A RESEARCH ON TECHNIQUES, MODELS AND METHODS PROPOSED FOR SHIP COLLISION AVOIDANCE PATH PLANNING PROBLEM

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SUMMARY

The development of soft computing techniques in recent years has encouraged researchers to study on the path planning problem in ship collision avoidance. These techniques have widely been implemented in marine industry and technology-oriented novel solutions have been introduced. Various models, methods and techniques have been proposed to solve the mentioned path planning problem with the aim of preventing reoccurrence of the problem and thus strengthening marine safety as well as providing fuel consumption efficiency. The purpose of this study is to scrutinize the models, methods and technologies proposed to settle the path planning issue in ship collision avoidance. The study also aims to provide certain bibliometric information which develops a literature map of the related field. For this purpose, a thorough literature review has been carried out. The results of the study have pointedly showed that the artificial intelligence methods, fuzzy logic and heuristic algorithms have greatly been used by the researchers who are interested in the related field.

NOMENCLATURE

CPA	Closest Point of Approach
TCPA	Time to Closest Point of Approach
DCPA	Distance to Closest Point of Approach
COLREG	International Regulation for Preventing Collisions at Sea
WoS	Web of Science
ARPA	Automatic Radar Plotting Aid
AIS	Automatic Identification System
OS	Own Ship
TS	Target Ship
f	Frequency
IF	Impact Factor
N/A	Not Available
USV	Unmanned Maritime Surface Vehicle
PC	Computer

1. INTRODUCTION

Over the years, ship navigation has conventionally been carried out thoroughly by human endeavour (Statheros et al., 2008), and it brings some human based errors (Nguyen et al., 2012; Su et al., 2012; Yıldırım et al., 2015; Yıldırım et al., 2017). Nowadays, developing technology has contributed to ship crew for minimizing these errors. These technologies may create some intelligent navigation systems in a close future. These types of systems will provide guidance to navigators and operators in planning optimal collision avoidance route (Statheros et al., 2008). Ships manoeuvres that might lead to substantial risk encounter situation. These matters may be overcome by providing ship handling procedures training. Marine officer's experience relevant with ship handling can play a vital role in safe navigation. On the other hand, they have also some limitations because of economical and human constrains. Besides, well-experienced marine officers might make wrong navigation judgments that can cause collision with human casualties and environmental disasters. For instance, an experienced marine officer can be affected by unexpected inadequacy of ship movement and communication failures under various environmental conditions (Perera et al., 2015). Limiting subjective decision by human in sea navigation and changing them with an intelligent decision-making system can reduce collision at sea (Perera et al., 2011).

Technological developments have led to increase ship traffic that causes navigation to become more difficult for marine officers. Performing navigation at sea is a complicated operation because continually analysing a large amount of data is required and assessing navigational situations improperly can cause to collision situations. In this respect, it is necessary to support marine officers in collision avoidance decision-making process (Lazarowska, 2012). If decision support systems are utilized the decision-making process in an encounter situation, human originated errors, resulting from subjective judgment, can be decreased and sea navigational safety can be improved (Tsou and Hsueh, 2010).

Collision avoidance process is a multi-criteria and non-linear programming problem and there has also to be equilibrium between navigational safety and economy simultaneously (Smierzchalski and Michalewicz, 2000). In other words, the collision avoidance process should not only keep on the danger assessment and action to avoid collision but also take into consideration optimizing the amount of yaw from the original trajectory (Su et al., 2012). In recent years, the optimization methods to solve ship encounter situation and ship collision avoidance planning problem proposed by researchers have increased and the field has become a popular subject. In this respect, the study aims to look over the methods in the literature proposed to solve ship collision avoidance path planning problem.

Review articles recently introduced by Tam et al. (2009) and Statheros et al. (2008) discussed published papers on autonomous ship navigation and encounter situation methods for ship particularly in close range encounters. The main difference of our study from these studies is the idea that our study reviews and discusses the related articles in four subtitles according to their approach types and gives bibliometric information without any time interval constraint.

2. THE PRINCIPLE AND PROCEDURE OF SHIP COLLISION AVOIDANCE

One of the most important safety issue for a vessel at sea is the risk of collision with other ships or objects that endangers sea navigation. The ship crew has the highest priorities to be sure of such a risk to be minimized. The officer on watch is responsible for this task by observing the environment around the vessel and advising the other crew on board (Ward and Leighton, 2010).

The data such as course, speed, ship position, Time to Closest Point of Approach (TCPA), Distance to Closest Point of Approach (DCPA), weather information provided from navigation equipment located on the bridge is crucial for the ship domain calculation and determination of a collision avoidance model. The encounter situation at sea is regulated by the International Regulations for Preventing Collisions at Sea (COLREG) for deciding the state of encounter for the give-way vessel and stand-on vessel. If the vessel is the give-way vessel that should act to avoid collision, recommendation of collision avoidance route by a decision support system is crucial for navigators and operators. This might be changeable due to different task phases, the trajectory solution to avoid collision can be divided into four phases (Tsou and Hsueh, 2010);

a. *Cruising Phase:* In this phase, the system is in alert and search condition continually. The alert range is set throughout collision avoidance considering the current navigation environment and ship safety domain size.
b. *Initial Warning Phase:* The phase consists of two steps as collision avoidance alert encountered by a single target ship and multiple target ships. For former one, if a target ship gets into the observation range, the encounter state and collision risk is determined. If there is a collision risk with target ship (CPA less than the safety domain) and the give-way vessel is an own vessel, route planning to avoid collision will be proceeded. On the other hand, when there are lots of targets in the vicinity, the encounter state and collision risk are determined for each ship. Then, the CPA for each target ship is calculated. If CPA is less than the safety domain, it is assumed to be a risk of collision. The target ship with the smallest TCPA has the highest risk of collision. This target ship is the first ship to be avoided (Davis et al., 1982 as cited in Tsou and Hsueh, 2010).
c. *Collision Avoidance Navigation Phase:* The small alterations of route for collision avoidance trajectory should be avoided, so the target ship is able to perceive the intention of the own ship (COLREG rule 8b). On the other hand, it should not be so large to prevent yawing too much from the original route.
d. *Return to Original Route Phase:* While deciding to return to the original route after collision avoidance is achieved, it needs to be made sure that the return course will not result any other collision risk.

3. METHODOLOGY

The purpose of making a literature review is often to evaluate and to map the existing literature to identify and to highlight the limit and boundaries of related literature (Tranfield et al., 2003). Literature reviews are applied into steps and categories in order to conduct systematic and transparent evaluation as an effective tool. For example, Seuring and Gold (2012) conducted their study in four steps such as material collection, descriptive analysis, category selection and material evaluation. In another study, Davarzani et al. (2016), inspired by Seuring and Gold (2012) and Rowley and Slack (2004), formed their study with the steps of identifying appropriate search terms, evaluating search results and generating bibliometric statistics, network and literature map (Fışkın and Bitiktaş, 2016).

This study basically comprises four steps. In the first step, appropriate search terms were determined, and initial results were evaluated regarding to the subject. In the second step, the proposed approaches were divided into categories according to their types. In the third stage, bibliometric statistics and literature map were presented. Finally, in the last stage, the findings were evaluated and conclusion and discussion about the findings were conducted. This study, covering a period of 41 years from 1976 to 2017, utilized some search engines such as Scopus, Google Scholar, Dokuz Eylül University Library Search Engine, Science Direct, WoS to reach existing studies in related literature. *The searching terms were defined as following: ("ship" OR "maritime" OR "marine" OR "USV" OR "vessel") AND ("route" OR "trajectory" OR "path" OR "encounter" OR "safe" OR "intelligent") AND ("collision" OR "avoidance" OR "guidance" OR "decision support" OR "decision making" OR "autonomous" OR "automatic") AND ("planning" OR "optimal" OR "optimization" OR "optimisation").* Besides, the reference lists of the accessed studies were examined, and the related studies were also obtained. As a result, a total of 180 published papers about the topic were reached. Master and PhD dissertations, notes, unpublished papers, news, reviews and analysis were excluded from the scope of the study. For this purpose, the following steps were followed to design an effective search process:

- identification and structure of searching terms,
- control of accessed papers regarding the scope of the study,

- selection of appropriate papers.

The selection criteria and evaluation framework applied in the study are given in Figure 1 in detail.

Contribution of each author, institution and country was analysed quantitatively and ranked using the model created by Howard et al. (1987). Single authored papers allocated to the author a single unit of point. In multi-authored papers, point was allocated to the authors proportionally according to equation (1):

$$\text{Score} = \frac{\left(1.5^{n-1}\right)}{\sum_{i=1}^{n} 1.5^{n-1}} \qquad (1)$$

where n is the total number of authors and i is the specific author's ordinal position. Therefore, for example, in a co-authored paper 0.60 point was given to the first author; the second author in a three-authored paper was given to 0.32 points and so on. By this model, the accumulated productivity score for each author, institution and country was calculated to reveal the contribution map of the related literature. The model was also recently implemented and used by researchers (such as Tsai and Wen, 2005; Fışkın and Nas, 2013; Yi and Chan, 2014; Greenbaum et al., 2016) in the literature.

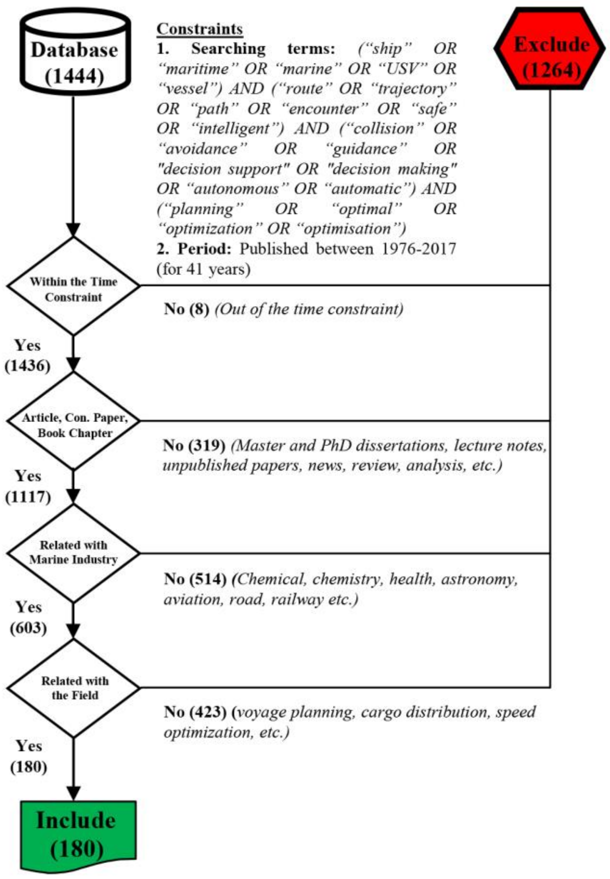

Figure 1. Selection criteria and evaluation framework.

4. THE TECHNIQUES, MODELS AND METHODS PROPOSED TO SOLVE SHIP COLLISION AVOIDANCE PATH PLANNING PROBLEM

The accident occurring in marine industry can lead to casualty, enormous entity loss and sea pollution. The related field researches have concentrated on anti-collision systems for maritime navigation especially in the last decade. Such problem has become a popular topic within the field and many methods and models have been proposed by researchers. The problem is the development of the systems that will take efficient action to avoid collision in compliance with the COLREGs. Additionally, development of the systems mimicking the behaviour of experienced navigators that can avoid collision automatically has come in the focus of the recent research. In case of encounter situation at sea, Automatic Radar Plotting Aid (ARPA) located on ships provides assistance to navigator. The aid reports that there is a potential collision risk between the ships (Chen et al., 2010), it cannot, however, propose any optimal manoeuvre to avoid collision. But, it has trail manoeuvre feature to simulate the effect on all tracked targets. The feature has been adopted by IMO in Resolution A.823(19) Performance Standards for Automatic Radar Plotting Aids (SOLAS Reg V/12). According to the resolution, the ARPA should be able to simulate the trajectories of all tracked targets and own ship (IMO, 1995).

In related literature, there have been many methods, techniques and models proposed to solve ship encounter situation. These approaches can be divided into four main subtitles as *deterministic approaches, artificial intelligence approaches, hybrid systems,* and *simulation approaches*.

Deterministic approaches refer to certain mathematical definition of navigation environment. This type of approaches (Tam and Bucknall, 2013; Szlapczynski, 2008; Szlapczynski, 2007; Yavin et al., 1997) utilizes a precise description to solve ship encounter situation problem. These algorithms are important in terms of providing exact and same solutions compared to heuristic algorithms, but the calculation of a solution may take a long time.

Artificial intelligence approaches comprise primarily fuzzy logic (Zadeh, 1965) (Grinyak and Devyatisil'nyi, 2016; Su et al., 2012; Perera et al., 2011; Lee et al., 2015; Perera et al., 2009), stochastic and heuristic approaches (Hao et al., 2007; Tsou et al., 2010; Cheng et al., 2007; Lazarowska, 2015b; Lazarowska, 2014a), and neural networks (Simsir et al., 2014; Lisowski, 2000). These types of algorithms can make complicated problem easier by means of their high computational efficiency and learning capacities. The computational time is shorter than deterministic approaches, but it usually provides a sub-optimal solution rather than an exact solution.

Hybrid systems to solve related problem (Perera et al., 2015; Zhuo and Hearn, 2008; Ying et al., 2007; Mohamed-Seghir, 2012a) propose a combination of the methods mentioned above. Neuro-Fuzzy, Fuzzy-Bayesian and Bayesian-Genetic algorithms are mostly implemented methods to solve the problem.

Simulation based approaches can provide a useful platform for optimal collision avoidance decision making (Liu et al., 2007b). The approaches which are significant in modelling and simulating system are generally based on multi-agent (Liu et al., 2007b; Liu et al., 2006a; Robert et al., 2003; Liu et al., 2008). Other type simulation based approaches (Itoh et al., 2003; Johansen et al., 2016a; Yang et al., 2006; Yang et al., 2007) apart from multi-agent based are also implemented to simulate ship collision avoidance decision-making problem.

Methods, models and techniques proposed to solve related problem according to their approach types are listed in Table 1.

Table 1. Distribution of articles according to the approach type.

Approach Type	Solution Method	Main Topic	References
Artificial Intelligence	Fuzzy Logic	A fuzzy based decision-making system	Grinyak and Devyatisil'nyi, 2016; Su et al., 2012; Perera et al., 2011; Lee et al., 2015; Perera et al., 2009; Kao et al., 2007a; Pietrzykowski and Chomski, 2003; Hwang, 2002; Hwang et al., 2001; Perera et al., 2010b; Hasegawa and Kouzuki, 1987; Kijima and Furukawa, 2002; Hara and Hammer, 1993; Rhee and Lee, 1996; You et al., 2013; Brcko et al., 2013; Pietrzykowski et al., 2010; Kao et al., 2007b; Mohamed-Seghir, 2017; Mohamed-Seghir, 2016
		Ontology-based fuzzy support system	Park et al., 2007
		Structure design for navigation collision avoidance	Liu and Yang, 2004
		Intelligent control system for collision avoidance	Shtay and Gharib, 2009; Feng and Li, 2012
		Fuzzy logic based autonomous collision avoidance	Lee, S. M. et al., 2004; Lee and Kim, 2004; Wen et al., 2016; Mao et al., 2015
	Bacterial Foraging Algorithm	To plan the dynamic collision avoidance process of ships	Hongdan et al., 2015a
		Tool for optimal collision avoidance strategy	Nguyen et al., 2012
		Optimization of ship collision avoidance	Ma and Yang, 2013
	Trajectory Base Algorithm	Trajectory base method for collision avoidance	Lazarowska, 2016
	Linear Extension Algorithm	A distributed anti-collision decision supporting formulation in multi-ship encounter situations	Zhang et al., 2015
	Cat Swarm Biological Algorithm	Heuristic algorithm based collision avoidance action	Wei et al., 2015
	Genetic Algorithm	Multi-objective route optimization for onboard decision support system	Hao et al., 2007; Xu et al., 2014; Vettor and Guedes Soares, 2014
		Heuristic algorithm based safe ship trajectory planning	Tsou et al., 2010; Cheng et al., 2007; Zeng, 2003; Zeng and Ito, 2001; Zeng et al., 2000a; Zeng et al., 2000b; Ito et al., 1999; Cheng and Liu, 2006; Fan et al., 2016; Zeng et al., 2001; Hornauer and Hahn, 2013
	Evolutionary Algorithm	Modelling of ship trajectory in collision situations	Smierzchalski and Michalewicz, 2000; Kolendo and Smierzchalski, 2015; Szlapczynski, 2011; Smierzchalski, 1999; Smierzchalski and Michalewicz, 1998; Smierzchalski, 2003; Kaminski and

			Smierzchalski, 2001; Kuczkowski and Smierzchalski, 2014; Tsou, 2016; Kuczkowski and Smierzchalski, 2017; Szlapczynski and Szlapczynska, 2012; Tam and Bucknall, 2010; Szlapczynski, 2009
	Ant Colony Algorithm	Heuristic algorithm based safe ship trajectory planning	Lazarowska, 2015b; Lazarowska, 2014a; Lazarowska, 2015a; Lazarowska, 2012; Lazarowska, 2015c; Lazarowska, 2015d; Tsou and Hsueh, 2010; He and Qi, 2007; Lazarowska, 2013; Lazarowska, 2014b; Escario et al., 2012
	Wolf Colony Search Algorithm	Heuristic algorithm based ship collision avoidance	Hongdan et al., 2015b
	Danger Immune Algorithm	Intelligent optimization algorithm based collision avoidance strategy	Xu, 2014; Yiming et al., 2012
	Artificial Neural Network	Decision support guidance for strait passing vessels	Simsir et al., 2014; Lisowski, 2000
	Game Control	Game control method in ship collision avoidance	Lisowski, 2012; Olsder and Walter, 1978; Lisowski, 2008; Miloh and Pachter, 1989; Lisowski, 2005; Lisowski, 2001; Lisowski, 2013a; Lisowski, 2013b
		Searching optimal collision avoidance route	Chang et al., 2003
	Modified Gaussian Mixture Model	Intelligent ship bridge collision avoidance	Zhang and Zheng, 2011
		Intelligent decision-making for vessel collision avoidance	Chen et al., 2010
		Ship trajectory control optimization in anti-collision manoeuvring	Zhang et al., 2013
		Automatic trajectory planning and collision avoidance	Xue et al., 2008
	Expert System	Method for personifying intelligent decision making for collision avoidance	Li et al., 2008
		Expert systems approach to collision avoidance	Li et al., 2003; Koyama and Yan, 1987
	Artificial Fish Swarm Algorithm	Decision support for collision avoidance	Ma et al., 2014a; Li and Ma, 2016
	Simulated Annealing Algorithm	Turning angle to avoid collision	Liu et al., 2007a
	Artificial Potential Field	Ship auto collision avoidance system	Zhong et al., 2008; Xue et al, 2012; Zhang and Shi; 2007; Wei and Xue, 2013 ; Wang, T. et al., 2017
	Tabu Search Algorithm	Heuristic algorithm based ship collision avoidance	Kim et al., 2015; Kim et al., 2017
	A* Algorithm	Trajectory planning for collision avoidance	Hornauer et al., 2015; Blaich et al., 2012a; Campbell and Naeem, 2012; Ma et al., 2014b; Naeem et al., 2012; Blaich et al., 2015; Zhang, 2013; Yang et al., 2012
	Lee's Algorithm	Extended grid based collision avoidance	Blaich et al., 2012b
	Differential Evolution	Generating optimal ship collision route	Zhao et al., 2014
	Particle Swarm Optimization	Decision support for encounter situation	Wang, K. et al., 2017; Chen and Huang, 2012
Hybrid Systems	Artificial Neural Network, Fuzzy Logic	Collision avoidance of ship manoeuvres by intelligent guidance	Perera et al., 2015; Zhuo and Hearn, 2008; Zhuo and Tang, 2008
		Expert system for path collision avoidance	Ahn et al., 2012
		The design of a fuzzy-neural	Liu et al., 2006b; Liu and Shi, 2005; Hiraga et al., 1995

		network for ship collision avoidance	
		Autonomous ship collision free trajectory navigation	Hong et al., 1999; Harris et al., 1999
	Fuzzy-Bayesian	Collision avoidance decision action model	Perera et al., 2012; Perera et al., 2010a
	Particle Swarm Optimization, Fuzzy Logic	Intelligent collision avoidance control approach for large ships	Zhuo and Hasegawa, 2014
	Bayesian Genetic Algorithm	Ship route designing for collision avoidance	Ying et al., 2007
	A* Search Algorithm, Fuzzy Logic	Expert system and search algorithm based collision avoidance system	Lee and Rhee, 2001
	Game Theory, Artificial Neural Network	Safe control in collision situation at sea	Lisowski, 2016; Lisowski, 2014; Lisowski, 2010; Lisowski, 2007;
	Particle Swarm Optimization, Bacterial Foraging Algorithm	Dynamic collision avoidance optimization	Hongdan et al., 2014; Liu et al., 2016
	Genetic Algorithm, Fuzzy Logic	Optimal safe ship trajectory in a collision situation	Mohamed-Seghir, 2012a
	Genetic Annealing Algorithm	Ship dynamic collision avoidance space model	Cheng and Liu, 2007
	Immune Particle Swarm Algorithm	Collision avoidance of ship manoeuvres by intelligent guidance	Tian and Pan, 2011
	Branch and Bound Method, Fuzzy Logic, Genetic Algorithm	Safe ship trajectory in fuzzy environment	Mohamed-Seghir, 1995; Mohamed-Seghir, 2014; Mohamed-Seghir, 2012b
	Analytic Hierarchy Process, Artificial Neural Network	Collision avoidance in complex water area	Wang, et al., 2016
Deterministic	Deterministic Solution Model	Cooperative path planning algorithm	Tam and Bucknall, 2013
		Planning collision avoidance manoeuvres for multi target encounter situation	Szlapczynski, 2008; Lazarowska, 2017
		Finding course alteration manoeuvre in a multi-target encounter situation	Szlapczynski, 2007; Johansen et al., 2016b
		Computation of feasible command strategies	Yavin et al., 1997
		Optimal control of a ship for collision avoidance manoeuvres	Miele et al., 1999; Miele and Wang, 2005; Miele and Wang, 2004; Kayano and Imazu, 2009; Wit and Oppe; 1979; Miele and Wang, 2006
		Methods to assign the safe trajectory avoiding collision	Lisowski and Smierzchalski, 1995
		Optimal turn manoeuvres for collision avoidance	Merz and Karmarkar, 1976
		Collision avoidance mechanism of ships at sea	Bi and Liu, 2015
		Modelling collision avoidance decisions support	Wang et al., 2010; Kwik, 1989; Curtis, 1986
		A negotiation framework for automatic collision avoidance	Qinyou et al., 2006

		The timing of collision avoidance manoeuvres	James, 1994
		Collision avoidance algorithm for USV	Oh et al, 2014
		Ship domain based collision avoidance	Chen et al., 2017
		Dynamic support system in close-quarters situation	Wang, X. et al., 2017
Simulation	Multi-Agent Information Fusion Model	Information fusion methods based ship collision avoidance model	Liu et al., 2008
	Multiagent-Based Simulation System	Multiagent-based simulation system for the decision-making	Liu et al., 2007b
		Direct perception interface for ship-ship collision avoidance	Liu et al., 2006a
		Cognitive demands of collision avoidance in simulated ship control	Robert et al., 2003
	Visualization-Based Simulation System	Visualization-based collision avoidance support system	Itoh et al., 2003
	Simulation-Based Model	Collision avoidance using simulation based control behaviour selection	Johansen et al., 2016a
		Analysing and assessment of manoeuvring for avoiding collision	Kumagai et al., 2012; Pedersen et al., 2003
		Finding safe passage for ships in collision situations	Xue et al., 2011
		The AIS assisted collision avoidance	Hsu et al., 2009
		CPA simulation model for automatic collision avoidance	Zhao et al., 1994; Svetak and Jakomin, 2005
		Construction of simulation platform	Yang et al., 2006; Yang et al., 2007
		Knowledge acquisition for collision avoidance	Hammer and Hara, 1990

5. BIBLIOMETRIC STATISTICS

5.1 AUTHORS AND AFFILIATIONS STATISTICS

Countries, authors, and institutions were selected from the data file, appearance frequency of them was recorded and productivity score was calculated using the method described in detail in methodology section. It was found that a total of 293 different authors from 92 different institutions and 24 different countries contributed to the related field. Table 2 shows the top ten most prolific authors, institutions and countries based on the productivity score. *Lisowski, J*. from Poland is the most prolific author with the score of 11.60 within a total of 293 different authors. *Lazarowska, A*. form Poland and *Mohamed-Seghir, M*. from Poland follow *Lisowski, J*. with the score of 10.00 and 6.00, respectively. The affiliations of the authors were selected from data file and statistical analysis was conducted. The city, where the institution is located, was obtained and the geographical location of the institutions contributing to related field was shown using the coordinates of these cities in *gpsvisualizer.com* as shown in Figure 2. The size of the circles represents the contribution level of each institution. It was revealed that the major density of contributing institutions was in North-western Europe and Eastern Asia. The statistics of the contributing countries, as seen in Table 2, shows that the *China* dominates the related research field by holding the highest productivity score which is 52.91. In terms of institutions, however, *Gdynia Maritime University* located in Poland is the most prolific institution with the score of 32.60.

Figure 2. The geographical dispersion of contributing institutions.

Table 2. Top contributing countries, institutions and authors.

Country Contributing Score		**Institution Contributing Score**			**Author Contributing Score**			
Country	**Score**	**Institution**	**Country**	**Score**	**Author**	**Country**	**f**	**Score**
China	52.91	Gdynia Maritime University	Poland	32.60	Lisowski, J.	Poland	12	11.60
Poland	43.00	Wuhan University of Technology	China	9.86	Lazarowska, A.	Poland	10	10.00
Japan	16.61	Dalian Maritime University	China	8.90	Mohamed-Seghir, M.	Poland	6	6.00
Taiwan	10.21	Shanghai Maritime University	China	8.63	Smierzchalski, R.	Poland	9	5.20
UK	11.54	Gdansk University of Technology	Poland	7.60	Szlapczynski, R.	Poland	5	4.60
South Korea	7.00	Technical University of Lisbon	Portugal	7.49	Liu, Y. H.	China	6	3.08
Portugal	7.49	Harbin Engineering University	China	7.07	Zeng, X. M.	Japan	5	3.01
Germany	6.05	Tokyo University of Mercantile Marine	Japan	6.00	Perera, L. P.	Portugal	6	2.73
USA	4.21	National Taiwan Ocean University	Taiwan	5.19	Miele, A.	USA	4	2.22
Netherlands	2.73	Jimei University	China	4.00	Tsou, M. C.	Taiwan	3	2.07
		Rice University	USA	4.00				

5.2 OTHER FUNDAMENTAL STATISTICS

An in-depth analysis was conducted to reveal the most frequent words used in the list of keywords, to determine the solution methods which were implemented to solve the related problem, the type of publication, and the approach type which was basically adopted in the articles. The results of the analysis are shown in Table 3 and Table 4 in detail. As seen in these tables, *Collision Avoidance* was the most frequently used keyword in the articles from a pool of 237 different keywords. Additionally, *Path Planning*, *Ship Collision Avoidance* and *COLREGs* were also commonly used by the authors as keywords in their studies. On the other hand, it was revealed that *Fuzzy Logic* was the most frequently applied solution method, the studies were mostly published in article type, *The Journal of Navigation* was the dominant publication media from a pool of 129 different journals and conference proceedings, and the *Artificial Intelligence* was basically adopted by authors in the studies as an approach type.

The dispersion of publications in each year was shown in Figure 3. Most of the publications were published in the last fifteen years in the 1976 – 2017 periods. Especially, the significant growth was more notable after 1999. Approximately, 80% of the studies were published after that year, but the diagram has showed a rolling graph over the years.

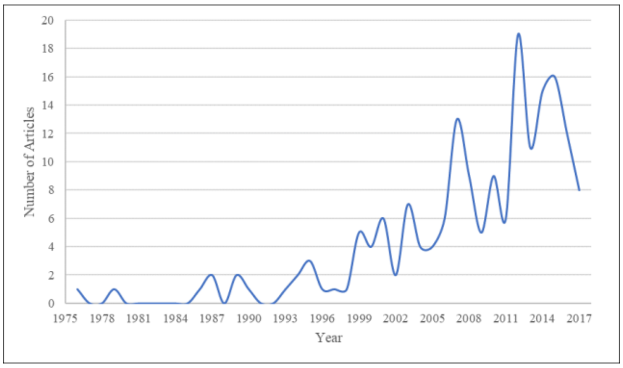

Figure 3. Dispersion of published articles by years.

Table 3. The statistical distribution of solution methods, keywords, publication types.

Solution Method	**f**	**%**	**Keyword**	**f**	**%**	**Publication Type**	**f**	**%**
Fuzzy Logic	45	18.7	Collision Avoidance	58	10.0	Article	94	52.2
Deterministic Solution Model	21	8.7	Path Planning	18	3.1	Conference Paper	78	43.3
Genetic Algorithm	19	7.9	Ship Collision Avoidance	16	2.8	Book Chapter	8	4.5
Artificial Neural Network	16	6.6	COLREGs	12	2.1	Total	180	100
Evolutionary Algorithm	14	5.8	Genetic Algorithm	10	1.7			
Game Theory	12	5.0	Ant Colony Optimization	9	1.6			
Ant Colony Optimization	11	4.6	Decision Support System	9	1.6			
Simulation-Based Model	10	4.1	Safe Ship Control	8	1.4			
Game Control	9	3.7	Evolutionary Algorithm	8	1.4			
A* Algorithm	9	3.7	Fuzzy Logic	7	1.2			
Particle Swarm Algorithm	6	2.5	Ship Navigation	7	1.2			
Bacterial Foraging Algorithm	5	2.1	Simulation	6	1.0			
Expert System	3	1.2	Others	409	71.5			
Others	61	25.3	Total	580	100			
Total	241	100						

Table 4. The statistical distribution of journals/conferences and approach types.

Journal / Conference	**f**	**%**	**Approach Type**	**f**	**%**
The Journal of Navigation (IF: 1,586)	12	6.7	Artificial Intelligence	116	64.4
Ocean Engineering (IF: 1,894)	6	3.3	Hybrid System	26	14.4
TransNav Journal (IF: N/A)	5	2.8	Deterministic	23	12.8
Journal of Optimization Theory and Applications (IF: 1,160)	5	2.8	Simulation	15	8.3
Journal of Marine Science and Technology (IF: 0,838)	5	2.8	Total	180	100
Maritime Research (IF: 0,776)	5	2.8			
International Conference on Machine Learning and Cybernetics	3	1.7			
International Conference on Knowledge Based and Intelligent Information and Engineering Systems Polish	3	1.7			
Navigation of China (IF: N/A)	3	1.7			
Journal of Oceanic Engineering (IF: 2,297)	2	1.1			
Others	131	72.8			
Total	180	100			

6. DISCUSSION

The deterministic approaches have the advantage of providing accurate and optimal results, but, generally, the longer-term solution process, comparing to heuristic algorithms, weakens real-time applicability, which is crucial for collision avoidance problem. The recent study introduced by Lazarowska (2017), however, showed that the deterministic based algorithm could also return more optimal solution in a shorter time than heuristic based method such as Ant Colony Optimization (ACO). When comparing the model with another deterministic model developed by Tam and Bucknall (2013) in terms of computational time, the former one returned the optimal solution in 1.77 second and the latter one returned 7.0 second, respectively, using the same processor PC for the similar scenarios (5 encounter ships cases). On the other hand, ACO and Genetic Algorithm (GA) based heuristic model proposed by Tsou et al. (2010) revealed through the experiments that ACO provided better results than GA. Hongdan et al. (2015a), Hongdan et al. (2015b) and Hongdan et al. (2014) proposed heuristic models based on Quantum Bacterial Foraging Algorithm (QBFA), Adaptive Wolf Colony Search Algorithm (AWSA) and Particle Swarm Optimization (PSO) based BFA to compare to each of them with BFA. The experimental results showed that the all of them outperformed than BFA in respect to both execution time and execution efficiency. The fuzzy logic method also implemented by researchers, especially to create a hybrid solution method by combining with other algorithms. Artificial Neural Network (ANN), GA, PSO, A* Algorithm were algorithms typically used for this purpose. Ahn et al. (2012), for example, proposed the neuro-fuzzy algorithm applied for developing the simply designed fuzzy system to deduce the enviable results, contentedly. The study revealed that the redesigned system was more practical and realistic than ordinary fuzzy inference system. This type of algorithms increased the performance of the execution efficiency.

In conclusion, the artificial intelligence approach has the advantage of real-time applicability due to short-term solution process but provides near optimal results rather than accurate and exact results. An integration of approaches such as fuzzy logic, neural network, GA, etc., which is called hybrid systems approaches, can constitute a ship collision avoidance intelligent system and had an advantage regarding execution efficiency. This type of approach will provide substantial contribution for the collision avoidance problem. The integration of the algortihm to create hybrid model, however, should be done well to get reliable and useful results. Deterministic approaches can provide exact and accurate solution, but execution process may take a long time. Simulation based algorithms can mimic the system to provide information about its behaviour, but detailed simulation structure may be toilsome regarding resources and time.

7. CONCLUSION

Research on ship collision avoidance route planning problem has begun to appear since the 1970s with the introduction of COLREGs. The problem has become a crucial research field with the increasing quantity of published articles, especially since 1999. In this respect, the study contributes to revealing the developments in the field via investigating solution methods and approach types used in the studies as well as providing authors, affiliations, publication types and keywords statistics.

Ship collision avoidance route planning problem stands as a complicated topic and the related literature shows that many methods and models have been proposed to solve this problem. Especially fuzzy logic, heuristic and artificial intelligence optimization methods are used to form a model for the related problem. Deterministic approaches and hybrid systems are also used but not as much as previously mentioned ones. It is revealed that most of the models have considered the COLREGs, while forming the algorithm structure but some others have ignored it. On the other hand, most of the models have used the terminology to define the ship that is operated by avoider and the ship to be avoided as own ship (OS) and target ship (TS), respectively. The geographical dispersion of the institutions shows that the ship collision avoidance and path planning optimization problem have attracted the research institutions from various parts of the world with several contributions especially from academicians and researchers in North-western Europe and Eastern Asia.

In this paper, various techniques, models and methods proposed to solve ship collision avoidance are briefly explained. In conclusion, intelligent collision avoidance systems will undoubtedly be beneficial for safe navigation as well as efficiency of fuel consumption by optimizing the route of ships and they will have a vital role in unmanned and autonomous ships.

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9. REFERENCES

1. AHN, J. H., RHEE, K. P. and YOU, Y. J. (2012). A Study on the Collision Avoidance of a Ship Using Neural Networks and Fuzzy Logic. *Applied Ocean Research,* 37, 162-173.
2. BI, X. and LIU, X. (2015). Research on Double Collision Avoidance Mechanism of Ships at Sea. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 9(1), 13-16.

3. BLAICH, M., KÖHLER, S., REUTER, J. and HAHN, A. (2015). Probabilistic Collision Avoidance for Vessels. *IFAC-PapersOnLine*, 48(16), 69-74.
4. BLAICH, M., ROSENFELDER, M., SCHUSTER, M., BITTEL, O. and REUTER, J. (2012a). Fast Grid Based Collision Avoidance for Vessels Using A* Search Algorithm. *In 17th International Conference on Methods and Models in Automation and Robotics,* 385-390
5. BLAICH, M., ROSENFELDER, M., SCHUSTER, M., BITTEL, O. and REUTER, J. (2012b). Extended Grid Based Collision Avoidance Considering COLREGs for Vessels. *9th IFAC Conference on Manoeuvring and Control Marine Craft,* 45(27), 416-421.
6. BRCKO, T., DIMC, F. and SVETAK, J. (2013). On Testing the Fuzzy Logic Approach in Anti-Collision at Sea Decision Making. *GNSS Vulnerabilities and Solutions Conference*, 37-52.
7. CAMPBELL, S. and NAEEM, W. (2012). A Rule-Based Heuristic Method for COLREGs-Compliant Collision Avoidance for an Unmanned Surface Vehicle. *IFAC Proceedings Volumes,* 45(27), 386-391.
8. CHANG, K. Y., JAN, G. E. and PARBERRY, I. (2003). A Method for Searching Optimal Routes with Collision Avoidance on Raster Charts. *The Journal of Navigation*, 56(3), 371-384.
9. CHEN, G., LI, L., YIN, Y. and YANG, S. (2010). Mechanism and Simulation of Personifying Intelligent Decision-making for Vessel Collision Avoidance. *2010 International Conference on Computer Application and System Modelling*.
10. CHEN, L. J. and HUANG, L. W. (2012). Ship Collision Avoidance Path Planning by PSO Based on Maneuvering Equation. *Future Computing, Communication, Control and Management,* 675-682.
11. CHEN, Y., YANG, J., ZHANG, Q., GUO, F. and LIU, Y. (2017). Ship Collision Avoidance on the Basis of 3-d Model. *International Conference on Intelligent Transportation Engineering (ICITE),* (pp. 309-313). IEEE.
12. CHENG, X. D and LIU, Z. Y. (2007). Trajectory Optimization for Ship Navigation Safety Using Genetic Annealing Algorithm. *In Third International Conference on Natural Computation*, 4, 385-392.
13. CHENG, X. D. and LIU, Z. Y. (2006). Study on Ship Collision Avoidance Trajectory Optimization in Inland Waterways with Genetic Algorithm. *Navigation of China*, 67(2), 38-46.
14. CHENG, X. D., LIU, Z. Y. and ZHANG, X. T. (2007). Trajectory Optimization for Ship Collision Avoidance System Using Genetic Algorithm. *IEEE In OCEANS 2006-Asia Pacific*, 1-5.
15. CURTIS, R. G. (1986). A Ship Collision Model for Overtaking. *Journal of the Operational Research Society*, 37(4), 397-406.
16. DAVARZANI, H., FAHIMNIA, B., BELL, M. and SARKIS, J. (2016). Greening Ports and Maritime Logistics: A Review. *Transportation Research Part D: Transport and Environment*, 48, 473-487.
17. DAVIS, P. V., DOVE, M. J. and STOCKEL, C. T. (1982). A Computer Simulation of Multi-Ship Encounters. *The Journal of Navigation*, 35(2), 347-352.
18. ESCARIO, J. B., JIMENEZ, J. F. and GIRON-SIERRA, J. M. (2012). Optimization of Autonomous Ship Maneuvers Applying Ant Colony Optimization Metaheuristic. *Expert System with Applications*, 39, 10120-10139.
19. FAN, Y., SUN, X., WANG, G. and ZHAO, Y. (2016). On evolutionary genetic algorithm in path planning for a USV collision avoidance. *Express Letters*, 10(7), 1691-1696.
20. FENG, M. and LI, Y. (2012). Ship Intelligent Collision Avoidance Based on Maritime Police Warships Simulation System. *In Electrical & Electronics Engineering (EEESYM)*, (pp. 293-296). IEEE.
21. FIŞKIN, R. and BITIKTAŞ, F. (2016). A Research on Models Proposed for Quay Crane Scheduling Problem in Container Terminals. *1st International Congress on Ship and Marine Technology*.
22. FIŞKIN, R. and NAS, S. (2013). A Content Analysis of the "International Journal on Marine Navigation and Safety of Sea Transportation" from 2007 to 2012. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 7(1), 145-149.
23. GREENBAUM, H., MEYER, L., SMITH, M. C., BARBER, A., HENDERSON, H., RIEL, D. and ROBINSON, D. H. (2016). Individual and Institutional Productivity in Educational Psychology Journals from 2009 to 2014. *Educational Psychology Review*, 28(2), 215-223.
24. GRINYAK, V. M. and DEVYATISIL'NYI, A. S. (2016). Fuzzy Collision Avoidance System for Ships. *Journal of Computer and Systems Sciences International*, 55(2), 249–259.
25. HAMMER, A. and HARA, K. (1990). Knowledge Acquisition for Collision Avoidance Maneuver by Ship Handling Simulator, *International Conference on Marine Simulation and Ship Maneuverability*, 245-252.
26. HAO, J. L., ZHAO, L. N., HU, J. F. and YANG, X. B. (2007). Decision-Making Model for Multi-Ship Collision Avoidance Based on Adaptive Genetic Algorithm. *In International Conference on Transportation Engineering*, 606-611.

27. HARA, K. and HAMMER, A. (1993). A Safe Way of Collision Avoidance Maneuver Based on Maneuvering Standard Using Fuzzy Reasoning Model. In International Conference on Marine Simulation and Ship Maneuverability, 1, 163-170.
28. HARRIS, C. J., HONG, X. and WILSON, P. A. (1999). An Intelligent Guidance and Control System for Ship Obstacle Avoidance. *Journal of Systems and Control Engineering*, 213(14), 311-320.
29. HASEGAWA, K. and KOUZUKI, A. (1987). Automatic Collision Avoidance System for Ships Using Fuzzy Control. *Journal of the Kansai Society of Naval Architects*, 205.
30. HE, Z. J. and QI, L. (2007). Research of a Method for AUV to Avoid Collision with Moving Obstacles Based on Ant Colony Algorithm. *Ship Science and Technology*, 6(2007): 86-89.
31. HIRAGA, I., FURUHASHI, T., UCHIKAWA, Y. and NAKAYAMA, S. (1995). An Acquisition of Operator's Rules for Collision Avoidance Using Fuzzy Neural Networks. *IEEE Transactions on Fuzzy Systems*, 3(3), 280-287.
32. HONG, X., HARRIS, C. J. and WILSON, P. A. (1999). Autonomous Ship Collision Free Trajectory Navigation and Control Algorithms. *7th IEEE International Conference on Emerging Technologies and Factory Automation,* 2, 923-929.
33. HONGDAN, L., SHENG, L. and YONG, Z.L. (2015a). Ship Collision Avoidance Path Planning Strategy Based on Quantum Bacterial Foraging Algorithm. *2nd International Conference on Electrical, Computer Engineering and Electronics,* 612-621.
34. HONGDAN, L., SHENG, L. and ZHUO, Y. (2015b). Application of Adaptive Wolf Colony Search Algorithm in Ship Collision Avoidance. *International Journal of Simulation: Systems, Science and Technology,* 16 (2A), 14.1-14.7.
35. HONGDAN, L., SHENG, L., LANYONG, Z. and ZHENGGUO, G. (2014). The Application Research with Particle Swarm Bacterial Foraging Intelligent Algorithm in Ship Collision Avoidance. *International Conference on Mechatronics, Control and Electronic Engineering*, 69-74.
36. HORNAUER, S. and HAHN, A. (2013). Towards Marine Collision Avoidance Based on Automatic Route Exchange. *IFAC Proceedings Volumes*, 46(33), 103-107.
37. HORNAUER, S., HAHN, A., BLAICH, M. and REUTER, J. (2015). Trajectory Planning with Negotiation for Maritime Collision Avoidance. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 9(3), 335-341.
38. HOWARD, G. S., COLE, D. A. and MAXWELL, S. E. (1987). Research Productivity in Psychology Based on Publication in the Journals of the American Psychological Association. *American Psychologist*, 42(11), 975-986.
39. HSU, H. Z., WITT, N. A., HOOPER, J. B. and MCDERMOTT, A. P. (2009). The AIS-Assisted Collision Avoidance. *The Journal of Navigation*, 62(4), 657-670.
40. HWANG, C. N. (2002). The Integrated Design of Fuzzy Collision-Avoidance and *H*∞-Autopilots on Ships. *The Journal of Navigation*, 55, 117-136.
41. HWANG, C. N., YANG, J. M. and CHIANG, C. Y. (2001). The Design of Fuzzy Collision-Avoidance Expert System Implemented by H∞-Autopilot. *Journal of Marine Science and Technology,* 9(1), 25-37.
42. International Maritime Organization. (1995). Resolution A.823(19) Performance Standards for Automatic Radar Plotting Aids.
43. ITO, M., ZHANG, F. and YOSHIDA, N. (1999). Collision Avoidance Control of Ship with Genetic Algorithm. *Proceedings of the International Conference on Control Applications,* 2, 1791-1796.
44. ITOH, H., NUMANO, M. and PEDERSEN, E. (2003). Modelling and Simulation of Sea Traffic and a Visualization-Based Collision Avoidance Support System. *International Congress on Modelling and Simulation (MODSIM),* 1996-2001.
45. JAMES, M. K. (1994). The Timing of Collision Avoidance Maneuvers: Descriptive Mathematical Models. *The Journal of Navigation*, 47(2), 259-272.
50. JOHANSEN, T. A., CRISTOFARO, A. and PEREZ, T. (2016b). Ship Collision Avoidance Using Scenario-Based Model Predictive Control. *IFAC-PapersOnLine*, 49(23), 14-21.
51. JOHANSEN, T. A., PEREZ, T. and CRISTOFARO, A. (2016a). Ship Collision Avoidance and COLREGs Compliance Using Simulator-Based Control Behavior Selection with Predictive Hazard Assessment. *IEEE Transactions on Intelligent Transportation Systems*, 17(12), 3407-3422.
52. KAMINSKI, R. and SMIERZCHALSKI, R. (2001). An Evolutionary Method of Ship's Anti-Collision Trajectory Planning: New Experiments. *WIT Transactions on The Built Environment*, 53, 125-132.
53. KAO, S. L., LEE, K. T., CHANG, K. Y. and KO, M. D. (2007a). A Fuzzy Logic Method for Collision Avoidance in Vessel Traffic Service. *The Journal of Navigation*, 60, 17-31.
54. KAO, S. L., SU, C. M., CHENG, C. Y. and CHANG, K. Y. (2007b). A New Method of Collision Avoidance for Vessel Traffic Service.

In International Conference on Maritime Technology ICMT, 153-159.

55. KAYANO, J. and IMAZU, H. (2009). A Study of a Collision Avoidance Support System. *International Conference on Systems, Man and Cybernetics*. (pp. 244-249). IEEE.

56. KIJIMA, K. and FURUKAWA, Y. (2002). Development of Collision Avoidance Algorithm Using Fuzzy Inference. *Proceeding of Pacific/Asia Offshore Mechanics Symposium*, 123-130.

57. KIM, D., HIRAYAMA, K. and OKIMOTO, M. (2015). Ship Collision Avoidance by Distributed Tabu Search. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 9(1), 23-29.

58. KIM, D., HIRAYAMA, K. and OKIMOTO, T. (2017). Distributed Stochastic Search Algorithm for Multi-Ship Encounter Situations. *The Journal of Navigation*, 70(4), 699-718.

59. KOLENDO, P and SMIERZCHALSKI, R. (2015). Ship Evolutionary Trajectory Planning Method with Application of Polynomial Interpolation. *Activities in Navigation: Marine Navigation and Safety of Sea Transportation*, 161-166. Netherlands: CRC Press.

60. KOYAMA, T. and YAN, J. (1987). An Expert System Approach to Collision Avoidance. *Proceeding 8th Ship Control Systems Symposium*, 3, 234.

61. KUCZKOWSKI, L. and SMIERZCHALSKI, R. (2014). Comparison of Single and Multi-Population Evolutionary Algorithm for Path Planning in Navigation Situation. *In Solid State Phenomena*, 210, 166-177.

62. KUCZKOWSKI, L. and SMIERZCHALSKI, R. (2017). Path Planning Algorithm for Ship Collisions Avoidance in Environment with Changing Strategy of Dynamic Obstacles. *In Polish Control Conference* (pp. 641-650).

63. KUMAGAI, K., MOCHIDA, T., TANAKA, Y. and KAYANO, J. (2012). Basic Study on Analyzing of Maneuvering for Avoiding Collision in the Congested Sea Area Where Many Ships Are Crossing by Using OZT. *In 2012 Fifth International Conference on Emerging Trends in Engineering and Technology*, 270-275.

64. KWIK, K. H. (1989). Calculation of Ship Collision Avoidance Maneuvers: A Simplified Approach. *Ocean Engineering*, 16(5-6), 475-491.

65. LAZAROWSKA, A. (2012). Decision Support System for Collision Avoidance at Sea. *Polish Maritime Research,* 19, 19-24.

66. LAZAROWSKA, A. (2013). Application of Ant Colony Optimization in Ship's Navigational Decision Support System. *Marine Navigation and Safety of Sea Transportation: Navigational Problems*, 53. Crc Press.

67. LAZAROWSKA, A. (2014a). Ant Colony Optimization Based Navigational Decision Support System. *18th International Conference on Knowledge-Based and Intelligent Information & Engineering System*, 1014-1022.

68. LAZAROWSKA, A (2014b). Safe Ship Control Method with the Use of Ant Colony Optimization. *In Solid State Phenomena*, 210, 234-244. Trans Tech Publications.

69. LAZAROWSKA, A (2015a). Swarm Intelligence Approach to Safe Ship Control. *Polish Maritime Research*, 22(4), 34-40.

70. LAZAROWSKA, A (2015b). Parameters Influence on the Performance of an Ant Algorithm for Safe Ship Trajectory Planning. *IEEE 2nd Cybernetics International Conference*, 140-145.

71. LAZAROWSKA, A. (2015c). Ship's Trajectory Planning for Collision Avoidance at Sea Based on Ant Colony Optimization. *The Journal of Navigation*, 68(2), 291-307.

72. LAZAROWSKA, A. (2015d). Safe Ship Trajectory Planning Based on the Ant Algorithm - the Development of the Method. *Activities in Navigation: Marine Navigation and Safety of Sea Transportation*, 153-160. Netherlands: CRC Press.

73. LAZAROWSKA, A. (2016). A Trajectory Base Method for Ship's Safe Path Planning. *Procedia Computer Science*, 96, 1022-1031.

74. LAZAROWSKA, A. (2017). A New Deterministic Approach in a Decision Support System for Ship's Trajectory Planning. *Expert Systems with Applications,* 71, 469-478.

75. LEE, H. J. and RHEE, K. P. (2001). Development of Collision Avoidance System by Using Expert System and Search Algorithm. *International Shipbuilding Progress*, 48(3), 197-212.

76. LEE, I. L., KIM, S. G. and KIM, Y. G. (2015). Fuzzy Relational Product for Collision Avoidance of Autonomous Ships. *Intelligent Automation and Soft Computing*, 21(1), 21-38.

77. LEE, S. M., KWON, K.Y. and JOH, J. (2004). A Fuzzy Logic for Autonomous Navigation of Marine Vehicle Satisfying COLREG Guidelines. *International Journal of Control, Automation, and Systems*, 2(2), 171-181.

78. LEE, Y. I. and KIM, Y. G. (2004). A Collision Avoidance System for Autonomous Ship Using Fuzzy Relational Products and COLREGs. *In International Conference on Intelligent Data Engineering and Automated Learning*, 247-252. Springer Berlin Heidelberg.

79. LI, L. N., XIONG, Z. N. and REN, Q. S. (2003). Generation and Optimization of Intelligent Decisions for Multi-Ship Collision Avoidance. *Information and Control*, 32(2), 189-192.

80. LI, L., YANG, S., SUO, Y., CHEN, G. and WANG, J. (2008). Automation Method for Personifying Intelligent Decision-Making for Vessel Collision Avoidance. *International Conference on Automation and Logistics,* 1876-1881.
81. LI, W. and MA, W. (2016). Simulation on Vessel Intelligent Collision Avoidance Based on Artificial Fish Swarm Algorithm. *Polish Maritime Research*, 23(s1), 138-143.
82. LISOWSKI, J. (2000). Multistage Ship's Optimal Control in Collision Situations Using a Neural Network. *In II International Conference Safe Navigation Beyond*, 109-119.
83. LISOWSKI, J. (2001). Optimal and Safe Ship Control as a Multi-Step Matrix Game. Systems Science, 27(3), 97-113.
84. LISOWSKI, J. (2005). Dynamic Games Methods in Navigator Decision Support System for Safety Navigation. *In Proceedings of the European Safety and Reliability Conference* (Vol. 2, pp. 1285-1292).
85. LISOWSKI, J. (2007). Intelligent Safe Ship Control Methods in Collision Situations. *In European Control Conference (ECC),* (pp. 2250-2257). IEEE.
86. LISOWSKI, J. (2008). Optimal and Game Ship Control Algorithms for Avoiding Collisions at Sea. *WIT Transactions on Information and Communication Technologies*, 39, 525-534.
87. LISOWSKI, J. (2010). Optimization Decision Support System for Safe Ship Control. *Risk Analysis*, WIT Press, Southampton/Boston, MA, 259-272.
88. LISOWSKI, J. (2012). Game Control Methods in Avoidance of Ships Collisions. *Polish Maritime Research,* 19, 3-10.
89. LISOWSKI, J. (2013a). Sensitivity of Computer Support Game Algorithms of Safe Ship Control. *International Journal of Applied Mathematics and Computer Science*, 23(2), 439-446.
90. LISOWSKI, J. (2013b). Optimal and Game Control Algorithms of a Ship in Collision Situations at Sea. *Control and Cybernetics*, 42(4), 773-792.
91. LISOWSKI, J. (2014). Computational Intelligence Methods of a Safe Ship Control. *Procedia Computer Science*, 35, 634-643.
92. LISOWSKI, J. (2016). Analysis of Methods of Determining the Safe Ship Trajectory. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 10(2), 223-228.
93. LISOWSKI, J. and SMIERZCHALSKI, R. (1995). Methods to Assign the Safe Maneuver and Trajectory Avoiding Collision at Sea. *WIT Transactions on the Built Environment*, 12: 495-502.
94. LIU, H., DENG, R. and ZHANG, L. (2016). The Application Research for Ship Collision Avoidance with Hybrid Optimization Algorithm. *International Conference on Information and Automation (ICIA),* (pp. 760-767). IEEE.
95. LIU, Q., PEDERSEN, E., OKAZAKI, T., FUKUTO, J. and TANAKA, K. (2006a). Direct Perception Interface for Ship-Ship Collision Avoidance. *International Conference on Systems, Man and Cybernetics*, 808-813.
96. LIU, Y. A., LIU, J., WU, J. and ZOU, X. H. (2007a). Application of Simulated Annealing Algorithm in Turning Angle to Avoid Collision between Ships. *Ship Building of China*, 4, 8.
97. LIU, Y. H. and SHI, C. J. (2005). A Fuzzy-Neural Inference Network for Ship Collision Avoidance. *International Conference on Machine Learning and Cybernetics*, 4754-4759.
98. LIU, Y. H. and YANG, W. L. (2004). The Structure Design of an Intelligent Decision Support System for Navigation Collision Avoidance. *International Conference on Machine Learning and Cybernetics,* 302-307.
99. LIU, Y. H., DU, X. M. and YANG, S. H. (2006b). The Design of a Fuzzy-Neural Network for Ship Collision Avoidance. *Advances in Machine Learning and Cybernetics*. Springer Berlin Heidelberg, 804-812.
100. LIU, Y. H., WANG, S. Z. and DU, X. M. (2008). A Multi-Agent Information Fusion Model for Ship Collision Avoidance. *International Conference on Machine Learning and Cybernetics,* 6-11.
102. LIU, Y. H., YANG, C. and DU, X. M. (2007b). A Multiagent-Based Simulation System for Ship Collision Avoidance. *Advanced Intelligent Computing Theories and Applications,* Springer-Verlag Berlin Heidelberg, 316-326.
103. MA, W. Y. and YANG, J. X. (2013). Optimization of Ship Collision Avoidance Route Based on Bacterial Foraging Algorithm. *Journal of Dalian Maritime University*, 39(2), 21-24.
104. MA, W. Y., WU, Z., YANG, J. and LI, W. (2014a). Decision Support from Artificial Fish Swarm Algorithm for Ship Collision Avoidance Route Planning. *Journal Navigation of China*, 2014(3): 63-67.
105. MA, Y., GAN, L., ZHENG, Y. and ZHANG, J. (2014b). Autonomous Ship Safe Navigation Using Smoothing A* Algorithm. *Open Cybernetics and Systemics Journal*, (8), 72-76.
106. MAO, Y. S., SONG, L. F., XIANG, Z. Q., ZHUO, Y. Q., MAO, P. X. and YAN, Z. (2015). Multi-Obstacle Intelligent Collision Avoidance Strategy for Unmanned Surface Vehicle. *Journal of Dalian Maritime University,* 41(4), 8-13.

107. MERZ, A. W. and KARMARKAR, J. S. (1976). Collision Avoidance Systems and Optimal Turn Maneuvers. *The Journal of Navigation*, 29(2), 160-174.

108 MIELE, A. and WANG, T. (2004). New Approach to the Collision Avoidance Problem for a Ship. *International Game Theory Review*, 6(01), 137-155.

109. MIELE, A. and WANG, T. (2005). Maximin Approach to the Ship Collision Avoidance Problem via Multiple-Subarc Sequential Gradient-Restoration Algorithm. *Journal of Optimization Theory and Applications*, 124(1), 29-53.

110. MIELE, A. and WANG, T. (2006). Optimal Trajectories and Guidance Schemes for Ship Collision Avoidance. *Journal of Optimization Theory and Applications,* 129(1), 1-21.

111. MIELE, A., WANG, T., CHAO, C. S. and DABNEY, J. B. (1999). Optimal Control of a Ship for Collision Avoidance Maneuvers. *Journal of Optimization Theory and Applications*, 103(3), 495-519.

112. MILOH, T. and PACHTER, M. (1989). Ship Collision-Avoidance and Pursuit-Evasion Differential Games with Speed-Loss in a Turn. *Computers & Mathematics with Applications*, 18(1-3), 77-100.

113. MOHAMED-SEGHIR, M. (1995). Application of Fuzzy Set Theory to Determinate Optimal Safety Trajectory of the Ship in a Collision Situation. *Modelling, Measurement and Control D,* 12(1), 49-54.

114. MOHAMED-SEGHIR, M. (2012a). Safe Ship's Control in a Fuzzy Environment Using a Genetic Algorithm. *In Solid State Phenomena*, 180, 70-75. Trans Tech Publications.

115. MOHAMED-SEGHIR, M. (2012b). The Branch-and-Bound Method and Genetic Algorithm in Avoidance of Ships Collisions in Fuzzy Environment. *Polish Maritime Research*, 19(s1), 45-49.

116. MOHAMED-SEGHIR, M. (2014). The Branch-and-Bound Method, Genetic Algorithm, and Dynamic Programming to Determine a Safe Ship Trajectory in Fuzzy Environment. *Procedia Computer Science*, 35, 348-357.

117. MOHAMED-SEGHIR, M. (2016). Computational Intelligence Method for Ship Trajectory Planning International *Conference on Methods and Models in Automation and Robotics* (MMAR), (pp. 636-640). IEEE.

118. MOHAMED-SEGHIR, M. (2017). The Fuzzy Properties of The Ship Control in Collision Situations. *International Conference on Innovations in Intelligent Systems and Applications (INISTA),* (pp. 107-112). IEEE.

119. NAEEM, W., IRWIN, G. W. and YANG, A. (2012). COLREGs-Based Collision Avoidance Strategies for Unmanned Surface Vehicles. *Mechatronics,* 22(6), 669-678.

120. NGUYEN, M. D., NGUYEN, V. T. and TAMARU, H. (2012). Automatic Collision Avoiding Support System for Ships in Congested Waters and at Open Sea. *2012 International Conference on Control, Automation and Information Sciences*.

121. OH, H. N. H., TSOURDOS, A. and SAVVARIS, A. (2014). Development of Collision Avoidance Algorithms for the C-Enduro USV. *IFAC Proceedings Volumes,* 47(3), 12174-12181.

122. OLSDER, G. J. and WALTER, J. L. (1978). A Differential Game Approach to Collision Avoidance of Ships. *In Optimization Techniques Part 1,* 264-271. Springer Berlin Heidelberg.

123. PARK, G. K., BENEDICTOS, J. L. R. M., LEE, C. S. and WANG, M. H. (2007). Ontology-based Fuzzy-CBR Support System for Ship's Collision Avoidance. *International Conference on Machine Learning and Cybernetics*, 1845-1850.

124. PEDERSEN, E., INOUE, K. and TSUGANE, M. (2003). Simulator Studies on a Collision Avoidance Display That Facilitates Efficient and Precise Assessment of Evasive Maneuvers in Congested Waterways. *The Journal of Navigation*, 56(03): 411-427.

125. PERERA, L. P., CARVALHO, J. P. and SOARES, C. G. (2009). Autonomous Guidance and Navigation Based on the COLREGs Rules and Regulations of Collision Avoidance. *Advanced Ship Design for Pollution Prevention*, Taylor & Francis Group, London, 205-216.

126. PERERA, L. P., CARVALHO, J. P. and SOARES, C. G. (2010a). Bayesian Network Based Sequential Collision Avoidance Action Execution for an Ocean Navigational System. 8th IFAC Conference on Control Applications in Marine Systems, 43(20), 266-271.

127. PERERA, L. P., CARVALHO, J. P. and SOARES, C. G. (2010b). Fuzzy-Logic Based Parallel Collisions Avoidance Decision Formulation for an Ocean Navigational System. *In Proceeding of the 8th IFAC Conference on Control Applications in Marine Systems,* 295-300.

128. PERERA, L. P., CARVALHO, J. P. and SOARES, C. G. (2011). Fuzzy Logic Based Decision-Making System for Collision Avoidance of Ocean Navigation Under Critical Collision Conditions. *Journal of Marine Science and Technology,* 16, 84-99.

129. PERERA, L. P., CARVALHO, J. P. and SOARES, C. G. (2012). Intelligent Ocean Navigation and Fuzzy-Bayesian Decision/Action Formulation. *IEEE Journal of Oceanic Engineering*, 37(2), 204-219.

130. PERERA, L. P., FERRARI, V., SANTOS, F. P., HINOSTROZA, M. A. and SOARES, C. G. (2015). Experimental Evaluations on Ship Autonomous Navigation and Collision Avoidance by Intelligent Guidance. *IEEE Journal of Oceanic Engineering,* 40(2), 374-378.
131. PIETRZYKOWSKI, Z. and CHOMSKI, J. (2003). A Navigator Decision Support System in Planning a Safe Trajectory. *4th IAMU General Assembly*.
132. PIETRZYKOWSKI, Z., MAGAJ, J., WOŁEJSZA, P. and CHOMSKI, J. (2010). Fuzzy Logic in the Navigational Decision Support Process Onboard a Sea-Going Vessel. *In International Conference on Artificial Intelligence and Soft Computing*, 185-193.
133. QINYOU, H., QIAOER, H. and CHAOJIAN, S. (2006). A Negotiation Framework for Automatic Collision Avoidance between Vessels. *In 2006 IEEE/WIC/ACM International Conference on Intelligent Agent Technology,* 595-601.
134. RHEE, K. P. and LEE, H. J. (1996). Development of a Collision Avoidance System Considering the Navigation Plan. *In Marine Simulation and Ship Manoeuvrability,* 96, 341-348.
135. ROBERT, G., HOCKEY, J., HEALEY, A., CRAWSHAW, M., WASTELL, D. G. and SAUER, J. (2003). Cognitive Demands of Collision Avoidance in Simulated Ship control. *The Journal of the Human Factors and Ergonomics Society*, 45(2), 252-265.
136. ROWLEY, J. and SLACK, F. (2004). Conducting a Literature Review. *Management Research News*, 27, 31–39.
137. SEURING, S. and GOLD, S. (2012). Conducting Content-Analysis Based Literature Reviews in Supply Chain Management. *Supply Chain Management,* 17, 544–555.
138. SHTAY, A. D. and GHARIB, W. (2009). An Intelligent Control System for Ship Collision Avoidance. *International Journal of Engineering and Technology*, 9(10), 36-41.
140. SIMSIR, U., AMASYALI, M. F., BAL, M., ÇELEBI, U. B. and ERTUĞRUL, S. (2014). Decision Support System for Collision Avoidance of Vessels. *Applied Soft Computing,* 25, 369-378.
141. SMIERZCHALSKI, R. (1999). An Intelligent Method of Ship's Trajectory Planning at Sea. *In Intelligent Transportation System,* 907-912.
142. SMIERZCHALSKI, R. (2003). Evolutionary Algorithm in Problem of Avoidance Collision at Sea. In *Artificial Intelligence and Security in Computing Systems* (pp. 81-90). Springer, Boston, MA.
143. SMIERZCHALSKI, R. and MICHALEWICZ, Z. (1998). Adaptive Modeling of a Ship Trajectory in Collision Situations at Sea. In Proceedings of IEEE World Congress on Computational Intelligence, pp. 342-347.
144. SMIERZCHALSKI, R. and MICHALEWICZ, Z. (2000). Modelling of Ship Trajectory in Collision Situations by an Evolutionary Algorithm. *IEEE Transactions on Evolutionary Computation*, 4(3), 227-241.
145. STATHEROS, T., HOWELLS, G. and MCDONALD-MAIER, K. (2008). Autonomous Ship Collision Avoidance Navigation Concepts, Technologies and Techniques. *The Journal of Navigation,* 61, 129-142.
146. SU, C. M., CHANG, K. Y. and CHENG, C. Y. (2012). Fuzzy Decision on Optimal Collision Avoidance Measures for Ships in Vessel Traffic Service. *Journal of Marine Science and Technology,* 20(1), 38-48.
147. SVETAK, J. and JAKOMIN, L. (2005). Model of Optimal Collision Avoidance Maneuver on the Basis of Electronic Data Collection. *Promet-Traffic & Transportation*, 17(6), 295-302.
148. SZLAPCZYNSKI, R. (2007). Determining the Optimal Course Alteration Maneuver in A Multi-Target Encounter Situation for a Given Ship Domain Model. *Annual of Navigation*, 12, 75-85.
149. SZLAPCZYNSKI, R. (2008). A New Method of Planning Collision Avoidance Maneuvers for Multi-Target Encounter Situations. *The Journal of Navigation,* 61, 307-321.
150. SZLAPCZYNSKI, R. (2009). Evolutionary Sets of Cooperating Trajectories in Multi-Ship Encounter Situations-Use Cases. *International Navigational Symposium on Marine Navigation and Safety of Sea Transportation,* pp. 443-448.
151. SZLAPCZYNSKI, R. (2011). Evolutionary Sets of Safe Ship Trajectories: A New Approach to Collision Avoidance. *The Journal of Navigation*, 64(1), 169-181.
152. SZLAPCZYNSKI, R. and SZLAPCZYNSKA, J. (2012). Customized Crossover in Evolutionary Sets of Safe Ship Trajectories. *International Journal of Applied Mathematics and Computer Science,* 22(4), 999-1009.
153. TAM, C. and BUCKNALL, R. (2010). Path-Planning Algorithm for Ships in Close-Range Encounters. *Journal of Marine Science and Technology*, 15(4), 395-407.
154. TAM, C. K. and BUCKNALL, R. (2013). Cooperative Path Planning Algorithm for Marine Surface Vessels. *Ocean Engineering,* 57, 25-33.
155. TAM, C., BUCKNALL, R. and GREIG, A. (2009). Review of Collision Avoidance and Path Planning Methods for Ships in Close Range Encounters. *The Journal of Navigation*, 62(3), 455-476.
156. TIAN, Y. B. and PAN, P. P. (2011). Application of Improved Immune Particle Swarm Algorithm

in Ship Collision Avoidance. *Navigation of China*, 34(1).

157. TRANFIELD, D., DENYER, D. and SMART, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, 14, 207–222.

158. TSAI, C. C. and WEN, M. L. (2005). Research and Trends in Science Education from 1998 to 2002: A Content Analysis of Publication in Selected Journals. *International Journal of Science Education*, 27(1): 3-14.

159. TSOU, M. C. (2016). Multi-Target Collision Avoidance Route Planning Under an ECDIS Framework. *Ocean Engineering*, 121, 268-278.

160. TSOU, M. C. and HSUEH, C. K. (2010). The Study of Ship Collision Avoidance Route Planning by Ant Colony Algorithm. *Journal of Marine Science and Technology,* 18(5), 746-756.

161. TSOU, M. C., KAO, S. L. and SU, C. M. (2010). Decision Support from Genetic Algorithms for Ship Collision Avoidance Route Planning and Alerts. *The Journal of Navigation*, 63, 167-182.

162. VETTOR, R. and GUEDES SOARES, C. (2014). Multi-Objective Evolutionary Algorithm in Ship Route Optimization. *Maritime Technology and Engineering,* London, UK: Taylor & Francis Group.

163. WANG, K., YAN, X., YUAN, Y., JIANG, X., LODEWIJKS, G. and NEGENBORN, R. R. (2017). PSO-Based Method for Safe Sailing Route and Efficient Speeds Decision-Support for Sea-Going Ships Encountering Accidents. International Conference on Networking, Sensing and Control (ICNSC), 14th (pp. 413-418). IEEE.

164. WANG, T., YAN, X., WANG, Y. and WU, Q. (2017). A Distributed Model Predictive Control Using Virtual Field Force for Multi-Ship Collision Avoidance Under COLREGs. *International Conference on Transportation Information and Safety (ICTIS)*, (pp. 296-305). IEEE.

165. WANG, X., LIU, Z., and CAI, Y. (2017). The Ship Maneuverability Based Collision Avoidance Dynamic Support System in Close-Quarters Situation. *Ocean Engineering,* 146, 486-497.

166. WANG, X. Y., ZHENG, R. J., SIMSIR, U. and XIAO, Y. Y. (2016). An Intelligent Collision Avoidance Algorithm Research. *International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI),* (pp. 2000-2004). IEEE.

167. WANG, Y. Y., DEBNATH, A. K. and CHIN, H. C. (2010). Modelling Collision Avoidance Decisions in Navigation. *In Proceedings of 10th Asian Conference on Marine Simulation and Simulator Research*.

168. WARD, N. and LEIGHTON, S. (2010). Collision Avoidance in the e-Navigation Environment. *In Proc. 17th Conf. Int. Assoc. Marine Aids Navig. Lighthouse Authorities* (pp. 4-10).

169. WEI, Y. and XUE, Y. Z. (2013). Simulation Research on Ship Automatic Collision Avoidance. *Journal of Dalian Maritime University*, 39(2), 18-20.

170. WEI, Z., ZHOU, K. and WEI, M. (2015). Decision-Making in Ship Collision Avoidance Based on Cat-Swarm Biological Algorithm. *International Conference on Computational Science and Engineering 2015*.

171. WEN, X., JIANGQIANG, H., JIANCHUAN, Y. and KE, L. (2016). Ship Automatic Collision Avoidance by Altering Course Based on Ship Dynamic Domain. *In Trustcom/BigDataSE/ISPA*, (pp. 2024-2030). IEEE.

172. WIT, C. and OPPE, J. (1979). Optimal Collision Avoidance in Unconfined Waters. *Navigation*, 26(4), 296-303.

173. XU, Q. (2014). Collision Avoidance Strategy Optimization Based on Danger Immune Algorithm. *Computer and Industrial Engineering*, 76, 268-279.

174. XU, Q., ZHANG, C. and WANG, N. (2014). Multiobjective Optimization Based Vessel Collision Avoidance Strategy Optimization. *Mathematical Problems in Engineering*, 2014: 1-9.

175. XUE, Y., CLELLAND, D., LEE, B. S. and HAN, D. (2011). Automatic Simulation of Ship Navigation. *Ocean Engineering*, 38(17), 2290-2305.

176. XUE, Y., LEE, B. S. and HAN, D. (2008). Automatic Collision Avoidance of Ships. *Journal of Engineering for the Maritime Environment,* 223(1), 33-46.

177. XUE, Y. Z., HAN, D. F. and TONG, S. Y. (2012). Automatic Trajectory Planning and Collision Avoidance of Ships in Confined Waterways. *Sustainable Maritime Transportation and Exploitation of Sea Resources*, 167. London: Taylor and Francis.

178. YANG, J. M., TSENG, C. M. and FAN, C. C. (2012). Collision-Free Path Planning for Unmanned Surface Vehicle by Using Advanced A* Algorithm. *Journal of Taiwan Society of Naval Architects and Marine Engineers,* 31(4), 173-184.

179. YANG, S. H., SHI, C. J., LI, L. and GUAN, K. (2006). Construction of Simulation Platform for Vessel Automatic Collision Avoidance with the Technologies of MAS and Navigational Simulator. *Journal of System Simulation*, 18, 686-690.

180. YANG, S., LI, L., SUO, Y. and CHEN, G. (2007). Study on Construction of Simulation Platform for Vessel Automatic Anti-Collision and Its Test Method. *In 2007 IEEE International Conference on Automation and Logistics*, 2414-2419.
181. YAVIN, Y., FRANGOS, C., MILOH, T. and ZILMAN, G. (1997). Collision Avoidance by a Ship with a Moving Obstacle: Computation of Feasible Command Strategies. *Journal of Optimization Theory and Applications,* 93(1), 53-66.
182. YILDIRIM, U., UĞURLU, Ö. and BAŞAR, E. (2015). Human Error in Grounding Accidents: Case Study for Container Ships. *Journal of ETA Maritime Science,* 3(1), 1-10.
183. YILDIRIM, U., UĞURLU, Ö., BAŞAR, E. and YÜKSEKYILDIZ, E. (2017). Human Factor Analysis of Container Vessel's Grounding Accidents. *International Journal of Maritime Engineering,* 159(A1), 89-98.
184. YIMING, B., XINJIE, H. and XIANYAO, M. (2012). Optimization of Strategy for Ship Collision Avoidance with Danger Model Immune Algorithm. *Navigation of China*, 35(2012), 29-32.
185. YI, W. and CHAN, A. P. (2014). Critical Review of Labor Productivity Research in Construction Journals. *Journal of Management in Engineering*, 30(2), 214-225.
186. YING, S., SHI, C. V and YANG, S. (2007). Ship Route Designing for Collision Avoidance Based on Bayesian Genetic Algorithm. *International Conference on Control and Automation*, 1807-1811.
187. YOU, Y., RHEE, K. P. and AHN, K. (2013). A Method of Inferring Collision Ratio Based on Manoeuvrability of Own Ship Under Critical Collision Conditions. *International Journal of Naval Architecture and Ocean Engineering*, 5(2), 188-198.
188. ZADEH, L. A. (1965) Fuzzy Sets. *Information and Control*, 8, 338–353.
189. ZENG, X. (2003). Evaluation of the Safe Path for Ship Navigation. *Applied Artificial Intelligence*, 17(2), 87-104.
190. ZENG, X. M. and ITO, M. (2001). Planning a Collision Avoidance Model for Ship Using Genetic Algorithm. *International Conference on Systems, Man, and Cybernetics,* 4, 2355-2360.
191. ZENG, X. M., ITO, M. and SHIMIZU, E. (2000a). Collision Avoidance of Moving Obstacles for Ship with Genetic Algorithm. *International Workshop on Advanced Motion Control*, 513-518.
192. ZENG, X. M., ITO, M. and SHIMIZU, E. (2000b). Planning and Keeping the Safe Course to Avoid Collision at Sea with Genetic Algorithms. Annual Conference of the Industrial Electronics Society, (Vol. 4, pp. 2388-2393).
193. ZENG, X. M., ITO, M. and SHIMIZU, E. (2001). Building an Automatic Control System of Maneuvering Ship in Collision Situation with Genetic Algorithms. *In Proceedings of American Control Conference,* 4, 2852-2853.
194. ZHANG, J., ZHANG, D., YAN, X., HAUGEN, S. and SOARES, C. G. (2015). A Distributed Anti-Collision Decision Support Formulation in Multi-Ship Encounter Situations under COLREGs. *Ocean Engineering*, 105, 336-348.
195. ZHANG, J.F., YAN, X.P., ZHANG, D. and HAUGEN, S. (2013). Ship Trajectory Control Optimization in Anti-Collision Maneuvering. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation,* 7(1), 89-93.
196. ZHANG, M. and SHI, C. (2007). Autonomous Collision Avoidance for Ships Using APF method. *In International Conference on Transportation Engineering,* (pp. 2687-2692).
197. ZHANG, W. and ZHENG, Y. (2011). Intelligent Ship-Bridge Collision Avoidance Algorithm Research Based on a Modified Gaussian Mixture Model. *International Conference on Multimedia Technology*, 6414-6419.
198. ZHANG, Y. L. (2013). A Method of Ship's Path Planning at Sea. *In Applied Mechanics and Materials* (Vol. 321, pp. 2038-2041). Trans Tech Publications.
199. ZHAO, J., TAN, M., PRICE, W. G. and WILSON, P. A. (1994). DCPA Simulation Model for Automatic Collision Avoidance Decision Making Systems Using Fuzzy Sets. *In OCEANS'94.'Oceans Engineering for Today's Technology and Tomorrow's Preservation Proceedings,* 2, 244-249.
200. ZHAO, Y. X., LI, W., FENG, S., OCHIENG, W. Y. and SCHUSTER, W. (2014). An Improved Differential Evolution Algorithm for Maritime Collision Avoidance Route Planning. *In Abstract and Applied Analysis (Vol. 2014).* Hindawi Publishing Corporation.
201. ZHONG, B. L., LIU, X. J., WU, J. S., QIU, J. N. and JIANG, H. (2008). Study on Ship Auto-Collision Avoidance System Based on Artificial Potential Field. *Journal of Guangzhou Maritime College*, 1, 004.
202. ZHUO, Y and TANG, T. (2008). An Intelligent Decision Support System to Ship Anti-Collision in Multi-Ship Encounter. *Proceedings of the 7th World Congress on Intelligent Control and Automation*, 1066-1071.
203. ZHUO, Y. and HASEGAWA, K. (2014). Intelligent Collision Avoidance Control for Large Ships. *In Information Science, Electronics and Electrical Engineering*

(ISEEE), 2014 International Conference on, 3, 1887-1891.

204. ZHUO, Y. and HEARN, G. E. (2008). A Ship Based Intelligent Anti-Collision Decision-Making Support System Utilizing Trial Maneuvers. *Chinese Control and Decision Conference*, 3982-3987.