	0.078	0	0.437	0.206

5 CONCLUSIONS

A shipping accident forecast model is proposed in this paper, and the method of the predicting shipping accident is developed based on the collision risk degree, environmental influence coefficient and instruction assessment calculated in real-time. The key technology is the integration of relevant information of the shipping safety and the composition of the model. Because many complicated factors are involved in the shipping system, there are still some factors which are not considered in this paper, to name a few, evaluation rules of instructions, the reliability of the sea scanning, and the influence of visibility on sea. It is believed that with our tirelessly work and continuous development of information technology the complex shipping system can be modeled accurately to predict and avoid shipping accidents.

6 ACKNOWLEDGMENT

REFERENCES

Colnill, R. D. & Wignall, D. & Dand I. 2004. The application of marine risk simulation to the "Nearcasting"and prention of collision incidents[C],vts 2004 *The 10th International symposium on Vessel Traffic Services.*

Davis, P V. & Dove, M.J.& Stockel C.T. 1982. A computer simulation of multi-Ship Enocounters. *The Journal of navigation* 35:347 -352.

Fuji, J & Tanaka K 1971. Traffic capacity. *The Journal of navigation* 24:543-552.

Goodwin, E.M. 1975. A Statistical Study of Ship Domains. *The Journal of navigation* 28: 329-341.

Lewison, G.R.G. 1997. The Modelling of Marine Traffic Flow and Potential Encounters. *Proceedings of International confereuce on Mathematical Aspects of Marine Traffic* pp.139 London

Rafal Szlapczynski 2006. A Unified Measure of Collision Risk Derived From The Concept of A Ship Domain. *The Journal of navigation* 59:477-490

Zheng Zhongyi & Wu Zhaolin 2000. ship collision avoidance decision-making . Dalian: *Dalian Maritime University.*