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INFLUENCE OF TRAFFIC SCHEMES ON THE LEVEL OF VESSELS SAFETY

WPŁYW TYPU SKRZYŻOWANIA NA POZIOM BEZPIECZEŃSTWA STATKÓW

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***Abstract**: The permanent increase of the ship's traffic density causes the growth of collision probability. Therefore, the probability evaluation of ship-ship collision is a very important topic. In the paper the method using theory of cellular automata is applied for maritime traffic safety evaluation. There are considered two types of traffic schemes: classical routes crossing and roundabout. The proposed model is implemented and computational results are obtained with the respect to ships safety prediction. The dependency analysis of the traffic flow structure and parameters on the ships safety is preformed. Finally, the results are summarized and a conclusion regarding future developments are given.*

***Keywords:** maritime traffic safety, ship collision probability, routes crossing, roundabout, simulation model*

***Streszczenie:** Ciągłe zwiększenie natężenia ruchu statków powoduje wzrost prawdopodobieństwa kolizji. Dlatego, ocena prawdopodobieństwa kolizji statków jest bardzo ważnym zagadnieniem. W artykule do oceny bezpieczeństwa ruchu morskiego zastosowana została metoda wykorzystująca teorię automatów komórkowych. Rozważamy dwa typy skrzyżowań: klasyczne skrzyżowanie oraz rondo. Zaproponowany model został zaimplementowany i otrzymano wyniki obliczeń komputerowych z uwzględnieniem prognozowania bezpieczeństwa statków. Przeprowadzona została analiza zależności struktury rodzajowej oraz parametrów strumienia ruchu ze względy na bezpieczeństwo statków. Artykuł kończy podsumowanie wyników i konkluzje przedstawiające dalszy rozwój prac.*

***Słowa kluczowe:** bezpieczeństwo ruchu morskiego, prawdopodobieństwo kolizji statków, skrzyżowanie dróg morskich, rondo, model symulacyjny*

1. Introduction

The AIS (Automatic Identification System) provides static information and accurate real-time dynamic information about the ship. It is an important information source for collision avoidance collision making. The MGIS has in disposal time and space dependent management concepts, the COLREGS provide the basis for collision avoidance when encountering other ships. CAS (Collision Alert System) of VTS information are used to establish rudder steering procedure. On the basis of all these information, supporting the navigator to make a reasonable decision what collision avoidance action to take, the final decision must be made by an individual navigator. A navigator assess consequences by intuition [11].

Decision-making is mainly based on visually observed information. Due to human limits of analysis capability, continuous monitoring, analysis of information, making decision and execution of evasive action becomes very difficult. Besides ship operators are confronted with data from a variety of sources and are then required to make collision avoidance decision in a tense situation. There are many human factors influencing ship safety such as fatigue, automation, situation awareness, communication, decision making, team work, health and stress [6]. Even having recognized and defined decision problem the navigator (decision-maker) can feel helpless while choosing which version of manoeuvre should be adopted from the point of view of ship safety. The other issue is estimating time interval, in which the decision should be taken. In the situation of collision risk, not only an appropriate avoidance action is required but also timing matters greatly.

Safety management systems have two interrelated main functions: to avoid accidents and improve safety [9]. Shipping is a global industry and highly complex business. In the safety area, many stakeholders (e.g., crew, shipping companies, unions, industrial bodies, national and international regulators) constantly act and react to internal and external changes. Although safety is to a large extent regulated and procedures and guidelines for best practices are in place, accidents and incidents still frequently happen [9].

At the shipping industry theories of safety management have started from technical age, the first development of SOLAS, to the age of management systems, the ISM Code. International safety regulations from one side stem from the International Maritime Organization (IMO) in the form of conventions, protocols, and resolutions but from the other are addressed by regional, flag state, and port state, which are transformed into the form of procedures and standards.

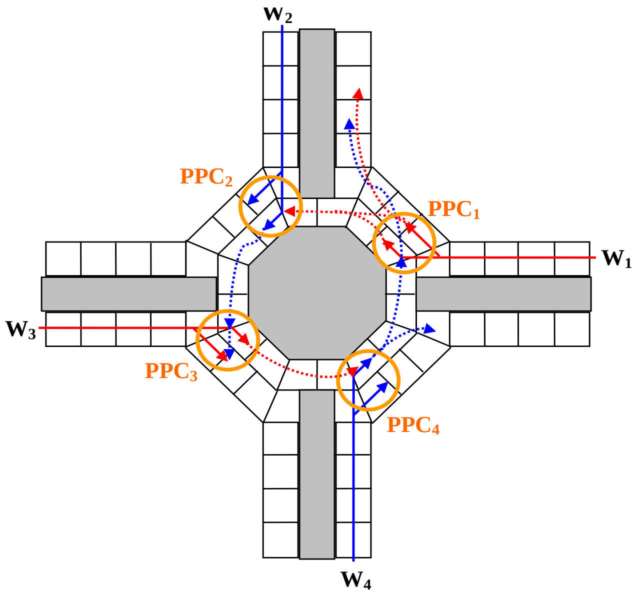
The main factor of the collisions accident is ignoring the company's Safety Management System and navigation procedures. It is not the root cause to why a collision happens. There are usually a chain of errors. To prevent the accident is sufficient to identify any of these errors and rectify it. A safety system should identify and prevent the chain of errors at an early stage.

On the other hand the size and speed of new ships are constantly increasing. Besides cargo transport increased rapidly and the waterways are more congested. It can reduce the manoeuvring options as a wide-ranging variety of operational data and information must be correlated and mentally assessed by ship operators. To face the logistical organization there is necessary to apply new alternative solutions for operational optimization [10][11]. Navigation is becoming more and more complicated task demanding a balance point between navigation safety and economics. Collision avoidance is a multi-criteria problem with at least two moments when the navigator is unsure of result, i.e. whether the other vessel being on the collision course knows the threat and will perform manoeuvre and if yes when and what manoeuvre will be performed. This situation is defined as uncertainty during decision making.

The use of simulation methods make possible assessing the risk of conflict in a given situation navigation by an external observer. It can determine which ships pose a threat. Simulation approach also allows analysis of how the traffic organization affects safety depending on the traffic flow parameters.

2. Simulation model

The suggested simulation model describing the traffic flow at the grade roundabout crossing is based on the cellular automaton model. It is able to reproduce the basic phenomena of maritime traffic as it can take into account the vessel's type, speed and length, the vessel's behaviour and maneuverability, the lane status and flow density.



W_1, W_2, W_3, W_4 – enter lines for roundabout

PPC_1, PPC_2, PPC_3, PPC_4 – Potential Points of Collision

Fig. 1. The scheme of grade roundabout crossing

In a maritime traffic scenario with a roundabout we consider a junction of four routes numbered 1,2,3,4 and four point of potential collision (Fig. 1). The traffic schemes of classical routes crossing is widely described by authors in [1][2]. We assume the traffic lanes 1 and 3 are main routes on that there are usually large vessels with less maneuverability. As a main flow we understand a flow with a highest density. In the simulation model we assume the distances between collision points are equal 1 nm. The vessels are observed in the lanes entering the roundabout-lane with a distance 6 nm.

The traffic lanes are divided into cells, similarly as in the Nagel-Schreckenberg model [8]. The cell size depends on vessels' lengths and velocities as well as flows' intensities. Details concerned with determining the crossing density and cell size can be found in [1]. The spatial discretisation corresponds to the vessels' lengths, whereas the temporal discretisation is based on vessels' velocities and a cell size. As in our model the vessels' lengths can differ and some vessel can occupy several consecutive cells we conclude it is a multi-cell model.

We assume each vessel can move headway throw the roundabout or starboard. The vessel entering the roundabout is randomly characterized by a predetermined exit lane with specified probability. Considering a roundabout model of the lanes crossing we have junction of four simple Y-shaped intersections.

The article deals with different levels of risk depending on the mutual distance of vessels that are on collision courses. Distance is measured in taxicab metric, according to the sequence of grid cells. The procedure of determining the threshold values of safety distances that define the states of collision risk is presented in [2].

We take into consideration following four states corresponding to risk levels and their critical distances:

state 0 – collision alert when two vessels' domains are overlapping [5];
state 1 – high risk of collision defined by a distance of passing clear;
state 2 – low risk of collision corresponding to a safety distance ;
state 3 – negligible risk of collision.

As we focus on estimating the probabilities of vessels being in safety states and the states are defined by the mutual distance between vessels the simulation time step should not exceed the time of vessel moving from one cell to another, in case not to miss the collision situation between consecutive time steps. Thus we assume the time step corresponds to time of vessel moving with the largest velocity from one cell to the next one. The vessels' speed is expressed in cells per time step. With a time step the position and state of all vessels (objects in the streams) are updated according to their velocity, move direction and possible collision avoidance manoeuvre. The transition rules are consecutively applied to all vessels in parallel (parallel update).

3. Vessels' priority scenarios

The numerical simulation is carried out for different scenarios of vessels' priority at the roundabout crossing. According to the rule 15 while crossing situation the vessel which has the other on her own starboard side shall keep out of the way and shall avoid crossing ahead of the other vessel. The second scenario we consider is under assumption that traffic lanes 1 and 3 are main routs with stand-on vessels and on routs 2 and 4 moves give-way vessels that should keep out of the way of vessels being on routs 1 and 3. The last considered situation is that vessel being on the roundabout-lane is a stand-on vessel with priority and the vessel moving on the lane entering the roundabout is a give-way vessel similarly as in traffic round [4].

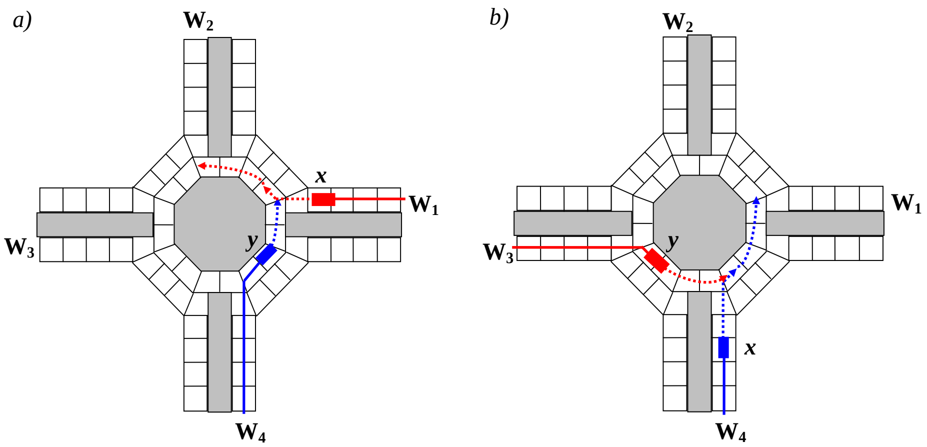


Fig. 2. The collision situation in case the vessel on the roundabout is a) on the lateral lane (has no priority) b) on the main lane (has priority)

According to the rule 15, in the case of risk collision during crossing situation, the vessel *y* which has the other vessel *x* on her own starboard side shall keep out of the way and shall avoid crossing ahead of the vessel *x*. This rule is clear when the vessel *x* is on the lane with a high density (Fig. 2a). However considering the roundabout crossing we distinguish some situation when the vessel being on the roundabout-lane has priority. When the vessel *y* on the roundabout is very large and with less maneuverability we assume it has priority and the vessel *x* entering on the roundabout crossing is directed to keep out of the way of vessel *y* (Fig. 2b).

In the program we assume a priori probability of taking evasive action by give-way and stand-on vessels. As ferries are generally quite fast, from [3] we get that more than 80% of observed vessels' velocities are not below 18 knots with the average velocity about 19 knots. Moreover the authors concluded from data that the faster the give-way vessel, the more likely it is to take evasive action first and the estimated probability of taking action by the give-way vessel is equal 0.94 if it is a ferry. On the basis of these results in the simulation model we assume this probability vary from 0.88 to 1.0. For other cargo ship we assume the probability the give-way vessel takes action first is estimated:

– from 0 to 0.19 if its speed is up to 5 knots,
– from 0.19 to 0.45 if its speed is between 5 and 10 knots,
– from 0.45 to 0.74 if its speed is between 10 and 15 knots,
– from 0.74 to 0.91 if its speed is between 15 and 20 knots,
– from 0.91 to 1 if its speed is over 20 knots.

Considering the behaviour of the stand-on vessel we have the probability of performing a collision avoidance manoeuvre in the interval from 0.3 to 0.6 in case the stand-on vessel is a ferry and we assume a probability from 0.2 to 0.4 for cargo ships. Taking into account the results of the simulation the probability of taking action by the give-way and stand-on vessels should be verified a posteriori by real data.

4. Simulation results

The simulation results clearly show the influence of the traffic organization to the risk of collision, Table 1., Fig. 3.. The ANOVA analysis shows that there is a statistically significant difference between the means of the variables at the 95,0% confidence level. To determine which means are significantly different from which others, the Multiple Range Tests was used.

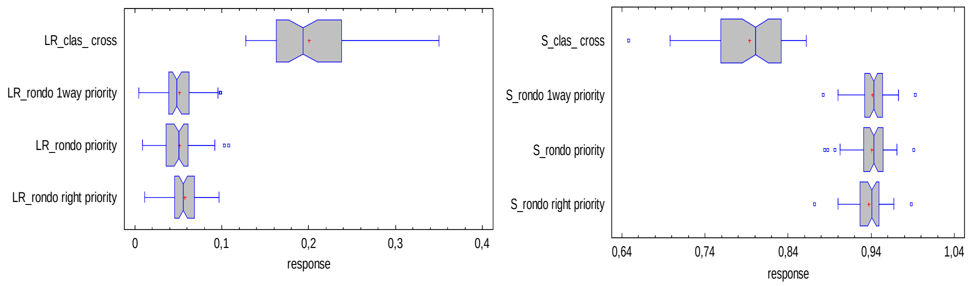


Fig. 3. Comparison of parameters for the different traffic organization, Box and Whisker plot

The method currently being used to discriminate among the means is Fisher's least significant difference (LSD) procedure, Table 1. There is a 5,0% risk of calling each pair of means significantly different when the actual difference equals 0.

Table 1. The pairs of means which are significantly different from others.

Contrast	*Sig.*	*Difference*
LR_clas_ cross - LR_rondo 1way priority	*	0,148844
LR_clas_ cross - LR_rondo priority	*	0,148703
LR_clas_ cross - LR_rondo right priority	*	0,142966
S_clas_ cross - S_rondo 1way priority	*	-0,147444
S_clas_ cross - S_rondo priority	*	-0,1473
S_clas_ cross - S_rondo right priority	*	-0,143536

* denotes a statistically significant difference. All statistical calculations were performed using the Statgraphics.

5. Final Remarks

The results of the vessel traffic simulation allows system dynamics analysis and detailed examinations of ships' routes traffic and ships' behaviour in collision situation. In the paper we have focused on comparing results concerned with probability of low and negligible risk of collision. For considered traffic schemes i.e. classical routes crossing and roundabout with different priority models there is performed testing the identity of samples. As a next step the statistical analysis with regard to type distribution identification can be conducted and the regression model can be built. The simulation results can also illustrate that particular variables have significant influence on the probability of collision risk. Future investigation could consider traffic organization as well as the distance between collision point that could be crucial from the point of view of safety management.

6. References

[1] Blokus-Roszkowska A. Smolarek L.: Collision risk estimation for motorways of the sea, Reliability: Theory & Applications, Vol. 1, No. 2(25), pp. 58-68, 2012.

[2] Blokus-Roszkowska A. Montewka J. Smolarek L.: Modelling the accident probability in large-scale, maritime transportation system, Journal of Polish Safety and Reliability Association, Summer Safety and Reliability Seminars, Vol. 3, No. 2, pp. 237-244, 2012.

[3] Chauvin Ch. Lardjane S.: Decision making and strategies in an interaction situation: Collision avoidance at sea, Transport Research Part F No. 11, pp. 59-269, 2008.

[4] Chen R. X. Bai K. Z. Liu M. R.: The CA model for traffic-flow at the grade roundabout crossing, Chinese Physics, Vol. 15, No. 7, pp. 1471-1476, 2006.

[5] Fujii Y. Tanaka K.: Traffic capacity, Journal of Navigation Vol. 24, pp. 543-552, 1971.

[6] Hetherington C. Flin R. Mearns K.: Safety in shipping: The human element, Journal of Safety Research No. 37, pp. 401-411, 2006.

[7] McNab R.: SimJava: a discrete event simulation library for Java. University of Newcastle upon Tyne. Available from http://www.javaSim.ncl.ac.uk, 1996.

[8] Nagel K. Schreckenberg M.: A cellular automaton model for freeway traffic, Journal de Physique I France Vol. 2 No. 12, pp. 2221-2229, 1992.

[9] Oltedal Helle A.: Safety culture and safety management within the Norwegian-controlled shipping industry, Thesis of PhD, University of Stavanger, N-4036 Stavanger, NORWAY, 2011.

[10] Su C. M. Chang K. Y. Cheng C. Y.: Fuzzy decision on optimal collision avoidance measures for ships in vessel traffic service, Journal of Marine Science and Technology, Vol. 20, No. 1, pp. 38-48, 2012.

[11] Zhuo Y. Hearn G. E.: A ship based intelligent anti-collision decision-making support system utilizing trial maneuvers, Proc. Chin. Control Decision Conf., pp. 3982 -3987, 2008.

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