TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 9
Number 3
September 2015

DOI: 10.12716/1001.09.03.06

Data Acquisition in a Manoeuver Auto-negotiation System

J. Szlapczynska
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Typical approach to collision avoidance systems with artificial intelligence support is that such systems assume a central communication and management point (such as e.g. VTS station), usually located on shore. This approach is, however, not applicable in case of an open water encounter. Thus, recently a new approach towards collision avoidance has been proposed, assuming that all ships in the encounter, either restricted or open water, communicate with each other and negotiate their maneuvers, without involving any outer management or communication center. Usually the negotiation process is driven by the collision avoidance software and called auto-negotiation. This paper elaborates on data acquisition problem in case of the maneuver auto-negotiation. It focuses on ships' initialization in the system and data gathering.

1 INTRODUCTION

Computational support for manoeuvers determination in ship encounter situations may significantly increase safety of passengers, crew and cargo. Various methods supporting collision avoidance manoeuvers for ships have been developed in the last decades. However, it was the digital and computer science fast progress in the last several years that made possible creation of effective telematics systems implementing these methods. Among hardware solutions one can distinguish such elements, already implemented on most of vessels, as *Automatic Identification System - AIS* or *Target Tracking - TT* (including *Automatic Radar Plotting Aid - ARPA*). These systems are utilized mostly to detect and evaluate presence and motion parameters of the other ships in the vicinity of the own ship.

Software collision avoidance solutions may be roughly grouped into two categories: deterministic and heuristic (or meta-heuristic) methods. The former one consists of algorithms that iteratively calculate optimal and safe trajectories (or their sets) in case of an encounter. A typical property of a deterministic collision avoidance method is a possibility to obtain a fully optimal solution. However, typically it is reached by investing significant amount of processing and/or computations, which results in long algorithm execution time. Another disadvantage here is a difficulty with handling some of the optimization constraints (e.g. dynamic constraints).

Unlike the deterministic ones, the heuristic collision avoidance methods base on fast converging optimization algorithms, thus usually they are able to return results after significantly shorter period of time. Also possibilities to model virtually any constraint in the optimization problem are unlimited. Yet, the main disadvantage here is that the results (trajectories or sets of trajectories) are usually sub-optimal. However, with a fine constructed heuristic it is possible to obtain both fast convergence and insignificant differences between optimal and sub-optimal solutions. One can distinguish also a subgroup of heuristic collision avoidance methods, namely the expert or decision support systems. These systems usually relay on heuristics as their optimization cores, but extend their functionality by providing additional decision making support.

All the above mentioned approaches to manoeuvers determination are based on an assumption that the methods are used, utilized or run in a central control traffic point, e.g. VTS station, usually located on shore. Hence, a decision on how the final manoeuvers should be like is made in an arbitral and centralized fashion. While this approach is natural for restricted harbor area, hardly it is possible for an encounter in open waters. Thus, recently a new idea of decentralized manoeuvers determination has emerged, as presented in (Hu *et al.*, 2008; Hornauer, 2013; Hornauer and Hahn, 2013). It assumes that encountering ships communicate with each other without participation of any outer party and establish their further collision avoidance actions by means of negotiation. If the whole process of manoeuvers determination (i.e. data acquisition, negotiation and optimization of manoeuvers) does not need any human interaction - it is called an auto-negotiation one. Computational part of manoeuver determination in the auto-negotiation proposals strongly relies on previously described centralized approaches to collision avoidance, namely deterministic or heuristic ones (especially the latter). However, in such case a few brand new elements must be introduced to the system, such as detailed data acquisition formats, negotiation protocols, results distribution, etc.

It is worth noticing that the decentralized collision avoidance actions, often based also on negotiations, are common for nowadays bridge communication routines on open waters. Indeed, in a case of an encounter, captains or navigators of the ships usually try to contact each other directly via VHS radio (open water) or via the VTS station (harbor area) to establish necessary maneuvering. Obviously, in all cases the arrangements ought to comply with COLREGS (1972) regulations.

This paper aims at presenting the author's proposal of a maneuvering auto-negotiation system, particularly focusing on its first element: data acquisition. The rest of the paper is organized as follows: section 2 presents a review of papers on collision avoidance in general and also the auto-negotiation one. The section 3 presents a general description of the proposed system. In the next section data acquisition in the system is presented in detail (separately as initialization and data gathering). Section 5 concludes and summarizes the material presented.

2 LITERATURE REVIEW

The centralized collision avoidance methods constitute a basis of the manoeuver auto-negotiation ones, thus a literature review of the former is essential in this paper. Following previously presented classification of collision avoidance methods with a centralized control point, they may belong to either deterministic or heuristic group of methods. A general, but thorough, review of both these groups was presented by Statheros et al. (2008).

Classical deterministic collision avoidance methods are based on differential calculus utilized to solve the optimization problem, as presented e.g. by Lisowski (1985). In this approach a set of ships is monitored and controlled during the main algorithm's run. It is based on a game model – strategies of all the vessels are taken into account as they were "thinking players". The differential elements are responsible here for modelling of ship dynamic. A similar, differential calculus-based, research has been conducted and presented in (Zak, 2004). It proposed utilization of multiple complex motion rules describing collision situation, which was a special case of a more general definition of controlled movement approach. Another deterministic method, called Collision Thread Parameters Area (CTPA), was proposed by Lenart (1982). In CTPA a navigator is able to select a safe combination of own course and speed utilizing a coupled coordinate polar system (presenting both speed and position of ships), taking into account circle-shaped ship domains. The CTPA method has been extended (FCTPA) to support any convex domain by Szlapczynski (2008).

Most of the heuristic collision avoidance methods benefit either from genetic algorithms (GA) or their successors – evolutionary algorithms (EA). One of the first such approaches has been proposed by Smierzchalski (1999), where EA was about to find the own ship trajectory assuming that all the other ships keep their courses unchanged. This research has been continued since then, i.e. in (Kolendo *et al.*, 2011) a new scaling function has been proposed. Similar collision avoidance GA/EA based methods have been also proposed by other authors. Ito *et al.* (1999) presented a GA algorithm utilized for collision avoidance maneuver optimization. Also Zeng (2003) and Tam & Bucknall (2010) proposed algorithms in which optimal own ship trajectory is sought by means of an EA algorithm. An extended approach, in which not only a single trajectory, but a set of trajectories for all the ships in the encounter is sought, has been proposed in (Szlapczynski, 2010; Szlapczynski & Szlapczynska, 2012). In this case not a single trajectory, but the whole trajectory set evolves at once. Quite different, though still heuristic, approach has been proposed by Cheng& Liu (2007) and Tsou & Hsueh (2010). The former presents genetic annealing algorithm for trajectory optimization, whereas the latter utilizes ant colony algorithm for the similar purposes. Another heuristic of swarm intelligence has been utilized in a decision support system proposed by Lazarowska (2012). In (Brcko and Swetak, 2013) fuzzy reasoning has been used to build a collision avoidance decision support system. Finally, Pietrzykowski *et al.* (2009) proposed a sophisticated decision aid system supporting maneuvering complying with COLREGS regulations.

The first papers on manoeuvers auto-negotiations, rejecting an axiom of having a central control point, emerged just recently. In papers (Hornauer, 2013; Hornauer and Hahn, 2013) a distributed system has been proposed in which ships negotiate their manoeuvers. The authors plan to base the optimization core on evolutionary sets of safe trajectories, following the paper (Szlapczynski, 2010). Their proposal assumes that there is a distinction between active ships, actively contributing to the negotiation process, and inactive (rouge) ships. The latter for various reasons (e.g. no proper hardware/software equipment), do not assist in the process and do not follow system recommendations towards planned maneuverings. The system takes into account presence of the inactive ships by predicting (based on historic data) their future movements.

Quite different assumptions lay at the basis of CANFO system proposed by Hu *et al.* (2008). Here auto-negotiation is only between two ships and optimization core is reduced to a deterministic method of manoeuver determination. The main advantage of the proposal is a detailed negotiation protocol description, based on pre-defined preference set. On the other hand, utilized straightforward calculus makes the method not applicable in case of an encounter with more than two ships. What is more, the authors assume that ship navigators sometimes would rather go for an illegal (according to COLREGS) maneuvering, if only economic factor (e.g. a way loss) would justify that. Such approach hardly is acceptable in practice.

This paper aims at presenting the author's proposal of a manoeuver auto-negotiation system, deriving the advantages of the already known solutions and trying to avoid their disadvantages as well as the known pitfalls. It is focused mainly on ships' initialization in the system and data gathering. It is following author's draft proposal of the system presented in (Szlapczynska, 2014).

3 GENERAL DESCRIPTION OF MANOEUVER AUTO-NEGOTIATION SYSTEM

The main idea of the proposed system is to combine a manoeuver control that is independent of any outer objects (such as e.g. a VTS station) with a semi-distributed control by the ships in the encounter. Unlike previous manoeuver auto-negotiation proposals, the one calls for control flow in which one of the ships in the encounter is a leader ship and all the others are ships-participants. The leader is responsible for gathering data, determination and optimization of manoeuvers, finally distribution of the results. This pattern, called here semi-distributed one, as opposed to a distributed one (in which all the ships equally try to contribute to the final result), is about to overcome the well-known problems of distributed system, such as accessing shared memory or deadlocks.

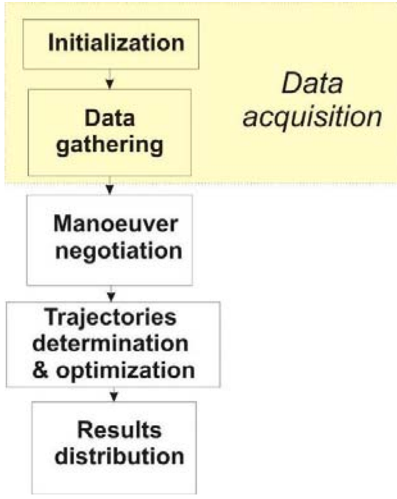

Figure 1. Proposed manoeuver auto-negotiation system

Flow of the proposed system, presented in Figure 1, reflects the previously presented one in (Szłapczynska, 2014). The following elements of the system have been distinguished there:

1 Initialization – at this stage ships come forward to be included in the auto-negotiation. The ship that initializes the process becomes a leader, all the others become ships-participants.
2 Data gathering – all the ships report to the leader their basic movement parameters such as current speed & course, initial and goal positions, etc. Moreover, each ship will transmit an initial set of possible / forbidden courses (or possibly courses & speeds). Both initialization and data gathering constitute data acquisition stage, which is elaborated in the next section.
3 Manoeuver negotiation – here preferences towards manoeuver possibilities and conditions (e.g. circulation radiuses) are exchanged. A detailed protocol describing the negotiations is to be prepared.
4 Trajectory determination and optimization – collected input data (based on original plans reported by all the ships, including also ships' preferences towards maneuvering possibilities and conditions) trigger the optimization process. It searches for an optimal (or sub-optimal rather) set of trajectories for all the ships. It is possible to apply here a multiobjective search pattern, thus a search for multiple goals is possible (e.g. the smallest way loss and the highest security of traveling). One of the key constraints here is that optimization procedure must be executed on a strict time regime, possibly in less than 1 minute. That forces utilization of heuristic approach to optimization. Further research on a heuristic method suited for the problem is required.
5 Results distribution – the last stage in the process, in which final results of computations (the set of trajectories) is distributed among the ships in the encounter. As the data is sent (via the selected communication link) as "suggested maneuvering", the system expects replies from each ship (sent manually by the navigator) confirming agreement for following the suggestions. Once all confirmations are gathered, the results obtain a new status of "accepted maneuvering". The "suggested" status remains unchanged in all other cases. No automatic

execution of the accepted manoeuvers is planned, it will remain in sole responsibility of the navigators. A detailed protocol describing results distribution is to be prepared.

The system would be able to work in various modes, depending on the situation and geographical localization of the encounter. These modes would include the following (as non-excluding items):
– open or restricted waters mode,
– waters including / not including TSS (Traffic Separation Schemes) regulations; in case of a TSS Rule 10 will be taken into account in manoeuver determination & optimization,
– for restricted waters only: waters under VTS / no VTS control,
– for good visibility (Rules 11 – 18 taken into account) / restricted visibility (Rule 19 taken into account).

4 DATA ACQUISITION IN THE SYSTEM

The first issue to be resolved when discussing data acquisition in the system is which communication channel should be established to assure fast, reliable and secure data exchange. As presented in (Szlapczynska, 2014) there are mostly two possibilities:
– AIS- based communication by utilization of ASM message broadcast,
– wireless communication ("Wifi on sea" working in peer-to-peer mode).

The key advantage of having the AIS-based channel is that its equipment, due to international regulations, is already present on most of vessels (but e.g. small vessels like fishery boats are still not obliged to have AIS on board). However, this kind of communication relies on broadcasting messages through an unsecured channel. This fact, as reported by (WWW_AIS, 2015), may cause the following:
– fake AIS signals (from non-existing vessels) could be transmitted, mostly to interrupt or collapse systems gathering AIS data,
– AIS signals from existing vessels could be amended e.g. by sending modified ship position and/or course, which could result in initiation of improper collision avoidance actions by the other vessels. Thus all may lead to a ship collision e.g. provoked on purpose by pirates.

Having the above in mind one should be aware that no classified information should be exchanged through the AIS channel, as it is defined at the moment (there are plans, however, to rewrite the AIS specification and thus in future to increase safety of the connections). The problem with exchanging classified information remains valid also for the purpose of the auto-negotiation system. On the other hand, the wireless approach with TCP/IP architecture applied is able to handle secure data exchange (e.g. via data encryption). Its disadvantage, however, is a necessity of having additional, quite expensive and not widespread, hardware equipment. Thus there is no possibility to use this way of communication to indicate ship's will to join the system. Therefore it is recommended to initialize the auto-negotiation system via the AIS channel, but continue further communication by establishing a secure wireless peer-to-peer connection.

The data acquisition element of the manoeuver auto-negotiation system may be split into two separate items, namely:
– initialization, when ships in an encounter that would like to utilize the system set up a negotiation group,
– data gathering from all ships in the group, to be used further by the trajectory determination & optimization core of the system.

The following subsections describe the abovementioned elements of the system.

4.1 *Initialization*

The main goal here is to set up a group of ships interested in participation in the auto-negotiation system and to select among them a group's leading ship (a leader, the ship that later would perform most of the computational tasks). Various approaches exist to handle such situation. As proposed previously by the author in (Szlapczynska, 2014), the initialization process (referred to as registration) would be organized as follows. Each ship, not in an encounter currently, periodically sends an AIS message broadcasting her will to become a leader of maneuver negotiation. If two or more such ships meet on a fixed area, e.g. an arena with 10Nm diameter, the first one that gets into the area becomes the leader and all the other become ships-participants. This approach in practice, however, is limited to fixed areas, e.g. precautionary areas. One also should have in mind that any COLREGS-compliant maneuver negotiation would be useful only for more than a simple ship-to-ship encounter (for two ships COLREGS state clearly what is the required maneuvering). Moreover, in some cases of multiple ship encounter the leader would have significantly smaller computational powers (necessary to perform manoeuver determination and optimization) than the other participants, which may lead to unacceptable long results' awaiting time.

To overcome these problems a different approach to initialization is proposed here. Let the ship that is the most interested in manoeuver negotiation (i.e. having the biggest number of constraints or ships to whom she is obliged to give way) to initialize the negotiation by sending the AIS message just once (or eventually repeated by limited number of times). The process of sending the message could be triggered either manually by the navigator or automatically by the system in case the Target Tracking (i.e. ARPA) reports e.g. more than two other ships in possible encounter with the own ship. All the ships (in AIS range) that receive the message, that would have the system installed and willing to participate, would send back information "I'm in", becoming automatically ships-participants. The others - that either would send "I'm NOT in" (having no such system or not willing to participate) or not sending any message - would not become participants. However, their presence would be noted (as passive ships) and monitored by the leader, further taken into account in all future computations.

4.2 *Data gathering*

After finalization of the initialization process, when a group of ships-participants, including a leader, is established, every communication should be performed only via a secure connection. As described earlier it could be achieved by utilization of wireless peer-to-peer communication. As for now it is assumed that such connection is available and already set up for the group of negotiating ships.

In the next step all the participants should send the leader information including their motion parameters (e.g. current course, speed, etc.). Based on the information, later on the leader would be able to determine required and optimized maneuvering. Obviously, the passive ships being in vicinity of the encounter would not send any information to the leader. Thus, introducing a mechanism to overcome this difficulty is necessary to obtain safe resulting collision avoidance actions.

The author thus proposes that the participants, instead of pure motion parameters, would send to the leader information packs, so-called here "Manoeuver Availability Arrays" (MAA). A MAA sent by a participant would consist of ranges of courses (in an extended version: courses and speeds) that would not result in a collision situation (according to COLREGS rules) with any of the nearby ships. That would also include all the passive ships being nearby the participant, as well as any other ship being out of the negotiation scope (not visible by the system, thus outside it) - not active nor passive one to the system. This way each active ship would introduce to the system additional information about collision threats in the near vicinity. The MAAs could be determined (in almost real-time fashion) in its basic form by utilization of DCPA & TCPA values or in extended version by utilization of FCTPA method.

An example of MAAs utilization (in its basic form) is presented in Figure 2. There are seven ships, but only three of them are active ones in the auto-negotiation system (Ship 1 is the leader, Ships 2 & 3 are participants). Within the range of the system there is also Ship 4, but due to lack of proper equipment she stays passive and do not contribute to the negotiations (nor sends any informations). Ship 5 is outside the scope of the system, but in near proximity to the Ship 3. Similarly, Ship 6 is outside but near to the Ship 1 and Ship 7 is outside but near to the Ship 2. The red & green circles around Ships 1-3 illustrate their MAAs determined by taking into account all vessels nearby the considered ship. The red MAA regions depict either forbidden (due to COLREGS rules) or undesired new courses, while the green ones – ranges of possible new courses. In the next process step (negotiation of maneuvers) the green and red areas may be slightly changed, as the ships would agree on some tolerance of the own undesired courses. Finally, the determination and optimization part will take care of finding the best set of maneuvering for Ships 1-3 taking into account the agreed (negotiated) possible courses (the green MAA areas). Further research thus will focus on the negotiation, optimization and results' distribution elements of the proposed auto-negotiation system.

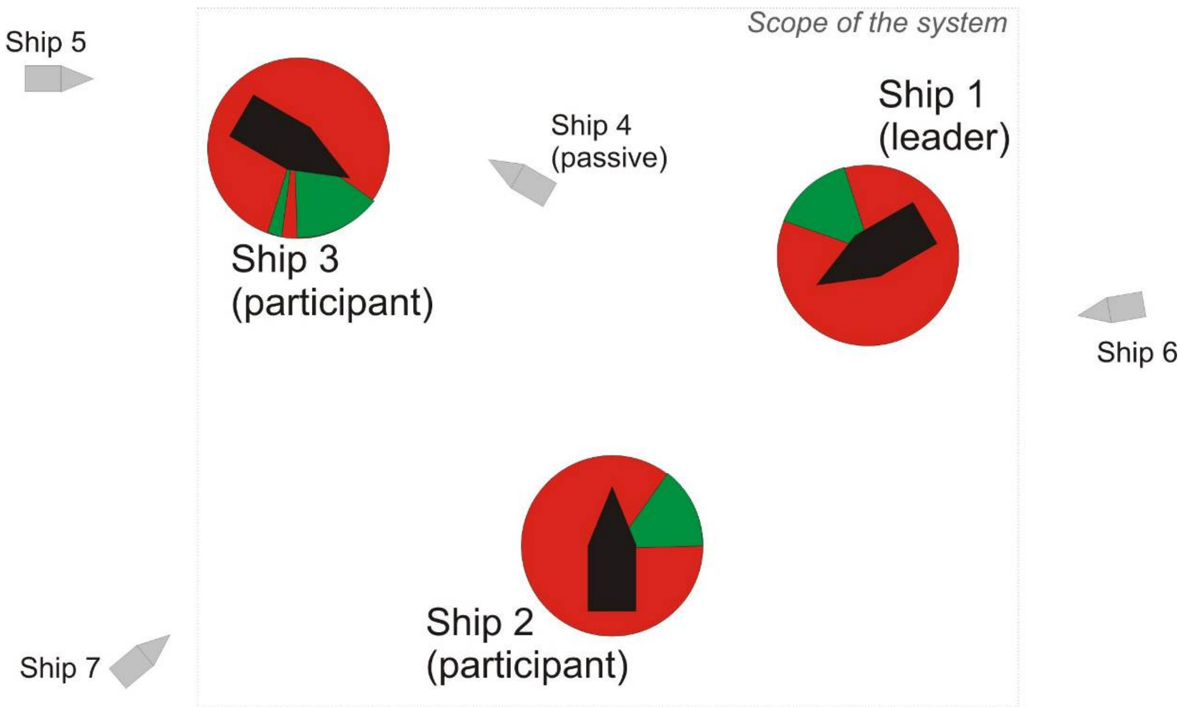

Figure 2. A sample collision situation with MAAs depicted for active ships (Ship 1 – 3) in the manoeuver auto-negotiation system

5 SUMMARY

The manoeuver auto-negotiation approach offers not only obvious improvement in automation of data exchange between ships in an encounter situation, but also may result in increased level of safety. Primarily, the issue of human error in communication is eliminated in this case. It is often that nowadays on international waters navigators that communicate with each other (either directly or via VTS) are not English native speakers. It may result, especially in a stressful situation of an encounter, that some language misunderstandings would cause a collision. However, when designing such a manoeuver auto-negotiation system, one has to be also aware of COLREGS regulations. Only systems obeying these regulations are able to assure proper global level of safety.

The proposal of a manoeuver auto-negotiation system presented in this paper is oriented at designing flexible and robust procedures of automatic ship communication while assuring compliance with COLREGS. After completing the next steps of the research (designing the negotiation, optimization and distribution elements of the system) author aims at developing a system applicable in practice into the navigational world.

REFERENCES

Brcko T., Svetak J., Fuzzy Reasoning as a Base for Collision Avoidance Decision Support System. Promet – Traffic & Transportation, Vol. 25, No. 6, str. 555-564, 2013.

Cheng, X., Liu, Z., Trajectory Optimization for Ship Navigation Safety Using Genetic Annealing Algorithm. ICNC 2007. Third International Conference on Natural Computation. vol. 4, str. 385 – 392, 2007.

COLREGS, Convention on the International Regulations for Preventing Collisions at Sea. International Maritime Organization, 1972 (with amendments on Dec 2009).

Hornauer S., Decentralised Collision Avoidance in a Semi-collaborative Multi-agent System. Multiagent System Technologies, Lecture Notes in Computer Science, Volume 8076, str. 412-415, Springer, 2013.

Hornauer S., Hahn A., Towards Marine Collision Avoidance Based on Automatic Route Exchange. Control Applications in Marine Systems, Volume 9, Part 1, str. 103-107, 2013.

Hu Q., Yang C., Chen H., Xiao B., Planned Route Based Negotiation for Collision Avoidance Between Vessels. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 2, No. 4, str. 363-368, Gdynia Maritime University, 2008.

Ito, M., Feifei Z., Yoshida, N., Collision avoidance control of ship with genetic algorithm. Proceedings of the 1999 IEEE International Conference on Control Applications, vol. 2, str. 1791 – 1796, 1999.

Kolendo P., Śmierzchalski R., Jaworski B., Experimental Research on Evolutionary Path Planning Algorithm with Fitness Function Scaling for Collision Scenarios. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 5, No. 4, str. 489-495, Gdynia Maritime University, 2011.

Lazarowska A., Decision support system for collision avoidance at sea. Polish Maritime Research. Volume 19, Issue Special, str. 19–24, De Gruyter, 2012.

Lenart A.S. 1982. Collision threat parameters for a new radar display and plot technique, The Journal of Navigation vol. 36: pp. 404-410.

Lisowski J., (1985). The analysis of differential game models of safe ship control process. Journal of Shanghai Maritime Institute, Volume 6, No 1, 25-38.

Pietrzykowski, Z. Magaj, J. Chomski, J., A navigational decision support system for sea-going ships. Pomiary, Automatyka, Kontrola, R. 55, nr 10, str. 860-863, Wydawnictwo PAK, 2009.

Statheros T., Howells G., McDonald Maier K., Autonomous Ship Collision Avoidance Navigation Concepts, Technologies and Techniques. The Journal of Navigation, 61(01), str. 129-142, Cambridge University Press, 2008.

Smierzchalski, R., Evolutionary trajectory planning of ships in navigation traffic areas. Journal of Marine Science and Technology, vol. 4, Issue 1, str. 1–6, Springer, 1999.

Szlapczynska J.: Propozycja systemu auto-negocjacji manewrów statków korzystającego z metod optymalizacji wielokryterialnej oraz Matematycznej Teorii Ewidencji (in Polish), Logistyka vol. 6/2014, pp. 10375-10384, 2014.

Szlapczynski R.: Fuzzy Collision Threat Parameters Area (FCTPA) – A New Display Proposal. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 2, No. 4, pp. 359-362, 2008

Szlapczynski R., Solving Multi-Ship Encounter Situations by Evolutionary Sets of Cooperating Trajectories. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 4, No. 2, str. 185-190, Gdynia Maritime University, 2010.

Szlapczynski R., Szlapczynska J., On Evolutionary Computing in Multi-Ship Trajectory Planning. Applied Intelligence, Volume 37, Issue 2, str. 155-174, Springer, 2012.

Tam, C., Bucknall, R., Path-planning algorithm for ships in close-range encounters. Journal of Marine Science and Technology, vol. 15, Issue 4, str.395-407, Springer, 2010.

Tsou, M. C., Hsueh, C. K. The study of ship collision avoidance route planning by ant colony algorithm. Journal of Marine Science and Technology, 18(5), 746–756, Springer, 2010.

Zeng X., Evolution of the safe path for ship navigation. Applied Artificial Intelligence. 17, str. 87–104, Taylor & Francis, 2003.

Zak B., The problems of collision avoidance at sea in the formulation of complex motion principles, Int. J. Appl. Math. Comput. Sci., 2004, Vol. 14, No. 4, pp. 503–514.

WWW_AIS, http://www.aisreporter.com/?news=ais-vulnerabilities-subject-of-scientific-research, web page accessed on 2015.02.01, 2015.