REVIEW OF METHODS AND INFORMATION TECHNOLOGY FOR SHIP COLLISION AVOIDANCE

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Keywords

collision avoidance, modern information technology, decision making, information flow

Abstract

The navigation safety component is the process of maintaining safe navigable waterways to provide for the movement of commercial and recreational vessels, and of promoting and regulating safe boating and shipping practices to minimize water accidents. Marine accidents continue to result in heavy loss of life and serious damage to the environment

To realize safe navigation, ship collision avoidance is one of the most difficult subjects. It requires seeing the complete situation such as meteorological and environment conditions, waterways traffic density, port zone and endogenous factors (ship type, onboard technologies, etc). In navigation traffic areas and within coastal zones, correct selection of a ship's speed, when accompanied by the necessary trajectory changes, is a crucial element of safe navigation. Also, it is important to realize connection with information-processing center in ports and ensure information flow. Useful information, especially that related to target ships, can be used to prevent accidents and to the future position and degree of future collision threat in sufficient time.

In those days, when ship navigation was performed manually, the seaman was able to perform ship navigation satisfactorily. In process of making judgment and controlling the ship, human decisions are depended on long experience and theoretical knowledge. But, the captain or officer who hasn't this ability can lead to accidents and ship collision. Now, applications of modern maritime and information technologies and techniques can reduce accidents drastically.

In this work we give the theoretical background these techniques and technologies and previous research. They can be grouped in simulators, mathematical models and formal methods such as Petri nets or techniques from AI (genetic algorithms, fuzzy logic, etc). In order to meet the challenge of modern maritime development, the responsibility of education is to produce a great many talents ideas and work abilities.

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Introduction

"*Shipping is perhaps the most international of all the world's great industries and one of the most dangerous*." (International Maritime Organization [IMO], 2002a)

Ships navigate the sea under an open and dynamic environment, within costal and harbour zones where there are many collision threats. It is possible that one ship crosses route of other, passes another ship, comes to another ship on a same line or stops on same course. Also, collision treat is connected with weather conditions as restricted visibility. In these narrow areas ships can be looked as rational and intelligent agents. Ships with navigators can detect the changes of the environment, collect the information of other ships, judge the dangerous degree of current situation, make decisions by use of some knowledge, and take actions to avoid the collision with other ships or obstacles. The ability to perform fast path planning and its modification, correct speed's selection is a useful skill for controlling a ship in a collision situation. It is important to realize connection with information-processing centre in ports and ensure information flow. Useful information, especially that related to target ships, can be used to prevent accidents and to the future position and degree of future collision threat in sufficient time.

Because modern marine traffic requires seeing not only the situation in the open sea but the complex situation and preserving dates such as delivery to harbours located all over the world, irrespective of meteorological and environment conditions, waterways traffic density, port zone and endogenous factors (ship type, volumes of transported cargo, onboard technologies, etc). On the other hand, there is a tendency to reduce ship operation costs, and realization of this task may unintentionally involve threats to human life and natural environment. Losing transported cargo is also possible. That is why securing safety of sea going is one of more important issues in present-time marine navigation.

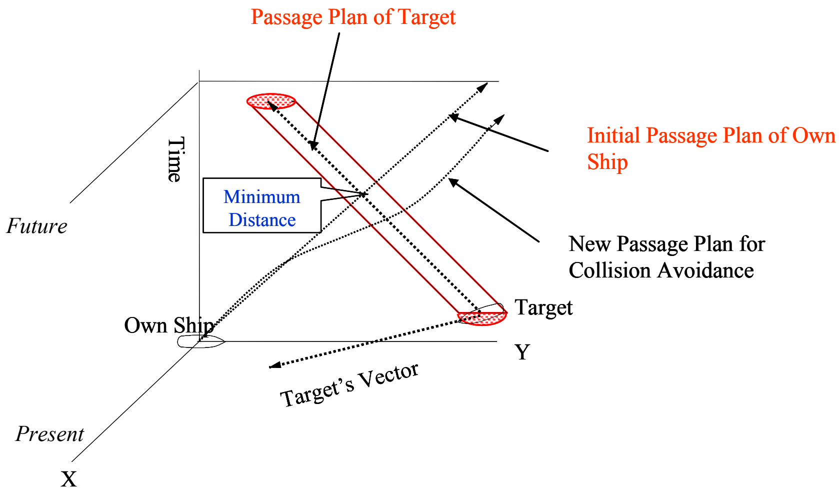
Humans are able to perform ship navigation at a satisfactory level, but their critical decisions are highly subjective and can lead to error and potentially, to ship collision. Therefore, many AI (Artificial Intelligent) methods such as expert system, decision support system, neural network, and genetic algorithm are available for supporting decision making automatically and assisting ship sailing safely [Liu, 2007].

To reduce collision threat to a minimum path planning and collision avoidance have been a research field for many years. There is a tendency to develop an automatic ship navigation system which would perform safe navigation in any navigation area and in all possible weather conditions. At present, most sea ports are equipped with special ship steering system which is focused on collision avoiding problem. New objectives and performance measures need to be identified and employed to evaluate the ship's position and assess the navigational situation. The increased technological level and specialization of ships and offshore structures, both at system as well as component level, requires dedicated education and training strategies, methods/tools and courses for the adaptation of customized options. Research Based Education for maritime sector in University programs should developed order to attract young men and women and to ensure proper education and training as Maritime Engineers and Researchers. In this context, this paper discusses literature related to techniques and technologies for reducing accidents and avoiding collision threats. They can be grouped in simulators, mathematical models and formal methods such as Petri nets or techniques from AI (genetic algorithms, fuzzy logic, etc).

2. Collision prediction and avoidance in navigation traffic areas

Collision avoidance is one of the major issues that mariners face. According to some resources [Jingsong, 2008], among all causes of sea accidents, collisions compose a relatively big group and they result from human error. Statistics prove that up to 50% of total marine accidents and incidents at see are collisions or groundings. Also, more than 90% of collisions and groundings is caused by operational errors and mostly preceded by failures in decision-makings and reactions during navigation. Out of fifteen biggest ships lost in years 2003-2004, as many as nine cases referred to collision or stranding. The current situation of two objects afloat which are going to collide is presented in Figure 1.

Figure 1: Prediction of Target and Own Ship Passage [Hayama, 2006]



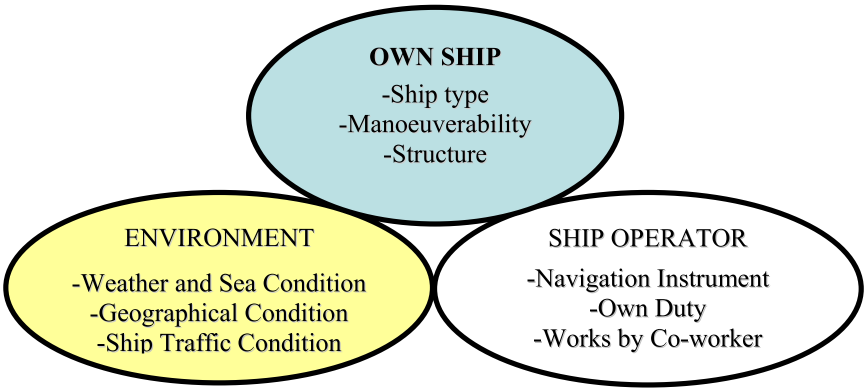
There are some factors that influence ship collision avoidance which are introduced below.

- *Own ship.* Which kind of evasive manoeuvres would be chosen depends of ship type (e.g. sail boat, speed boat, commercial ship, passenger ship etc.) since speed, payload, agility and manoeuvrability can differ from one ship type to another. For each ship type the piloting crew has special training. The important ship design parameters relating to the vessel control are the engine and rudder performances and the hydrodynamic and aerodynamic behaviour of the vessel. Simulation and mathematical models respect ship types and design parameters. These models are used for studying ship manoeuvring characteristics as affected by geographical and hydrographical conditions. Also, they provide prediction ship behaviour in the development of accident risks under different navigation scenarios.

- *Environment*. The master's judgment in controlling his ship is influenced by the data he has about his environment (geography, bathymetry, meteorological conditions and locations of other vessels in the waterway). Some of these data may be obtained by means of the vessel's own sensors but the ones that cannot be obtained must be transmitted to the vessel from shore facilities. Since measured data can only be available at a few suitably selected sensor sites modelling and simulation of the key environmental processes is needed in order to provide advice to the masters on the predicted spatial and temporal variability of the environment. The *weather and sea conditions* influence in every aspect of the ship navigation. The weather affects to choose evasive manoeuvres for ship collision avoidance which can be different for different ship types. For example, in sever weather conditions, the ship manoeuvres have to combine safety (avoid capsizing and sinking) and collision avoidance concurrently [Statheros, 2008]. Not less important factor affecting accident risks relates to *traffic regulations* in force in the waterway which stipulate priorities for entering the waterway and navigational advice for safe passage taking into account the size, weight and cargo (hazardous, non-hazardous) characteristics of the vessels which are to use the waterway. Simulator is possible to estimate the traffic capacity of the waterway and to determine navigational rules which would assure safe and efficient passage of vessels through the waterway.

- *Navigation and information technology.* The past century saw radical changes in marine navigation. The magnetic compass was succeeded by the gyrocompass, the sextant and chronometer by radio navigation and binoculars and telescopes by radar. The paper navigation chart now competes with electronic displays that can locate the ship on a chart in real time, display other ships' positions on the chart, superimpose radar information over the chart and suggest manoeuvres (Smeaton&Coenen, 1989; Baziw, 1996; Rolfe, 1996). Today, the ship usually equips ARPA system, which processes the radar information and announces caution when dangerous ships appear in near field. ARPA system provides continuous, accurate and rapid situation evaluation in order to improve the standard of collision avoidance at sea.
- *Crew* numbers have been reducing as the results of cost cutting due to the prevailing economic climate together with the fact that less people want to work on board ship over the last couple of decades. The inevitable results are that safety levels decrease and the amount of labour increases for deck officers, as more and more of other people's work is transferred to them. According to the Collision Regulations and the SOLAS convention, deck officers must keep proper lookout at all times. So it is a necessary development a system which helps them to achieve this objective and to supply them with information to make collision avoidance decisions effectively. For a precise judgment and operation, theoretical criteria are not useful and a plenty of experience is required. The captain or officer who has this ability is decreasing and necessity of automatic collision avoidance system is increasing. Therefore, many AI (Artificial Intelligent) methods such as expert system, decision support system, neural network, and genetic algorithm are available for supporting decision making automatically and assisting ship sailing safely.

Figure 2: Diagram illustrating factors of ship collisions



We expect that the proposed solution may reduce a number of accidents recorded in sea navigation, as well as to increase the safety of sea going, decreasing sea pollution and reduce operating costs.
The objective of this article is to provide a vision of how technological developments have been applied to improve the education of marine engineers. It focuses on the developments in the field of computing and information technology and their potential application in determination the optimal system composition for the formulation of rules and procedures necessary to reduce risk of accidents in waterways. Interactive simulators in comparison with educational facilities

equipped with only a real on-board hardware, are obviously becoming a powerful tool to achieve this goal.

3. Ship collision avoidance mathematical models

Collision avoidance problems at sea have also been addressed by mathematical models algorithms. These models and algorithms are connected to the position of an observation line and to a change in position of the point and the direction of observation. They simulate a variety of factors that influence water based collision avoidance, such as, ship's dynamics, ship's vector of motion (map location, speed and direction), ship's manoeuvres and trajectories, etc.

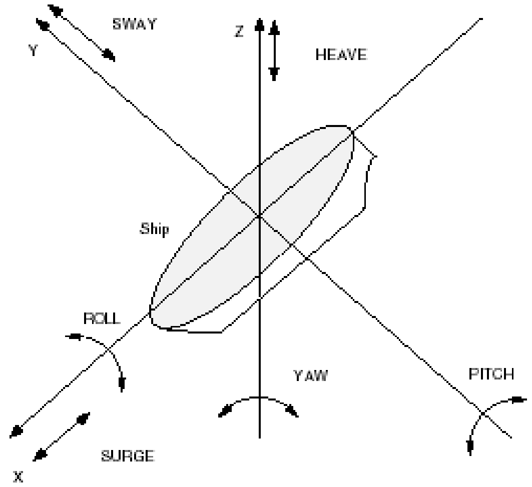
The mathematical models and algorithms for collision avoidance can be grouped into three main categories:

- Firstly, the mathematical models that simulate ship dynamics.
- Secondly, the multi-ship collision avoidance algorithms that optimise the ships trajectory for collision avoidance.
- Finally, the real-time collision avoidance algorithms.

The last category is not based on a predefined trajectory generation as happens in the second category. Both the second and third categories can use the first (ship dynamics) to obtain more accurate collision avoidance results.

Most of the ship's dynamics mathematical models [Browning, 1991] consider the ship to have six degrees of freedom as shown in Figure 3.

Figure 3: Six degrees of freedom [Statheros, 2008]



(Zak, 2004) proposes a mathematical model of a collision situation for objects afloat based on the rules of a multiple complex motion. It also contains an analysis of the presented model and the equations of the ship motion can be formulated as follows:

$$\left.\begin{aligned}
&\frac{dV_0}{dt}=\frac{cos\,\beta}{cos\,2\beta}\frac{1}{m_x}F_x-\frac{sin\,\beta}{sin\,2\beta}\frac{1}{m_y}F_y+\frac{cos\,\beta}{cos\,2\beta}\frac{1}{m_x}V_0\omega_z\left(\frac{m_x}{m_y}cos\,\beta-\frac{m_y}{m_x}sin\,\beta\right),\\
&\frac{d\varphi_0}{dt}=\omega_z,\\
&\frac{d\beta}{dt}=\frac{sin\,\beta}{cos\,2\beta}\frac{1}{m_x}\frac{1}{V_0}F_x-\frac{cos\,\beta}{cos\,2\beta}\frac{1}{m_y}\frac{1}{V_0}F_y+\omega_z\left(\frac{m_y}{m_x}\frac{sin^2\beta}{cos\,2\beta}-\frac{m_x}{m_y}\frac{cos^2\beta}{cos\,2\beta}\right),\\
&\frac{d\omega_z}{dt}=\frac{1}{I_{zz}}M_z-\left(m_x-m_y\right)sin\,\beta\,cos\,\beta,
\end{aligned}\right\}\qquad(1)$$

where

$F_x=f_1\left(V_0,\varphi_0,\omega_x,\beta,\alpha,\dot{\alpha},n\right)$ – external forces which have an effect on the x axis of the ship,

$F_y=f_2\left(V_0,\varphi_0,\omega_x,\beta,\alpha,\dot{\alpha},n\right)$ – external forces which have an effect on the y axis of the ship,

$M_z=f_3\left(V_0,\varphi_0,\omega_x,\beta,\alpha,\dot{\alpha},n\right)$ – moment with respect to the z axis,

m_x,m_y – mass of the ship together with the mass of the accompanying water with respect to the x and y axes, respectively,

V_0,φ_0 – speed and course of the ship, respectively,

ω_x,β – angular speed of the turn and angle of ship drift, respectively,

n – rotational speed of the driving motor,

$\alpha,\dot{\alpha}$ – angle and angular speed of the rudder fin deflection, respectively.

The equations of ship movement (1) allow the determination of the parameters of the controlled movement provided that the parameters of the encountered object are known. He suggested the method to determine the minimum-time control of ships in a situation of colliding with other objects afloat is presented for a mathematical model of a collision situation. Making use of multiple complex motion rules to describe the collision situation of objects afloat shows a close relationship between theoretical mechanics and a controlled movement of the object afloat.
Many of researches have used present ship's dynamic data such as present speed, position and course to calculate collision risk. However when a ship commences avoidance action, the real situation is quite different with one that has been estimated by the ship's initial data due to the ship's manoeuvring characteristic. Therefore it is better to take into account ship's manoeuvring characteristic in ship collision avoidance system from the initial stage of collision decision. [Im, 2006] included these effects in the developed system. In his study, he proposed ship avoidance algorithm to solve ship's manoeuvring characteristic under external disturbance effect. Wind effect was considered as external disturbance effect.

4. The use of the simulator

Computer-based simulation training is suitable for the learners' knowledge-based training. Simulators offer the best method of developing practical skills and assessing practical abilities with minimum danger to live and property. It is widely known that one can reduce human errors, prevent catastrophic accidents, loss of life and or property through use of simulator-based training.

Marin Navigational Simulators (MNS) are founded to be useful, even essential, tools for general training of seamen in order to prepare them to cope with unusual situation during sailing, transportation or maritime activity of all kind. MNS at the Centre for Marine Simulation (CMS) of the Maritime Faculty Split is a full ships' bridge installed on a six degrees-of-freedom motion platform, surrounded by a 360x visual projection screen and operated by a Norcontrol computer system. The wheelhouse was equipped with a Norcontrol DB 2000 ARPA radar console and an electronic chart display system. The display system presents an electronic chart oriented to and coordinated with the ships' position as displayed by an ''own ship'' mark on the chart. The user can vary the chart orientation and scale. The system allows the user to superimpose a transparent radar overlay at the same position, scale and orientation as the chart. The radar display remains oriented to the chart display as the ship moves. This simulator provides modules for ship control, external effects and navigational aids. The elements for ship control are: options for the engine selection change of rudder angle and selection of thrusters (if they exist). The controllable external effects are direction and speed of wind and current. A three dimensional view of the environment and radar video images are used as the navigational aids. The hydrodynamic characteristics of a vessel can be specified using analytic and empirical methods and are tabulated as parameters of a system of equations.

Figure 4: Simulator wheelhouse

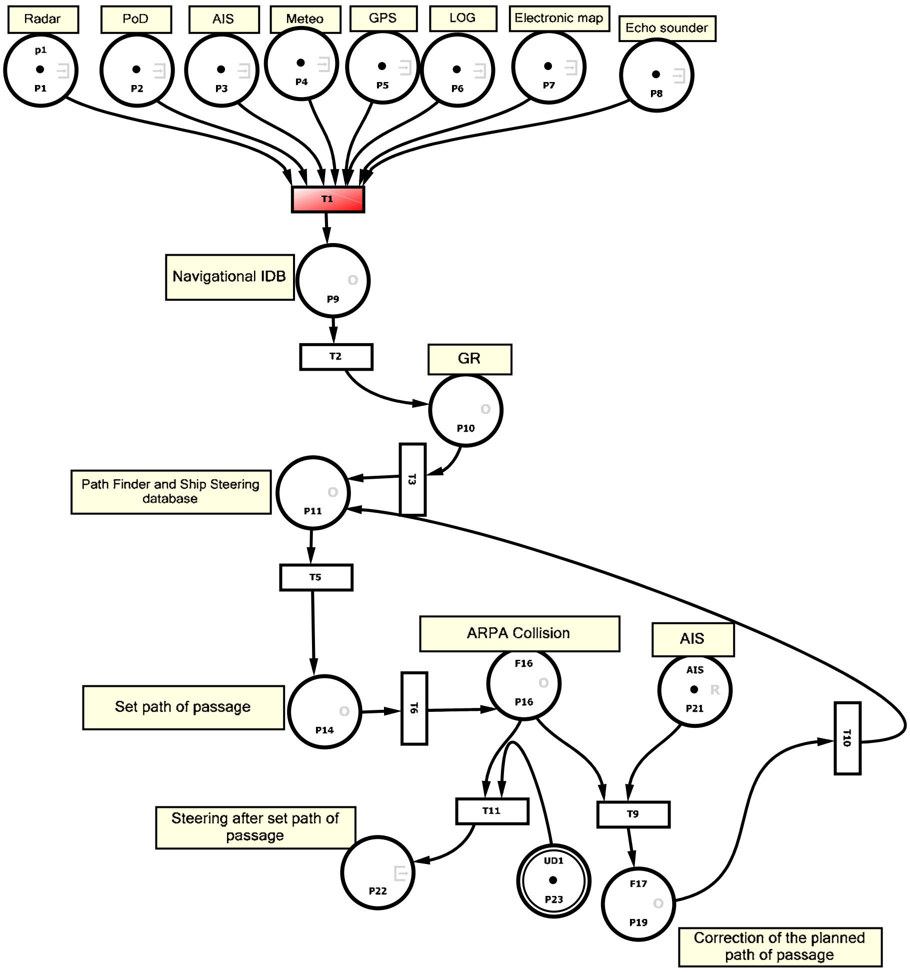
Simulations are exercises that trainees participate in to demonstrate the real thing, probably present the sea regions with critical navigation conditions. Students have to predict ship's behaviour and hence, they must take into account numerous and instantly changing external conditions, which influence the ship's motion. During the exercises, the teacher issued engine and rudder commands to a student who carried them out on the steering stand which for the duration of this study also contained the engine controls.

5. Formal methods for ship collision avoidance

Much research has already been done in this field [Zhao,1992], [Gudelj,2008]. *Petri nets* are general methods for collision avoidance include the modelling of the own ship and its immediate environment. Previous research results prove usefulness of Petri nets as a tool for information streams modelling [Gudelj, 2006, 2007, 2008]. The information flow of own ship control in a collision situation is shown in Figure 5.

Taking into account the dynamics of the own ship and the existing hydrometeorological conditions, on the basis of the trajectory determined by the GR (Global Route) subsystem, control parameters will be determined for the real trajectory of the own ship. The information will be transmitted to the supervisor, the task of which is to control ship's motion along the trajectory. The trajectory controller will supervise the motion of the own ship along the trajectory segments linking consecutive turning points (place P14). From this place the information will be transmitted to the ARPA subsystem. The transition T9 will be activated in cases of collision threat subsystem will be activated in cases of collision threat signalled by the ARPA system. ARPA will deliver processed data from the radar system on current positions and speed parameters of other object moving in the vicinity of the own ship. These data will be also compared with those received, via radio, from AIS (Automatic Identification System). In cases when the safety zone, defined by the navigator around the own ship, will be intruded by another ship, or the trajectory of the own ship crosses that of another moving object, ARPA generates a collision alarm signal. When this situation will take place, the alarm signal will make corrections in the global trajectory already determined for the own ship. Anyway, transition T11 will be fired. This is the conflict situation. To avoid this conflict control place UD1 is introduced. It contains a rule which determine a number of tokens in place P22. The rule has the following syntax: IF(AIS ==1) THEN (UD=0).

Figure 5: Petri net model of information flow for ship collision avoidance



6. Genetic algorithm

Among many artificial intelligence techniques GA will be used for the path planning and modification purpose. Previous research results prove their usefulness as a tool to solve global optimization problems [Gudelj, 2008], [Krcum, 2007]. Knowledge about examined problem improves the effectiveness of calculations. This knowledge improves process of obtaining better solutions during evolution.

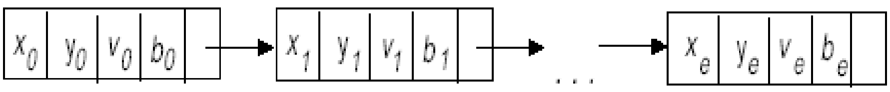
The subject of problem is how to avoid one or several ships which are oncoming, crossing or passing her own route safely. The difficulty of this subject is that the head direction to have the optimum course changes every time depending on a ship position or condition. To decide the optimum avoiding course, [Gudelj, 2008] applied Genetic Algorithm. As the evaluating function, following conditions were considered: (i) - the level of danger is better as it is lower; (ii) - the length of avoiding path is better as it is shorter; (iii) - the avoiding course is better as it is more straight; (iv) - the loss of energy is better as it is smaller. From those conditions, avoiding course is evaluated the with following equation:

$$f = w_1 \cdot a + w_2 \cdot b + w_3 \cdot c + w_4 \cdot d\,, \qquad (2)$$

where w_1, w_2, w_3, w_4 are weighting factors.

Using genetic algorithms to plan the safe path for ship in congested traffic situation, [Śmierzchalski, 1999] proposed a new gene vector. The gene vector is composed of the position and speed of our ship, as well as a noise model (see Figure 6). The noise model describes the influence on a manoeuvring ships system of wind, sea waves and the other natural factors. Each node contains *x* and *y* coordinates of the turning point to-gether with a state variable *b*, which provides information on feasibility of the knot point and the following segment, and with a speed variable *v*, which determines the speed of the own-ship for traversing the segment starting at this turning point. The point (x_1; y_1) is the first turning point after the starting point and the point (x_e; y_e) is the end point.
To test and verify the new gene vector, the equipment installed on "Shioji Maru" (the training ship of his university) have been applied to an automatic collision avoidance system. In the experimental system, the ARPA system was used to collect information on the navigational obstacles around our ship. The information was processed. Useful information, especially that related to target ships, was extracted and used to derive a stochastic predictor that can predict the future position and degree of future collision threat in sufficient time. The information relating to our own ship was detected with GPS and other sensors. These data were introduced to a GA optimum controller. The optimum or semi-optimum path was evolved from a set of possible safe paths based on the fitness function. Many experiments have been done and the results were presented.

Figure 6: A linked list chromosome representing a path



There is possibility to make more effective searching of solution using hybrid techniques which combines EA with other techniques (fuzzy logic, neural networks, other EA algorithms, etc). EA are robust method for searching the solution in complex domain. Robust method is compromise between effectiveness and calculation complexity.

7. Conclusion

Ship collision avoidance is a complex multi-task problem. The degree of complexity depends on weather and waterways traffic density, ship type, onboard technologies and navigation influencing factors. The degree of human navigation ability depends on both the level of experience and the psychological status of each individual. On the other hand, in order to meet the challenge of modern maritime development, greater skills and knowledge are required. The education is becoming even more important and the responsibility of education is to produce a great many talents with ideas and work abilities.

Integration of modelling, simulation and optimization tools will allow looking at the overall picture and help guide better decision-making. Ship collision avoidance mathematical models are effective when the exogenous inputs are not extreme. In case of extreme exogenous input the ship dynamics introduce non-linearity, which also introduces computation complexity. This complexity eliminates the real-time capability of the ship autonomous navigation system.
We proposed the use of Petri net model and the genetic algorithm which are improved usefull to obtain the good solutions. This approach turns out to be very convenient for achieving the desired tasks because the Petri's nets are based on the graphical representation by means of the net elements is easily perceived by man, i.e. there an easy way of visualization of the transport problem under consideration. If an intuitive and easy-to-read graphical model is the main concern rather than an exact description of the underlying system. It is shown the potential of genetic algorithm to improve the solutions. All these techniques are very effective for improving the engineers and officers' management experiences and operation skills in emergency situation. But for cadets who were lack of practical experiences, they had to spend most part of terms to learn theoretical courses and got course's marks on land.

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Author biography

Anita Gudelj was born in Split, Croatia (1970). She received her B.S. degree in mathematics and computer science (1993) from University of Split, Faculty of Mathematics. Since 2006 she is a senior lecture at the Maritime Faculty University of Split. Also, she received the M.Sc degree in information science from Faculty of Organization and Informatics, Varaždin, Croatia (2000). Her postgraduate research was "Design and Implementation of Temporal Database". Her research interests include database design, genetic algorithms and Petri nets. Her main activity is focused on performance modeling of automated transportation systems, vehicle dynamics and control, and optimization. She is the author and co-author of several research papers in these areas. She is also a member of several national and international societies (e.g. IEEE, INTERNATIONALSTARS…)

Maja Krčum was born in Split, Croatia (1958). She was graduated from the Faculty of Electrical, Mechanical Engineering and Naval Architecture, University of Split on March 1981. She received a graduate degree (M.Sc.) at the Faculty of Electrical Engineering, University of Zagreb in 1996. Her master's thesis was entitled "Simulation on Model of Shipboard Electrical System". In 1997, she was appointed Head of Department, also working as a tutor and counsellor. Now, she is quality manager at the Faculty. She was participated in a number of both national and international conferences where her papers and lectures were generally acknowledged as an active and valuable contribution towards the development of her profession. Her primary interest lies in the field of shipboard propulsion systems, with a special emphasis on electrical propulsion and its numerous applications (simulation methods). She is also a member of several national and international societies (e.g. IEEE, TIEMS, KOREMA…)

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