

Application of a decision support tool for the collision avoidance of a container vessel

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ABSTRACT

In this paper, a decision support tool for collision avoidance is presented. The collision probability of the investigated container vessel is estimated using a 3-step approach. In this methodology, the manoeuvrability and the propulsion system performance of the own vessel is taken into account, increasing the accuracy of the collision risk probability. The results of the validation process are presented and the collision risk probability at various near miss counter scenarios is evaluated. Moreover, the methodology presented herein, allows the holistic assessment of the impact that actions in accordance to the IMO COLREGs or violating them have. They are all included in the selection of the optimum control options to minimize the risk of a collision at sea.

KEY WORDS: 3-DOF manoeuvring; propulsion system performance; collision avoidance; risk index; quantitative risk analysis, decision support tool; COLREGs.

INTRODUCTION

The growth dynamics of the international commodities and people transports has resulted to the rapid expansion of the world fleet, as 80 per cent of world trade is transported by sea (IMO, 2019). The containerization in particular has increased the demand of containership application in maritime logistics (UNCTAD, 2017). The boost of the world maritime fleet increases the collision risk probability, especially in straits and coastal waters (EMSA, 2017). International Maritime Organization (IMO) has published the COLREGs guidelines with the procedures to be followed for the avoidance of collision (IMO, 1972). Moreover, the decisions on board are supported by modern electronic instrumentation that provides information and awareness regarding the navigational safety of the vessels (IMO, 1974). However, these tools estimate a posterior probability, neglecting the manoeuvring characteristics and the propulsion system of the own vessel, parameters that affect the collision risk estimation (af Geijerstam, et al., 2008). Furthermore, state-of-the-art quantitative risk analysis (QRA) models depend for their validity on how well they estimate the ship-ship collision conditional to an encounter (Goerlandt et al., 2014). However, in most cases they still rely on the blind navigation assumption.

Many studies indicate that the correct system awareness has a great influence to the navigational safety (Harrald, et al., 1998; Corovic & Djurovic, 2013; Yildirim, et al., 2017). During the navigation, the officer on the watch (OOV) receives a vast number of data concerning the relative distance, speed and navigation course that need to be processed for risk probability assessment and decision-making process, with low predictability of the vessels' course when a vessel manoeuvre is performed. Moreover, the marine accidents reports indicate that a collision may occur even under good visibility and weather conditions if one of the encountering vessels doesn't comply with the IMO's established procedures and regulations (AIBN, 2018). These concerns have initiated discussions in IMO regarding the safe routing of ships (IMO, 2014) and the integration of anti-collision modules into navigational systems (IMO, 2013; IMO, 2015).

In the majority of the previous studies (Zhu, et al., 2001; Lee & Kim, 2004; Tsou, et al., 2010; Kolendo, et al., 2011; Liang & Cai, 2016), data-learning and optimization techniques are applied for the estimation of the optimum course that a vessel should follow to avoid the collision with target vessels or other objects, using a quantitative Index to estimate the Collision Probability (CPI). In these cases, the manoeuvrability of the vessel and the propulsion system's response are usually neglected due to the limited availability of data for the model setup and the increased computational cost for the accurate prediction of the ship's course. The first approach introducing a manoeuvring model to the investigation of a collision situation was performed by (Curtis, 1986). Following this study, the ship motions were taken into account in several CPI prediction models, developed for the more accurate estimation of the vessel's yaw rate during manoeuvring (Zhang, et al., 2012), the application of potential field theory to predict the planned course of the vessel (Xue, et al., 2011), as well as for the development of the Model Predictive Control Technique (Yan & Wang, 2012) and the Local Reactive Obstacle Avoidance model (Tang, et al., 2015).

The limitations of the selected propulsion system may affect the overall manoeuvrability of the vessel as it was presented by Mizythrass et al. (2017). The governor limiters of each main engine affect the maximum power that can be delivered at various engine speeds. Thus, the

investigation of the collision risk probability should take into account several conditions that may affect the manoeuvrability of the vessel. The initial vessel speed and the propulsion system performance, along with the environmental conditions are considered as the main parameters that affect the vessel's manoeuvrability. Particularly, the vessels in coastal areas are not expected to sail at the design speeds and special attention should be given during vessels' acceleration and deceleration, departing from the port or arriving to areas with high marine traffic. Therefore, an investigation of the main engine and propulsion system components response is crucial for the accurate prediction of the CPI.

In this paper, a Decision Support Model that estimates the CPI and suggests the available control options is applied for the case of a container vessel. This novel methodology takes into account the manoeuvring characteristics of the own vessel for the prediction of the collision risk probability. Moreover, the impact of the propulsion system to the overall manoeuvrability of the vessel is investigated, including the effect of the engine limiters. The proposed approach can be used for the development of a Decision Support Model with the aim to provide guidance to the officer on the watch, recommending the appropriate actions that will minimise the collision risk probability at any particular scenario during the navigation of the ship.

In this study, the Kriso Container Ship's (KCS) hull form is used as the investigated own container vessel (Van, et al., 1997). The method estimates the collision risk probability using a 3-step approach. The first step includes the validation of the vessel turning ability and the propulsion system performance. The validation is important for the accurate estimation of the vessel's hydrodynamic performance and its main engine response in demanding conditions such as the ship's manoeuvres. The second step focuses on the establishment of a database with the possible manoeuvring scenarios of the investigated own vessel. The scenarios have been selected based on the most common manoeuvres that marine vessels can perform to avoid an obstacle at the sea. Finally, the third step is the feeding of the performed scenarios to the developed decision support tool for the estimation of the collision risk probability.

In the second section, a short description of the original methodology presented in (Mizythras, et al., 2019) is given with main focus on the collision risk probability estimation. The developed model has been modified considering the control options that should be selected from the own vessel's OOW in case the encounter vessel does not follow the IMO'S COLREGs procedures. An additional amendment to the initial method is the application of a 0-D physical engine model for the estimation of the parameters required for the engine model setup. Furthermore, special focus is given to the selection of the propulsion system and the validation of the simulation models. Utilising this methodology, a database with the possible manoeuvres of the container vessel is developed. With the assistance of this database, various near-miss collision scenarios are investigated, evaluating the risk probability and suggesting the available control options. Finally, the benefits from the application of this methodology are discussed.

METHODOLOGY DESCRIPTION

The estimation of the collision risk probability requires a multistep methodology to investigate the performance of the own vessel during manoeuvring, taking into account the engine response and the hydrodynamic forces acting on the hull. In the following sections, the considered assumptions and the parameters that affect the probability estimation are described, as well as the computational method that is used for the evaluation of the overall risk probability.

Considerations

The uncertainty during a collision avoidance manoeuvre is affected by many parameters. Indicatively, some of these are the sensitivity of the installed sensors on board in both the own and the encounter vessel, the redundancy of the communication and measuring instruments, the hull and systems response and their interaction with the environment, and the decisions made by the humans on board and on shore. Thus, a number of constraints and assumptions should be adopted during the simulation of a realistic scenario for the accurate prediction of the CPI.

In this research, the encounter scenario involves two vessels. The propulsion simulation system and the system of motions equations are applied only to the own vessel, whilst a predefined course is assumed for the target vessel. The course of the target vessel is described using the relative distance and angle of encounter between the own and target vessels at the beginning of the simulation, as well as its initial speed vector (Fig. 1). The advantage of this approach is that it reduces the uncertainty introduced in the simulation model. The selection of a pre-defined course for the target vessel can be considered realistic, assuming that this tool can be used when the target vessel does not respond to the commands of the OOW or the own vessel should perform anyway manoeuvre to avoid collision.

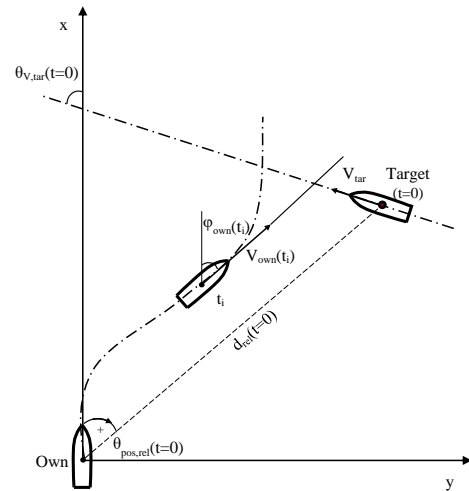


Fig. 1. Coordinate system for the estimation of the own and target vessel trajectories.

Additional assumptions are required for the application of the selected propulsion and manoeuvring simulation models. In the developed methodology, the ship motions are estimated in three degrees of freedom (3-DOF), namely surge, sway and yaw, using a horizontal plane model that predicts the dynamic position of the ship. Moreover, the effect of the target vessel's wake to the own vessel hydrodynamic motions is considered negligible during the CPI estimation. Regarding the environmental conditions, the investigation of different manoeuvring scenarios takes place in calm sea, neglecting the forces induced by wind, waves or currents. Moreover, the hull and the propeller are considered clean.

Model Structure

For the modelling of the own vessel's hydrodynamic performance in various sea conditions and the generation of a database with own vessel's response, the coupled model presented in (Mizythras, et al., 2017) is selected. The initial steps of the methodology include the identification of the engine and propeller characteristics for the investigated own vessel. These parameters are essential for the setup and the validation of the manoeuvring and engine sub-models. Since the coupled model is setup, a

database with the hydrodynamic performance of the own vessel at different manoeuvring scenarios is generated. This database is required for the Decision Support Model and the estimation of the CPI during encounter situations. A brief description of the developed methodology that is used for the estimation of the CPI of the investigated own vessel for the given initial conditions is presented in the Fig. 2.

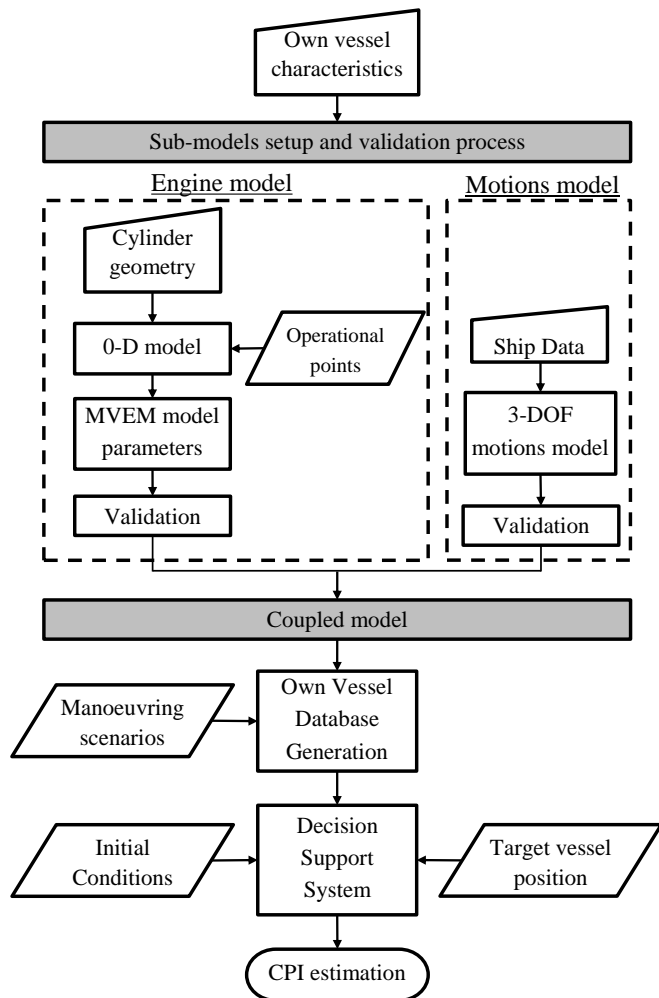


Fig. 2. Flowchart of the developed methodology for the estimation of the CPI.

For an actual ship, the sea trial and the makers' data will be used. In the absence of accurate data for the own vessel, an estimation of the required engine brake power is performed by taking into account the desired design speed and the main particulars of the investigated hull form, and the resistance coefficients as an outcome of the hydrodynamic study of the vessel. Based on these requirements, the propeller and the engine characteristics are selected. Considering that the matching of the propeller with the engine is not the main objective of this methodology, the main objective during the selection of the engine and propeller couple is the compliance of the propulsion system with the desired power of the ship and the rotational speed of both components. The propeller characteristics can be estimated either by the suggested propeller design for the investigated hull or by using a propeller series polynomial (Carlton, 2012).

The geometric characteristics of the main engine are identified by the project catalogue of the engine manufacturers. Although the propeller performance can be estimated by its characteristics, the simulation of the engine performance requires more information than the simple geometric

characteristics and operational profile, especially, if the engine response is required to be investigated in dynamic conditions, such as the ship manoeuvres. In this study, a combination of physical models is used for the accurate simulation of the engine performance. The main disadvantage of the physical models is the increased computational cost and parameters that is required for a time-domain simulation (Stiech, 2013). The Mean Value Engine Model (MVEM) allows the sufficient prediction of the engine response in transient condition at low computational cost (Theotokatos, 2010). However, the setup of this model requires a good knowledge of the engine's thermodynamic performance at different operational points, accuracy that can be obtained only through experiments or using detailed physical models. In the developed methodology, the 0-D model described in (Nilsson, 2007) is used for the estimation of the thermodynamic properties at various operational points using the geometric characteristics of the engine, collected from the available shop trials or from the engine's project guide. Based on the complete description of the engine simulation model, the MVEM setup is performed for the simulation of the selected engine, reducing the computational cost of the overall methodology.

Considering the impact of the engine's response to the own vessel's manoeuvrability, the hydrodynamic motions model is coupled to the engine model. The selection of the appropriate simulation models for the evaluation of the vessel performance depends mainly on the availability of the collected data. In order to simplify the evaluation of the ship motions, a 3-DOF manoeuvring model is selected (Pollalis, et al., 2016). Following this approach, the number of required own vessel hydrodynamic coefficients is reduced, maintaining the required accuracy for the prediction of the vessel's trajectory and the change of the vessel speed during the navigation. The setup of the manoeuvring model requires the accurate estimation of the vessel's hydrodynamic coefficients for the simulation of a real scenario. The coefficients can be collected either from existing experimental data, or using semi-empirical or/and analytical methods (Vantorre, 2001).

The successful coupling of a MVEM model with a 3-DOF manoeuvring model is presented in (Mizythras, et al., 2017), where the vessel's speed during manoeuvring and the turning ability of the vessel were predicted with high accuracy. Considering the requirement for the CPI estimation in shallow water conditions, Ankudinov's model (Ankudinov, et al., 1990) and Li's coefficients (Li & Wu, 1990) are selected for the estimation of the water depth effect to the hydrodynamic coefficients and the added hydrodynamic mass of the hull respectively.

During the establishment of a database with the possible scenarios for the own vessel, the governor limiters and the rudder controller are introduced into the coupled propulsion – manoeuvring model. The limiters are necessary for the safety maintenance of the propulsion engine. The allowance of a 10% overload for a period of one hour within 12-hour normal operation is taken into account, allowing increased power from the engine during the manoeuvring. The rudder controller that is used for the evaluation of the vessel's manoeuvring at different scenarios is described in (Mizythras, et al., 2019), in respect of the yaw angle and rate of the own vessel. Once the database of alternative manoeuvring scenarios is generated, the Decision Support Model of the own vessel can be used for the estimation of the CPI, given the initial conditions and the relative position of the own and the encountered vessel. The method for the estimation of the CPI is described in the next section.

Risk Areas and Probability Index Estimation

The existing shipboard systems assess the collision risk by using the relative distance (DCPA) and time (TCPA) of the close point of approach. The estimation of these indicators uses the speed and the scheduled courses

of the own and target vessels with limited predictability regarding the change of their course. In this study, the introduction of safety domains around the target and own vessels is selected, as it was initially proposed in (Hara, et al., 1990). Several approaches have been proposed on the shape and the size of the safety domain around the vessel (Szlupczynski, 2006; Zhang, et al., 2012; Gang, et al., 2016). The selected shape around the vessel in the developed Decision Support Model is elliptic, a geometric shape that approximates the water plane area of single hull vessels sufficiently although other shapes have been proposed (Szlupczynski, 2017). The selection of the maximum range of the safety domain is usually subjective (Kim, et al., 2015). A fair approximation of the domain's maximum range is the distance that the vessel will cover within 60 sec (2 min).

The developed safety domain is categorized at various risk levels. The area within the water plane of the vessel is considered as the highest risk level. The model also allows the control of the risk level distribution within the safety zone, depending on the uncertainty of the vessel's position prediction and the desired severity during the collision risk assessment. An indicative distribution of the risk zones around the hull is presented in the Fig. 3.

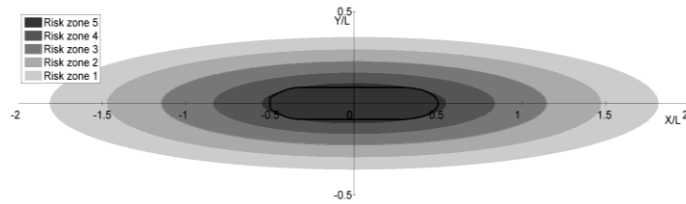


Fig. 3. Distribution of risk levels within safety domain of a vessel.

The calculation of the risk probability takes into account several parameters for each selected manoeuvring scenario. The main parameter considered during the evaluation of the risk at each simulation time step is the intersection of the own and target vessels' safety domains. The maximum product of the intersected risk levels is considered as a metric of the collision risk probability. In case that the velocity vectors of the vessels are not in parallel and there is intersection of the vessels' safety domains, the collision risk probability is increased as a function of the vessels relative angle θ , taking into consideration the greater damage that will be caused during a side collision rather to the aft or the fore reinforced parts of the vessels.

When the collision risk probability is estimated at each time step, then the CDPA and TCPA collision risk probability of the simulation are estimated. The DCPA risk corresponds to the maximum value of the collision risk that has been estimated during the simulation, whilst the TCPA is estimated as the moment when the maximum DCPA will occur. An additional parameter that is taken into account for the estimation of the risk probability is the time duration that the safety domains of both vessels are intersected. Following this approach, the navigation of two vessels sailing at a close distance is considered in the collision risk probability estimation. A detailed analysis on the calculation of these risks and the contribution of each risk to the final risk probability is presented in Mizythras, et al. (2019).

CASE STUDY

The selected vessel in this paper is the KCS hull form. Based on the experimental tests (Larsson, et al., 2003) and following the ITTC procedure (ITTC, 2014) the resistance of the hull is identified at the design speed of 24 knots. The hydrodynamic derivatives and added masses of the KCS hull form for the 3-D manoeuvring model, as well as the hull, rudder

and the wake coefficients are estimated from the study published by (Yoshimura, et al., 2008). Taking into account the propeller characteristics (Van, et al., 1997), the 2 – stroke engine that is able to cover the power requirements of the KCS vessel is the 7S80ME-C9.5 engine.

Validation Process

The validation of the two developed models is important for the improvement of the accuracy of the established manoeuvring scenarios database, which is required for application of the Decision Support Model. The propulsion system model is validated against the engine shop trials, collected by (MAN Diesel & Turbo, 2018) and the 3-DOF manoeuvring model is validated using the turning circle of the KCS model, presented in (Yoshimura, et al., 2008).

The main geometric characteristics and the maximum continuous rating (MCR) power and speed of the selected 2 – stroke Diesel engine are presented in the Table 1, next to the main characteristics of the single, fixed-pitch propeller that is used for the propulsion of the hull. An increase to the selected propeller's diameter is performed to match the selected engine power and speed to the available propeller speed and hull resistance, in respect of vessel's maximum draught and bottom clearance. Due to the change on the propeller's diameter, the corresponding hydrodynamic coefficients are amended accordingly. The main engine simulation model is validated at various loads. A comparison of the propulsion system performance regarding the exhaust gas temperature after the turbine ($T_{E,exit}$), the exhaust gas mass flow rate (\dot{m}_E), the scavenging receiver pressure (p_{scav}), the break specific fuel consumption (BSFC) and the brake power (P_b) of the engine is presented in the Table 2.

Table 1. Engine and propeller characteristics.

MAN 7S80ME – C9.5 Engine				Propeller	
Bore (mm)		800	Diameter (m)		8.9
Stroke (mm)		3450	Blades (-)		5
MCR Power (kW)		30000	P/D at 0.7R (-)		0.997
MCR Engine (rev/min)	Speed	78	A_e/A_0 (-)		0.8

The validation process shows a good correlation between the propulsion system simulation model and the data collected from the manufacturer's engine data report. The greatest deviation from the manufacturer's data is noticed at low engine loads for the brake specific fuel consumption and for the exhaust gas temperature after the turbine. However, the simulation model predicts with high accuracy the brake power of the selected system, which is the main objective of this study. Following the validation of the propulsion system, the developed manoeuvring model is validated against the model presented in (Yoshimura, et al., 2008). The validation of the manoeuvring model is performed independently, disconnecting the main engine's simulation model and setting a constant speed to the propeller. The validation is performed at starboard and portside turning manoeuvres and the results of the process are presented in the Fig. 4.

The validation results of the 3-DOF model show a good prediction of the KCS hull form manoeuvrability in turning circles. A small deviation between the turning circles is caused due to the different propeller diameter that has been selected. After the validation of both propulsion system and manoeuvring model, the first step of the proposed methodology is completed and the developed models that describe the KCS vessel hydrodynamic performance can be coupled for the establishment of the database that is required for the Decision Support Model.

Table 2. Error percentage between the simulation results and the MAN 7S80ME – C9.5 engine’s data at various operational points.

Parameter	25%	50%	75%	90%	100%
P_b	-3.96%	-5.04%	-3.49%	-2.14%	-4.40%
BSFC	5.86%	4.14%	3.95%	3.11%	3.43%
P_{scav}	2.80%	23.10%	5.49%	0.41%	-1.05%
$T_{E,exit}$	8.79%	-0.14%	-2.12%	-1.82%	1.86%
\dot{m}_E	-8.28%	19.57%	9.03%	1.44%	-3.32%

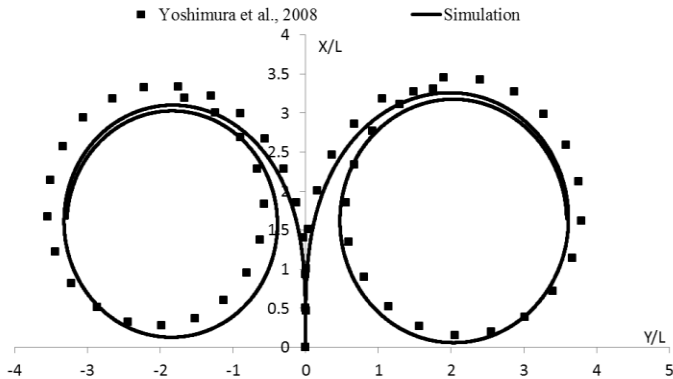


Fig. 4. Comparison of port and starboard turning circle between simulation model and model proposed by (Yoshimura, et al., 2008).

Manoeuvring Scenarios Database

The structure of the proposed Decision Support Model requires the development of a database that can be used for the representation of the own vessel’s manoeuvrability under different scenarios. The control parameters that have been set for the investigation of the coupled system are the ratio of the sea depth over the vessel’s draught, the initial and the ordered engine speed, as well as the ordered rudder angle. The database is produced for two different manoeuvring scenarios (Fig. 5). In the first case, a zig-zag manoeuvre is investigated, assuming that the vessel requires moving to a course parallel to the original. The second scenario investigates the change of the course heading angle to a new one that will allow the vessel to avoid the collision. In the latter case, the selection of the heading angle is used as additional control parameters to the simulation.

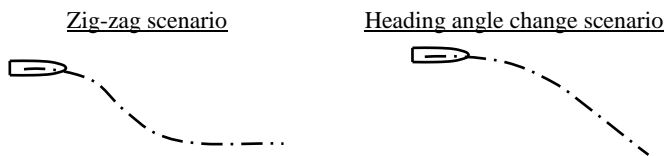


Fig. 5. Zig-zag and heading angle change manoeuvring scenarios.

The possible combinations of the selected control parameters deliver 144 zig-zag manoeuvres and 768 heading angle scenarios, which form the database of the Decision Support Model. The main results stored in the database are the own vessel trajectories coordinates, the vessel and the engine speed before and at the end of each manoeuvre and the timings that the rudder direction changes. Thus, the Decision Support Model is able to approximate the possible courses of the own vessel as well as the rudder change profile that should be followed to perform a manoeuvre. In order to improve further the efficiency on the storage and the reading speed and selection of the established database, the developed trajectories of each investigated scenario are stored as a 7th – order Bernstein – Bezier approximation curves.

During manoeuvring, the vessel performs in dynamic conditions. Although the desired yaw angle and rate are achieved at the end of the manoeuvre, there is a delay until the vessel speed is restored to the steady state condition that corresponds to the selected ordered engine speed. In this case, various scenarios of KCS hull acceleration and deceleration are investigated at various initial conditions in order to feed the Decision Support Model. The control parameters that are used as input variable to describe the acceleration and deceleration of the vessel are the initial engine and vessel speed, the sea depth over the sea draught ratio and the ordered engine speed that is selected by the OOW. The boundaries of the selected parameters are set when the simulation of the various zig – zag and heading angle change manoeuvring scenarios are concluded. The simulation results of the three possible vessel manoeuvres are provided to the Decision Support Model for the estimation of the CPI, depending on the encounter situation.

CPI Estimation Results

The COLREGs procedures identify three possible encounter situations: the head-on, overtake and crossing situations. The procedure that should be followed by each vessel depends on the relative angle of the vessels’ courses (IMO, 1972). In this study, the crossing situation is investigated, considering it as the situation with the greatest probability that may happen during vessel’s lifetime. The main particulars of the target vessel and the initial conditions of the simulation that are set to the Decision Support Model tool are presented in the Table 3. The initial conditions given in the Table 3 lead to a collision between the own and the encounter vessel in case that no action is considered.

Table 3. Target vessel characteristics and initial conditions of the Decision Support Model simulation study.

	Situation ‘A’	Situation ‘B’
Sea Depth/Draught (-)	1,4	
L_{tar} (m)	135	
B_{tar} (m)	17	
$d_{rel}(t=0)$ (-)	$7L_{own}$	
$\theta_{pos,rel}(t=0)$ (degrees)	40	-40
$V_{own}(t=0)$ (knots)	20.5	
$V_{tar}(t=0)$ (knots)	23.3	
$\theta_{v,rel}(t=0)$ (degrees)	-85	85

Concerning the application or not of the COLREGs procedures, two different crossing situations are investigated. In the situation ‘A’, the target vessel approaches the own vessel from the starboard direction. In this case, the own vessel should perform a manoeuvre in order to keep out of the target vessel’s way, following the IMO’s procedures. In the alternative situation ‘B’, the target vessel approaches the own vessel from the portside direction but the OOW of the target vessel does not obey either to the calls of the own vessel and port officers or to the IMO guidelines. In this scenario, the COLREGs limitations are deactivated from the Decision Support Model and the possible options are suggested to the own vessel avoiding the collision.

The simulation on the Decision Support Model is performed for both zig-zag and heading angle change manoeuvres. In the case of a zig-zag manoeuvre the CPI is estimated at various combinations of the ordered engine speed and the rudder angle, whilst in the heading angle change manoeuvre, the desired heading angle of the new course is added as an independent control parameter. The results of the zig-zag manoeuvres in the situations ‘A’ and ‘B’ are presented in the Fig. 6 and Fig. 7 respectively, illustrating the possible CPI for each combination of ordered speed and rudder angle. In the situation ‘A’, the application of the

COLREGs rules implies the OOW of the own vessel to turn the vessel to the starboard direction. Due to that, the collision risk on the portside is assumed to be the highest (100%), discouraging the OOW to turn the vessel to that direction. In case that the vessel continues to sail to the initial course, the risk probability for collision is over 90% and it decreases as long as the ordered rudder angle turns the vessel to the starboard side. The impact of the ordered engine speed to the CPI is smaller than the effect of the rudder angle change but it is still noticeable.

In the situation ‘B’, the available control options of the own vessel are expanded to the rudder turning in both portside and starboard directions. When the vessel comes from the portside without to change her initial course, then the most preferable solution for the own vessel is to turn the rudder to the portside direction and try to keep out aft of the target vessel. This combination provides the minimum collision risk probability. An alternative solution that may be considered is the deceleration of the own vessel. In this case, the collision risk probability remains close to the high-risk zone and the own vessel should keep the initial course or she should perform a zig-zag manoeuvre turning the full rudder to the starboard direction.

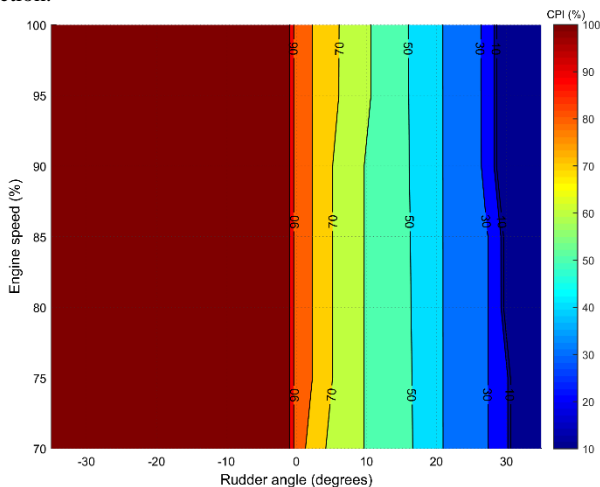


Fig. 6. Estimation of the collision risk’s probability using zig – zag manoeuvres for the encounter situation ‘A’, including the COLREGs procedures application.

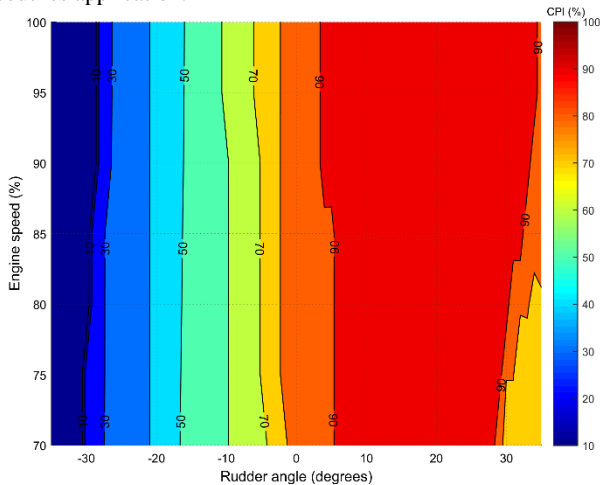


Fig. 7. Estimation of the collision risk’s probability using zig – zag manoeuvres for the encounter situation ‘B’, neglecting the COLREGs procedures application.

Instead of the zig – zag manoeuvre selection, the OOW may change the heading angle of the vessel and follow an alternative course. In that case,

the Decision Support Model takes into consideration the effect of the rudder angle change, the desired new heading angle and the effect of the engine speed. The estimated CPI of the own vessel in the Situation ‘B’ is presented in the Fig. 8 at various ordered engine speeds. The results of the Decision Support Model evaluation indicate that the own vessel has many alternative choices to avoid the collision with the target vessel.

Changing the heading angle to the portside, there are the most available control options that will give a lower CPI than turning to the starboard side. Increasing the ordered rudder angle for portside turn, the probability decreases. Moreover, the impact of the ordered engine speed to the collision probability is greater in this manoeuvring scenario. A decrease to the ordered engine speed reduces the CPI and increases the number of the available ordered rudder and heading angle combinations. Apart of changing the heading angle of the own vessel to the portside, the Decision Support Model indicates a combination of orders that could reduce the probability to the minimum if the vessel turns to the starboard side. The collision avoidance in this scenario is feasible only if the vessel makes a 90 degrees starboard turn, giving ‘Right full rudder’ order. The CPI in this option is further reduced if a lower engine speed is ordered to the vessel.

CONCLUSIONS

In this study the risk probability in near – miss collision situations is investigated for a container vessel. The prediction of the collision risk probability is performed in respect of the hydrodynamic performance of the own vessel, the selected engine’s response and the environmental conditions. During the estimation of the own vessel’s CPI, various parameters are defined to identify the target vessel’s course, as well as the uncertainty on the prediction of the final risk probability.

Through the presented methodology, the available risk control options that can be selected from the OOW to avoid the collision can be evaluated. In order to simplify the orders and the steps that should be followed, the ordered engine speed, the rudder angle and the heading angle are the three main options suggested by the System, predicting the effect of each one of them to the estimated risk probability. Although the results of this study indicate that the rudder angle has the highest impact in avoiding a collision with the target vessel, the impact of the ordered engine speed to the manoeuvrability of the vessel is noted, reducing further the CPI. The selection of the ordered engine speed depends on the specific situation.

The Decision Support Model allows the investigation of any encounter situation independently, taking into consideration the actual manoeuvrability of the own vessel and the impact of the hull clearance to the vessel motions for the prediction of the risk probability. The estimation of the CPI through time simulations gives the ability to the OOW to assess better each situation by increasing the awareness and receiving all the possible actions that should be applied to avoid the collision. The possibilities of this tool are not limited only to the operational conditions of the vessel by assisting the officers on board, but they can be expanded to the initial design phase of a vessel as a tool for the successful assessment of the vessel’s manoeuvrability. The model may also increase the validity of QRA collision models by increasing the accuracy of their ship-to-ship collision probability conditional to an encounter. Finally, the proposed method improves the man-machine interface for the early information of the OOW and the operability of the vessel in terms of safety and manoeuvrability, addressing important challenges of navigation and assisting to the development of the maritime autonomous surface ships context.

However, even if the proposed Decision Support Model can be used for the prediction and the suggestion of the various actions that should be followed to avoid a collision, many aspects of the system can be further

improved individually for the better assessment of the CPI. An additional step that would improve the accuracy of the model is the investigation of the uncertainty during the estimation of the risk probability, taking into account the course and the actions of the target vessel in real time. Further improvements of the developed system may include in the effects of wave, wind and current forces, the investigation of the risk probability in multi-encounter situations and the integration of the support tool to a course planning tool, taking into account the performance of the vessel.

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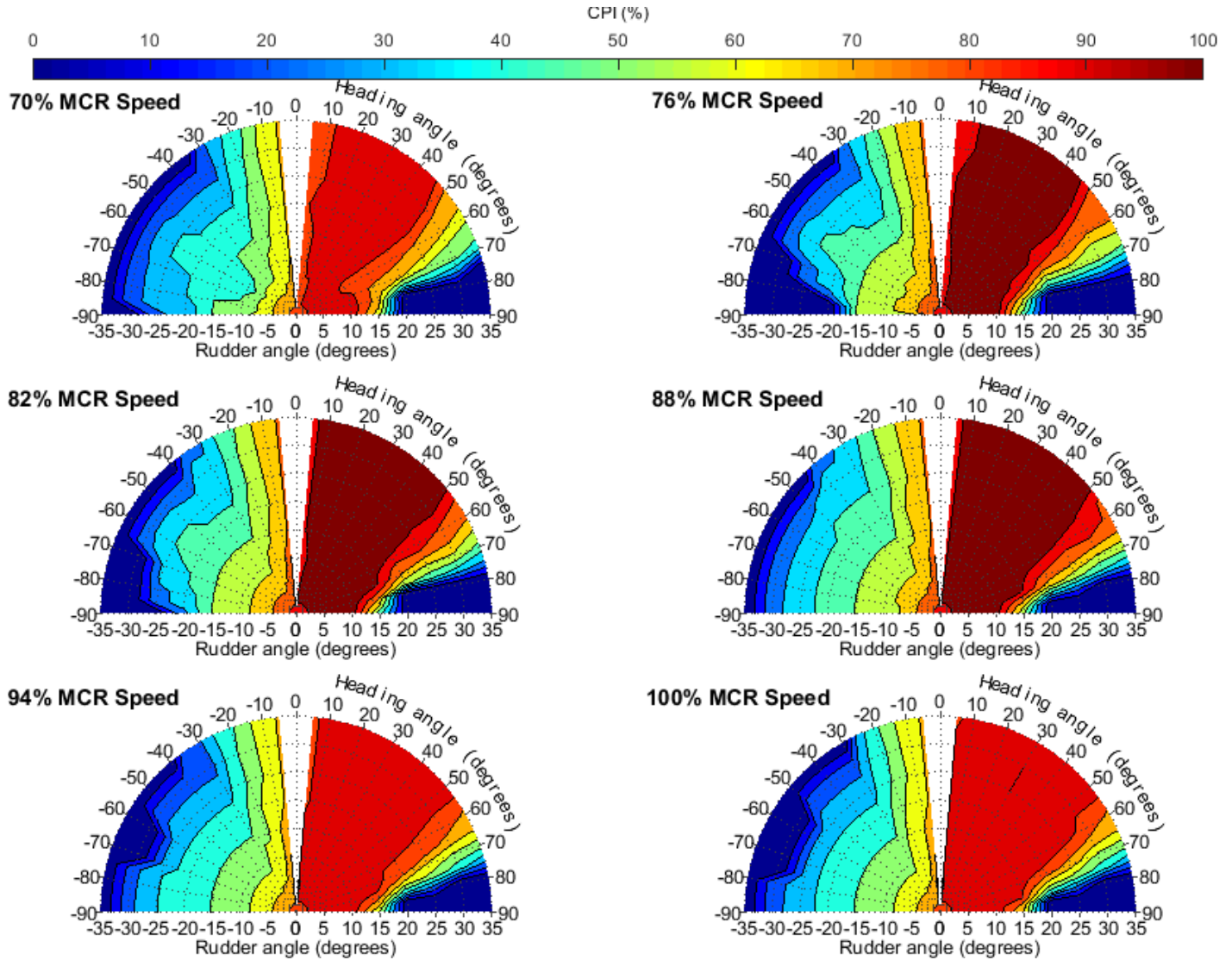


Fig. 8. Estimation of the collision risk’s probability using heading angle change manoeuvres for the encounter situation ‘B’, neglecting the COLREGS procedures application.

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