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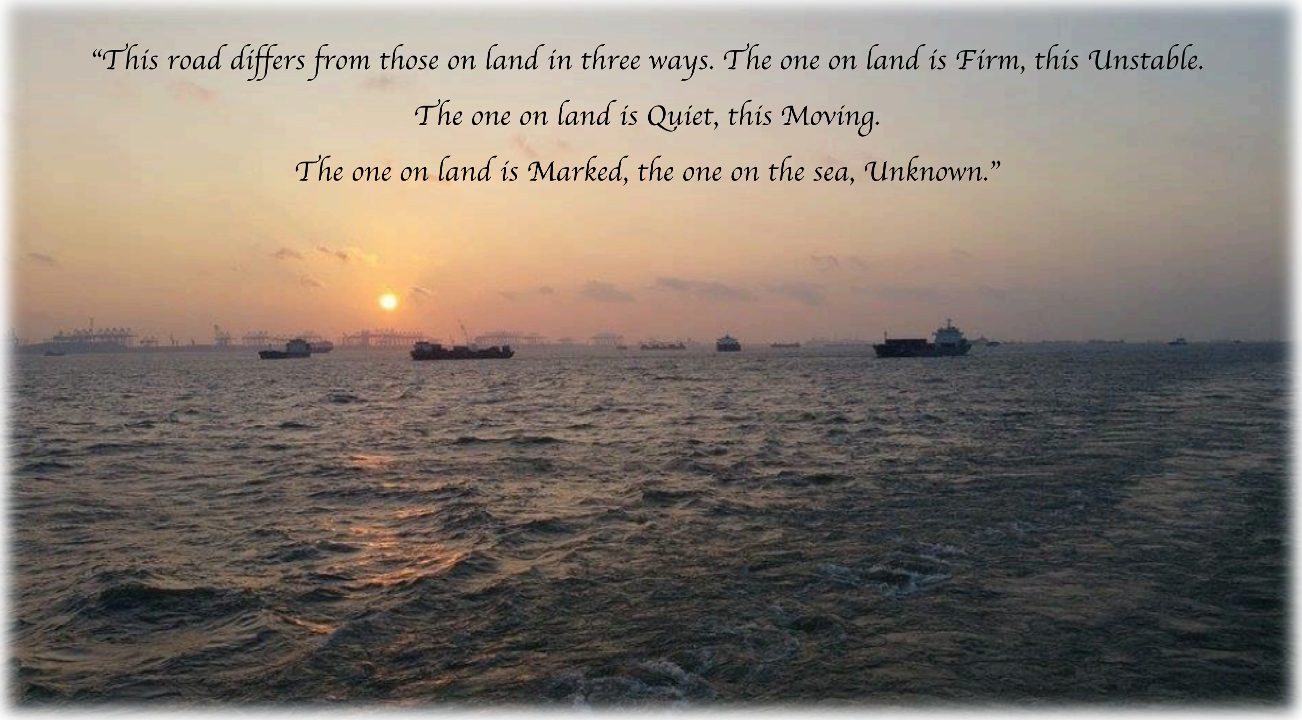

Development of a maritime collision safety index method

Bachelor thesis in Nautical Science

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Gothenburg, Sweden 2018

BACHELOR THESIS 2018:17

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Cover:
Matín Cortés, ”Breve compendio de la esfera” Cited in Arturo Pérez-Reverte:
The Nautical chart

Printing /Department of Mechanics and Maritime Sciences
Gothenburg, Sweden 2018

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Abstract

Safety has always been a topic with continuous progress. Since the 1990s, the shipping industry has been looking into opportunities to introduce modern technology to improve maritime safety. One recent on-going European project that focuses on safe and efficient navigation is called: Sea Traffic Management (STM), but before it gets implemented it needs to be validated. Research has been done to find accurate methods of validation. The method introduced in this paper is a possible basis for this validation.

In this project a maritime collision safety index method has been developed by evaluating the safety in various angles of a two-vessel traffic scenario taking the CPA (Closest Point of Approach) and TCPA (Time of Closest Point of Approach) into consideration. This is a basis that can be used in a multi-vessel traffic scenario. It can be done by splitting up the multi-vessel scenario to each traffic encounter and choosing the collision safety index from the least safe encounter.

The risky zones observed around a vessel were when a vessel is crossing in front of the bow of another, manoeuvrings not according to the COLREG and when the starboard side of a vessel is occupied. The factors contributing to a lower safety index are: rough environmental conditions, heavy traffic, confined waters and technical issues.

Keywords: Sea Traffic Management, traffic situation, collision safety index method, situational awareness.

Sammanfattning

Säkerhet har alltid varit ett ämne i fokus med kontinuerliga försök för förbättringar. Handelssjöfarten har sedan början av 90-talet undersökt möjligheter att införa modern teknik för förbättring av sjösäkerhet. Sea Traffic Management (STM), ett pågående europeiskt projekt som inriktar sig på säker och effektiv navigering, måste valideras innan det kan komma i bruk. Forskning görs för att hitta noggranna metoder för validering. Metoden som beskrivs i denna rapport kan vara en möjlig grund för denna validering.

I detta projekt utvecklades en kollisionssäkerhetsindex-metod genom att utvärdera säkerheten i olika vinklar i en två-trafiks scenario med hänsyn till CPA (Closest Point of Approach) och TCPA (Time of Closest Point of Approach). Detta kollisionssäkerhetsindex kan användas som en grund till en fler-trafikscenario. Detta kan ske genom att dela upp fler fartygs scenario till de olika möten och välja kollisionsindex från det minst säkra möte.

De riskabla zonerna runt ett fartyg visades vara när ett fartyg korsar den andres stäv, manövrar som inte tar hänsyn till COLREG och när styrbordssidan på ett fartyg blir upptagen av ett annat fartyg så manövrering på denna sida inte är möjlig. De faktorer som påverkar kollisionssäkerhetsindex är: svår väderlek, mycket trafik, trånga farleder, och tekniska problem.

Nyckelord: Sea Traffic Management, Trafiksituation, Kollisionssäkerhetsindexmetod, Situations bedömning.

Acknowledgments

The authors would like to thank their supervisor, head of division of maritime studies and lecturer at Chalmers University of Technology, Fredrik Olindersson, for his continuous support, commitment and enthusiasm for this project. His involvement in the validation of the European Sea Traffic Management (STM) project has been an advantage. Additionally, they would like to thank the STM validation team at Chalmers University of Technology, for providing contacts for the interviews and the instructors of the simulator for evaluating the multi-vessel scenarios. Last but not least, the authors would like to express their gratitude to all the officers, for being interested and taking their time to contribute to the development of a collision safety index method that will lay the foundation for the validation of the STM project.

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Abbreviations & Definitions:

AIS: Automatic Identification System: system that shares key information such as identification, position, course, speed, CPA and TCPA between vessels within VHF band range.

ARPA: Automatic Radar Plotting Aid: technical aid for plotting other vessels with radar.

ATM: Air Traffic Management: an aviation term, that is about the procedures, technology and human resources which make sure that the aircraft are guided safely through the sky and the ground and that its managed to accommodate the changing needs of air traffic over time.

BCR: Bow Cross Range: the range at which a target vessel will cross the own ship's bow.

COLREG: International Regulations for Preventing Collision at Sea: international regulations for preventing collision at sea admitted by International Maritime Organisation.

CPA: Closest Point of Approach: the minimum distance from the own ship to another, based on the actual course and speed of the respective vessel.

ECDIS: Electronic Chart Display and Information System: an electronic navigational system that replaces paper charts via presentation on digital display.

EMSN: European Maritime Simulator Network: a macro simulation environment for ship handling simulators in different countries in Europe.

ENC: Electronic Navigational Chart: digital sea charts for ECDIS.

GPS: Global Positioning System: a global radio navigation satellite system that provides geolocation and time information to a GPS receiver on or near Earth where there is an unobstructed line of sight to four or more GPS satellites.

IMO: International Maritime Organisation: The International Maritime Organisation consists of shipping members' states. The organisation is under the UN and controls large parts of the regulatory framework that concerns shipping.

M: Nautical mile: 1852 meters.

MMSI: Maritime Mobile Service Identity: a unique contact number for locating and identifying ships digitally.

MSI: Marine Safety Information: navigation warnings and weather/ice information.

OOW: Officer of Watch: The officer that is responsible for the navigation at the bridge.

SESAR JU: Single European Sky ATM Research Joint Undertaking: is the European public-private partnership that is managing the development phase of the SESAR programme that will give Europe a high-performance ATM infrastructure, which will enable the safe and environmentally friendly development of air transport.

SOLAS: International Convention for the Safety of Life at Sea: a convention that regulates many aspects of shipping, including how ships should be designed and equipped, how to handle cargo and how the journey is to be planned and managed. In addition to the rules for individual vessels, inspection, sea rescues and more are regulated.

STCC: Sea Traffic Coordination Centres: maritime traffic control stations, which are included in the STM concept.

STM: Sea Traffic Management: the shipping's equivalent to the flight coordination system.

TCPA: Time to Closest Point of Approach: the time it takes until your own ship reaches the minimum distance to another vessel based on the current course and speed of the respective vessel.

TSFS: Transportstyrelsens författningssamling: The Swedish transport agency's regulations.

TSS: Traffic Separation Scheme: traffic-flow is separated in lanes according to COLREG Rule ten. Most commonly found in heavily traffic areas with limited operating space or with special navigational risks.

VHF: Very High Frequency: marine communication radio.

VTS: Vessel Traffic Service: depending on the service level, this service has an advisory to a controlling role in VTS-areas that usually are TSSs or port inlets.

1 Introduction

The sea is a road for many bridges; the only thing is that it's unstable and relatively unknown. That is why the Officer of Watch (OOW) needs to make the voyages safe and be in control of the situations that may unexpectedly arise. The International Regulations Preventing Collisions at Sea; (COLREG) was founded by the International Maritime Organisation (IMO) to establish safe navigation practises that prevents collisions. In 1889 in Washington, the first international conference was held to discuss maritime regulations. The rules that were presented as proposals were enforced in 1897 in the Unites States, UK and in other countries. In 1972 a conference was held to establish a new format in London due to radar-related accidents. The new amendments and the changes were introduced during the conference and came into force later in 1977 (Cockcroft & Lameijer, 2004).

Navigators shall be skilled officers; they need to know how to handle the equipment they work with and have situational awareness. Through the years the advancement of the navigational equipment brings more and more tools to strengthen the officers' ability for making the right decisions. Today's bridge equipment gives the OOW a range of information about the current traffic situation as well as the historical track data. For the establishment of a comprehensive and broad situational awareness, a significant component is missing: the intention route of the approaching vessels. After all, the decisions are made primarily to affect future traffic situations, which must be anticipated by the OOW when making the actual decisions.

Although new navigational equipment is often combined with enhanced computer-based systems installed on ships' bridges, collisions still occur. Marine accident investigations dealing with collisions, performed by the Nautical institute showed that 24% were due to insufficient assessment, 23% due to poor look-out and 13% showed that the vessels were completely unaware of each other until or just before they collided (Baldauf, Benedict, Fischer, Motz and Schröder-Hinrichs, 2011).

A recent European project: Sea Traffic Management (STM) is taking the next step of hopefully making navigation safer. To do that, the system needs to be validated to conclude if it increases the situational awareness of the officer. However, the question is, where is the line drawn between safe and unsafe? In this paper we are going to explore the terms of safety in various traffic situations to develop a collision safety index method.

1.1 Purpose

The purpose of this study is to develop a collision maritime safety index method, with consideration to CPA and TCPA in six different two-vessel scenarios. This method can be useful when comparing the enhancement of the traffic safety in various situations; it can also be used when implementing new regulations or navigational systems.

1.2 Question

- How can a maritime collision safety index method be developed?
- Are there any combinations of CPA and TCPA with particularly high risk in the defined scenarios?
- Which other factors except CPA and TCPA, are affecting the value of the collision safety index?
- Are CPA, TCPA and type of situation between two vessels sufficient factors to assess a general traffic situation with multiple vessels?

1.3 Delimitation

Traffic situations at sea normally include multiple vessels, but in this project traffic situations with two vessels with equal ship´s particulars have been carried out. The scenarios were under the same environmental conditions such as good visibility, good weather conditions and open sea. Due to the lack of time, aspects as: human factors, rough environmental conditions, confined and shallow waters, navigation in Traffic Separation Scheme (TSS), technical issues and efficient flow in the marine traffic, were disregarded.

2 Background

Many research studies have been done concerning anti-collision. In the 1970s, the concept of ship domain was introduced with various designs until 2006 (Wang, Meng, Xu & Wang, 2009). Recently the STM project, including the MONALISA as a forbearer project, provides improvement and development of efficiency in order to ensure a safer and environmentally friendly maritime industry. STM services enable on-shore personnel as on-board personnel to assess the situation based on real-time information. Some examples of these services are: route optimisation, ship-to-ship route exchange, enhanced monitoring and port call synchronisation. Proper application of the STM services would reduce risks related to human factors, appropriate steaming, in time arrivals and reduced administrative burden (Lind, Hägg, Siwe & Haraldson, 2016). Today STM is in validation phase, so validation and safety concerning methods are being developed.

2.1 Ship domains

The concept of ship domain, which was first defined by Fujii and Goodwin in the 1970s, has been a major contribution in the assessment of a navigational situation and the avoidance of vessels collisions. Humans tend to have a personal area around them that should remain clear from threats. In the maritime this area is referred to as the ship domain. Violation of the ship's domain tends to be a threat to navigational safety (Pietrzykowski & Uriasz, 2009).
Over the past 30 years, many research studies have presented various ship domains with different shapes and sizes taking into account different factors affecting the domain parameters. The models are described in a geometrical manner which is easy to understand but not applicable in practices or simulations. (Wang, Meng, Xu & Wang, 2009)

2.1.1 Circular ship domains

Goodwin designed a ship domain in 1975 that is divided in three sectors: the two arcs of a vessel's sidelights and the stern light, as shown in Figure 1a. In the 1980s, Davis designed a simpler modified ship domain, as shown Figure 1b. The ships domain is a circle of which the area is equal to the total of segments of the Goodwin design, but the position of the vessel is off-centred. It consists of two circles, where the second one with the vessel off-centre, referred to as the vessel arena, should not be violated (Wang, Meng, Xu & Wang, 2009).

In 1993, Zhao et al. introduced a fuzzy ship domain that can be shown as the broken lines in the Figure 1a. It is based on the Goodwin design using fuzzy theory, where the safety boundary in the ship domain is uncertain. (Wang, Meng, Xu & Wang, 2009).

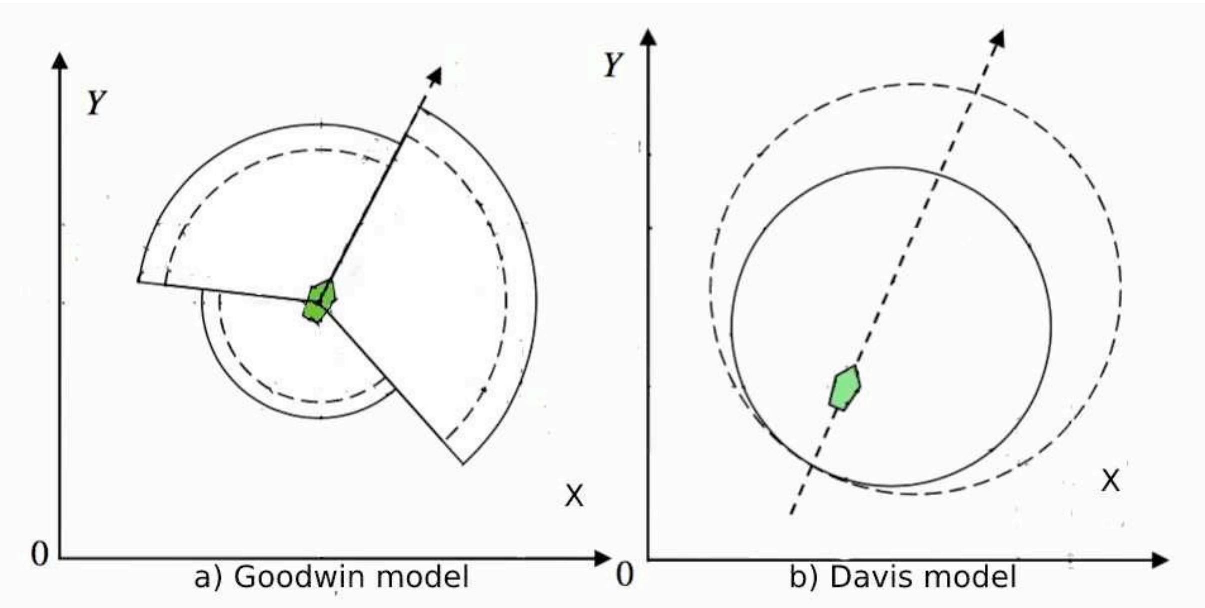


Figure1.   Circular ship domains

2.1.2 Elliptical ship domains

The first elliptical ship domain was introduced by Fujii in 1971 from countless recorded data registering the vessels position and trails in Japanese waters by statistical methods. The design is an ellipse as shown, in Figure 2a, of which the geometrical centre is identical to the position of the vessel. In the 1980s, Coldwell introduced another elliptical ship domain, shown in Figure 2b, using related statistical methods for head-on and overtaking encounters in restricted waters. The design is a half ellipse of which the geometrical centre is no longer identical to the position of the vessel for the head-on design. Figure 2c shows an ellipse with the vessel on the geometrical centre. Later in 2001 and 2003, Kijima introduced a new ship domain by a combination of the two ellipses, a design of a dynamic ship domain, which accounts for ship dimensions, manoeuvrability, encounters situations and target ship states (Fig.2d) (Wang, Meng, Xu & Wang, 2009).

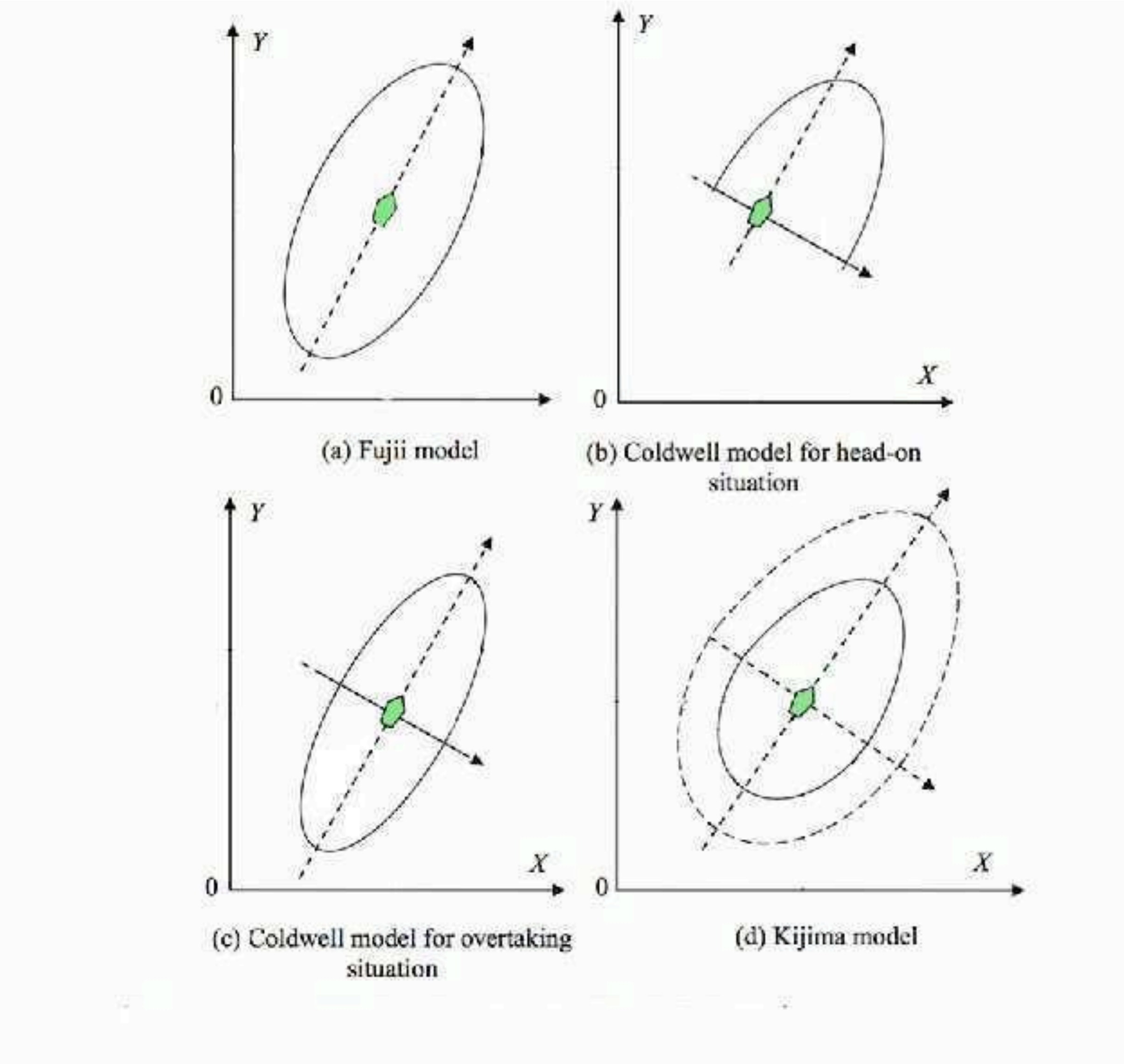


Figure2. ***Elliptical ship domains***

2.1.3 Polygonal ship domains

Smierzchalski in 2001, 2003 introduced a design as shown in Figure 3a that is a hexagon defined on the basis of dynamic parameters of own ship and other targets. This analytical method makes it possible to define a ship domain precisely; however, the human factor has not been taken in account. Later in 2004, 2006 Pietrzykowski designed the model in Figure 3b. He defined ship domains as polygons of which the shapes depend on the discretization step of the targets' ship course and usually is octagonal since the discretization steps adopt 45° angle. (Wang, Meng, Xu & Wang, 2009).

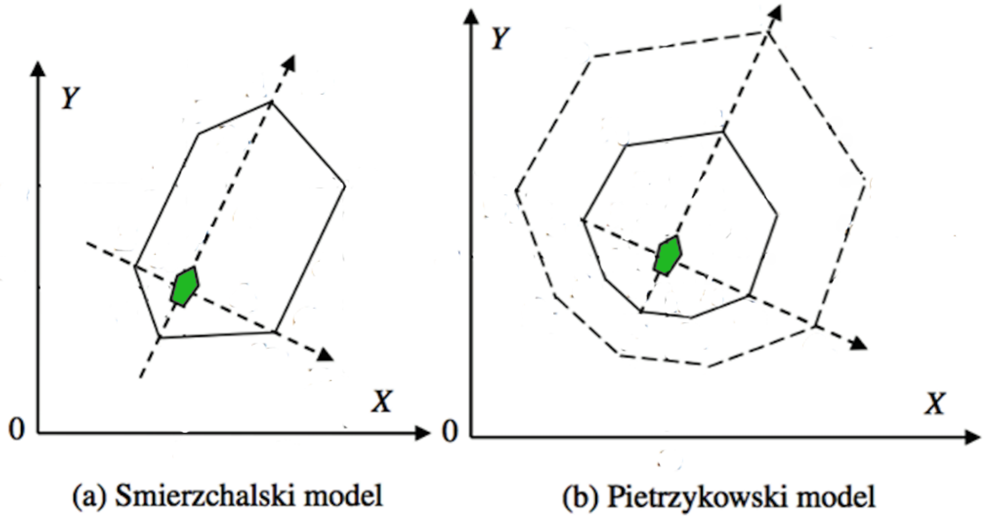


Figure3. Polygonal ship domains

2.2 Sea Traffic Management

Over the years many efforts have been made to improve safer transportation. Due to the fact that the new technology is growing rapidly, and in a world where our environment is at stake, the European project; STM was established. It was inspired from the Single European Sky ATM Research Joint Undertaking (SESAR JU) programme, which produced Air Traffic Management (ATM) as one of its results. SESAR JU was created by the European Commission in 2007 to tackle the increase of air traffic, which resulted in an increase of the flying costs in Europe due to greater delays and high emissions of CO_2 (Gurtner, Bongiorno, Ducci & Micciche', 2016).

In a world where the digital information on-board and on shore is abundant, STM proposed that sharing information to optimise the maritime transport chain would increase safety and sustainability. Nowadays the shipping industry connection is point-to-point; that prevents the opportunities from becoming more efficient and profitable. The vision of STM is a maritime world where the crew focuses on safe navigation instead of reporting and where the port calls become even more efficient. By providing vessels with the ability to see each other's planned routes, navigators get a more complete picture of how surrounding vessels will influence their voyage. The enhanced situational awareness on the bridge and the comprehension of planned routes will help optimise planning as well as reduce the number of incidents and accidents. Reduced number of fuel and cargo spills is also an advantage for the environment (Lind et al., 2016).

Other services of STM are able to provide information and offer advice to vessels on their routes, such as recommendations to avoid congestion in areas with high traffic, potential hazards, avoidance of environmentally sensitive areas and maritime safety information (MSI). Planning and performance regarding arrivals, departures and turnaround times will be improved between vessels and port actors by changing information. As a conclusion, all actors involved in the transport can be better prepared and their resources can be utilised more efficiently. Shorter routes, just-in-time arrivals and shorter port calls are factors that will strengthen the competitiveness of the maritime sector. As a result, making maritime shipping the main transportation option for more goods would create significant additional value for the maritime transport chain (Lind et al., 2016).

2.3 MONALISA

The STM started with the research project MONALISA 1.0 between the years 2010 and 2013 and then continued as MONALISA 2.0 from 2013 to 2015. Their focus was to introduce STM in the Baltic Sea Region. The MONALISA introduced the Sea Traffic Coordination Centres (STCC) on land; the STCC took part in the ships' travel planning by collecting route information. Today we have Vessel Traffic Service (VTS) stations that advise or specifically control TSSs or port inlets. The STCC provided additional services including, comprehensive strategic services to vessels using Electronic Chart Display and Information System (ECDIS). The STCC could recommend alternative routes based on factors such as: squat, fuel saving, weather and MSI (Gustafsson & Åding, 2014).

2.4 Other Safety index methods

To validate the effect of implementing STM, tests were done both on real vessels and in simulator environments. To indicate if the new equipment will increase safety or not, a safety index has been developed by Olindersson, Bruhn, Scheidweier & Andersson (2017) taking into account both the probability of grounding and collision.

The survey consisted of 145 different traffic situations and 42 maritime traffic experts were surveyed to evaluate a safety index in 50 randomly chosen traffic situations. A safety index number was assessed from zero to ten, where: zero indicated: collision, one: immediate danger, five: medium risk of collision and ten, a totally safe situation. The survey contained traffic situations such as:

- Two-vessel situations
- Traffic situations in TSS
- Traffic situations on shallow waters
- Situations where one vessel has made an avoiding manoeuver
- Multi-vessel situations

The concluded results were the following:

1. Crossings from the port are considered to be less safe than crossings from the starboard.
2. Overtaking situations are considered to be less safe if the target vessel is located on the starboard side of the ship.
3. In a crossing situation with a vessel passing ahead of the own ship with a Closest Point of Approach (CPA) of one nautical mile (M), the less safe situation is when the target vessel still has to pass the heading line within a Time of Closest Point of Approach (TCPA) of four minutes.
4. A situation with a CPA of zero M, a head-on situation is assessed to be safer than a crossing situation with the same TCPA.
5. If an avoiding manoeuver has been made by a target vessel on the port side of the own ship, the situation is assessed to be safer than if the give-way vessel did not make that manoeuvre.
6. In multi-vessel situations the safety index is always equal to or lower than each individual situation.

7. In situations where the own ship has another vessel on her starboard side, which makes an avoiding manoeuvre more difficult, then the safety index results in considerably lower values compared to other situations (Olindersson et. al., 2017).

2.5 Route exchange and International Regulations for Preventing Collisions at Sea

In a study about the relation between, route exchange ship-to-ship and COLREG by Gustafsson & Åding, (2014) it was indicated that route exchange gave an enhanced overview and increased the understanding of traffic situations. It was also found that the rules in COLREG do not need to be changed. On the other hand, it showed that route exchange would affect and simplify most of the regulations by its implementations. Route exchange will be used as a system to determine if there is a risk of collision and also as an additional source of information to provide better assessment for the OOW who is in charge of making the decisions (Gustafsson & Åding, 2014).

3 Theory

Safety management and its implementations is one of the imperative factors that affect all elements of the maritime industry. International regulations, conventions and guidelines set the boundaries of safety and efficiency in shipping. Consequently, evaluation and the improvement of advanced technology in the maritime industry has brought changes in the existing system by presenting new equipment with the aim of minimising danger.

According to International Maritime Organization (IMO), risk is a “combination of the frequency and the severity of the consequence”. The factors that play an important role in an organisation´s decision-making in risk assessment are human behaviour towards facing new issues, their situational awareness and constant vigilance of those involved.

After the Titanic disaster, many changes have been made in regard to navigational safety of the regulation terms and technology. Dependence on certain technology may lead to accidents; however, some of the new technologies that have substantially improved the maritime industry are as follows:

- RADAR for anti-collision
- AIS for identifying and locating vessels
- VHF for communication
- ECDIS for anti-grounding

Navigation in the shipping industry has become considerably safer during the past decades, but further developments of technologies bring new challenges. The shipping industry will deal with these challenges in order to provide solutions for future problems.

3.1 Safety and risk

Safety can be defined in very general terms as a system’s condition or a status free of danger according to Baldauf et al. (2011) meaning free of hazards and error enforcing conditions. In engineering terms, “risk” is often defined as a combination of the frequency of failure in a hazardous environment and its consequences. The so-called As Low As Reasonably

Practicable principle aims to reduce risks to a negligible or at least a tolerable level in safety-critical systems. Acceptable risk can be seen as the borderline between a safe and an unsafe status of a system or process (Baldauf et. al., 2011).

In maritime safety, the risk of collision and grounding are two operational risks. The factors that affect the risk of collision are the distances between the specific vessels, the relative speed and the difference in the ship's heading, the vessel type, its difference in size and manoeuvrability (Baldauf et. al., 2011). That is why collision and grounding avoidance are the main task of the OOW. Many technical solutions are provided in order to assist the human operator who is dependent on the reliable use of the highly automated human-machine systems on the ships bridges for a safe and efficient ship operation. Here it is important that the information flow between the OOW and the machines is adapted to their skills and abilities. Today there are complex decision support systems. Information is collected from different sensors and systems are combined in integrated navigation and bridge systems that provide the OOW with warning facilities of any potentially dangerous situation.

3.2 The OOW tools for anti-collision

The primary purpose of safe navigation is to avoid collision and grounding. ARPA (Automatic Radar Plotting Aid), AIS, VHF radio and ECDIS are tools that can be used during navigation, whenever in harbour or offshore, and they represent the knowledge of navigation and collision avoidance. Using these tools properly and judiciously expands the OOW´s situational awareness.

According to COLREG rule seven, "Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist." The OOW is responsible to know all the equipment and make sure that all necessary tools have been used for a safe navigation without relying upon only one aid.

3.2.1 Radar

A basic instrument for navigation at the bridge that does not depend on other instruments is the radar. It can show the other vessels by using only their echoes. It sends the information through Very High Frequency (VHF) and cannot show vessels that are far away or in radar shadow which is also depended in the earths curving. Radar does not show any information about the vessels identity either (Lin & Huang, 2006).

The radar can continuously be tested for its functionality by the OOW. During the process of situation assessment, the OOW has to evaluate and assess the results of observations in order to detect any risk of collision. When a developing or existing risk of collision is detected, the OOW has to decide when and how to avoid the potential danger, usually by a manoeuvre to increase the expected passing distance. On the radar the OOW can plot the targets that are in danger and ARPA will show their vectors and calculate the targets: course, speed, bearing, CPA and TCPA. The OOW will then make a decision if the vessel is in a potential risk of collision, where an action must be taken according to the COLREG. The effects and the consequences of the action shall be followed and monitored. Sometimes the OOW needs to correct or adjust the manoeuvre. After the safe passing, the vessel has to be brought back to the original path and course respectively (Lin & Huang, 2006).

3.2.2 Automatic Identification System

AIS equipment is used to send information mainly between ships and land stations. It sends and receives static, dynamic and travel-related information. Depending on the type of data, updating of information differs slightly. Static and travel data including vessel dimensions, names, Maritime Mobile Service Identity (MMSI) numbers, destinations and navigation status are updated every six minutes. Dynamic data, such as speed and course over ground from the vessel's sensor, is updated every three minutes for vessels at anchor and approximately every ten seconds for moving vessels depending on speed and course changes.

The advantages of the AIS according to Stitt (2004) are that in an early stage it can show if the AIS-target has changed its status. For example, if a vessel suddenly becomes under restricted manoeuvrability the AIS will show the status change before it can be visualised by vessel lights or day signals. AIS shows the targets and their information much quicker than the ARPA.

The disadvantages with AIS, according to Lin & Huang (2006), are that not all the vessels are equipped with the system. Vessels can also switch off their AIS for different reasons, like in a piracy attack. AIS is additionally dependent on GPS information so if the GPS system displays an incorrect position, that is transferred to the AIS system. Likewise, if the GPS equipment stops functioning, the AIS system stops functioning as well. The given destination on AIS is optional and since it is inserted manually by the OOW it may be incorrect.

3.2.3 Very High Frequency

At sea, the radio frequency is sent by VHF band and it is used for emergency, safety and standard communications. It is also used for communication between ships, VTS and coastal radio stations. The communications on VHF shall not be used to make agreements that have already been stated in the COLREG (Stitt, 2003). The disadvantage of VHF communications is that language misinterpretations can lead to misunderstandings.

3.3 International Regulations for Preventing Collisions at Sea

The basics for actions to avoid collisions are laid down in the COLREGs. In the Swedish Transport Agency's regulations (TSFS 2009:44), all the 38 maritime rules of COLREG have been implemented. Rules one to three are general rules, concerning application, responsibilities and definitions while 4 to 19 are referred to as control and sailing rules. Rule 4 explains that rules 4 to 10 apply under all visibility conditions. Rule 11 explains that rules eleven to 18 apply to ships in view of each other. Rule 19 concerns ships performance in reduced visibility. The other rules concern signal characters and audio/light signals.

3.3.1 COLREG Rule 5: Look-out

On board constantly, sharp look out shall be maintained. Sight, hearing and all the available means in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

3.3.2 COLREG Rule 7: Risk of collision

In this rule it is said that all the tools have to be used right to determine if there is a risk of collision. If there is the minimum insecurity, risk of collision exists. The radar plotting should be done at an early stage to determine the risk. A risk also exists when the compass bearing of another vessel does not change. Even when it does, a risk of collision may exist if the distance is reducing to a large vessel or a towed object.

3.3.3 COLREG Rule 8: Action to avoid collision

Action to avoid collision should be taken visibly in ample time and with good seamanship. The alternation of course or speed to avoid a collision shall be large enough to be readily apparent to the other vessel. The effectiveness of the action shall be carefully checked until the other vessel is finally past and clear. If necessary to avoid a collision or allow more time to assess the situation, a vessel shall slacken her speed or take all way by stopping or reversing her means of propulsion. A stand on vessel is not relieved of this obligation and has to act if the other vessel is approaching so as to involve a risk of collision.

3.3.4 COLREG Rule 10: Traffic separation schemes

A vessel using a TSS, shall follow the direction of the traffic lane, keeping clear from the separation line/zone, joining or leaving a traffic lane with a small angle. Crossing the TSS shall be avoided, if needed to be done; it shall be done by a right angle. A vessel shall not use an inshore traffic zone or separation zone only in case of safety, to and from harbour, offshore installation or structure and in case of a pilot station. On the other hand, vessels of 20 meters, sailing vessels and vessels engaged in fishing may use inshore traffic zone and a separation zone. A vessel navigating in areas near the termination of a TSS shall do so with particular caution. A vessel not trafficking in the TSS, shall avoid as far as practicable from it. Anchorage shall be avoided in the TSS or in areas near its terminations. A vessel engaged in fishing, sailing and a vessel under 20 meters should not impede the passage of any vessel following a traffic lane. Except for a vessel restricted in her ability to manoeuvre when engaged in an operation for the maintenance of safety of navigation and while engaging in the operation for the laying, servicing or picking up of a cable.

3.3.5 COLREG Rule 13: Overtaking

A vessel shall be deemed to be overtaking with coming up with another vessel from a direction more than 22.5 degrees abaft her beam. The overtaking vessel shall keep out of the way of the vessel being overtaken. When a vessel is in any doubt as to whether she is overtaking another, she shall assume that this is the case and act accordingly.

3.3.6 COLREG Rule 14: Head-on situation

When two power-driven vessels are meeting on counter or nearly counter courses so that risk of collision can be involved, both vessels shall alter course to starboard so that each shall pass on the port side of the other.

3.3.7 COLREG Rule 15: Crossing situation

When two power-driven vessels are crossing so that risk of collision can be involved, the vessel which has the other on her own starboard side, shall keep out of the way and shall, if the circumstances permit it, avoid crossing ahead of the other vessel.

3.3.8 COLREG Rule 16: Action by give-way vessel

Every vessel that is directed to keep out of the way of another vessel, shall, so far as possible, take early and substantial action to keep well clear.

3.3.9 COLREG Rule 17: Action by stand on vessel

The stand on vessel shall keep her course and speed. If the give-way vessel does not act according to the rules, then the stand on vessel has to manoeuvre to avoid a collision. The stand on vessel shall never alter her course to port when she has a vessel on her port side.

3.3.10 COLREG Rule 19: Conduct of vessels in restricted visibility

In restricted visibility the vessel shall always be ready for a manoeuvre. A manoeuvre to port for a vessel forward of the beam, shall be avoided, other than for a vessel being overtaken. An alteration of the course towards a vessel abeam or abaft the beam shall be avoided.

3.4 Electronic Chart Display and Information System

Paper charts are nowadays more and more becoming memories; they are getting replaced by ECDIS, an electronic navigational system on a digital display. The shipping industry has been looking into opportunities to introduce modern technology since the early 1990s. In 2010 the IMO introduced a mandate for ECDIS on certain types and sizes within the International Convention for the Safety of Life at Sea (SOLAS) regulation between the years: 2012-2018 (IMO, 2018). ECDIS works by displaying Electronic Navigational Charts (ENC) on displays and sensors as GPS and gyro that are integrated so that the position of the own ship, heading, course and speed over ground are displayed.

3.5 E- navigation

ECDIS was the first step towards the future of new technologies within e-Navigation where safety and ship efficiency around the world is a priority. This concept changed the ship-focused navigational support to a bridge-shore integrated planning and navigational concept. The aim of e-Navigation is to integrate data streams, resulting in information for situational awareness, which enables better-informed decisions for mariners on ships and support teams on shore (IMO, 2018).

Route exchange is the new navigational tool within the IMO concept of e-Navigation (IMO, 2018). Route exchange would be visually displayed in the ECDIS as an optional alternative to the targets seen in the AIS. It would also be possible to change the waypoints with regard to MSI and traffic situation, so that other ships will be able to perceive this. Furthermore, VTS could be more in control, by proposing a modified route to a ship if they consider it necessary for safety and detecting ships that deviate from their planned route (Gustafsson & Åding, 2014).

COLREGs rules five and seven: “Sight, hearing and all the available means in the prevailing circumstances and conditions shall be maintained so to make a full appraisal of the situation and of the risk of collision” and “all the tools have to be used right to determine if there is a risk of collision…” This indicates that all useful resources like route exchange are possible new technologies that can be used and also be included in the definition of the look out. To avoid a collision: “all available means shall be used, and route exchange shall be one of them” sated a COLREG expert (Gustafsson & Åding, 2014).

4 Method

The project consists of two main tasks, interviews and evaluation of the results for a collision safety index method based on empirical data.
Interviews were conducted with active officers in order to investigate relative safety in six different traffic scenarios. Research and previous studies have been conducted in order to form efficient interviews.

4.1 Interview

The choice of the face-to-face interview provides a practical overview and prevents any misinterpretations of the questions compared to questionnaires. Gathering and analysing the participants' experiences and opinions has been crucial to collect relevant data. Interviews can be done in two ways: either open or more structured. An open interview will allow the interviewee to explain his/her experiences more freely, compared to structured or semi-structured interviews, where the interviewer predetermines the questions that focus on a particular subject (Denscombe, 2017). The project used semi-structured interviews, with a number of core questions that were the same for all interviewees. The questions were based on the previous literature studies in the field of traffic situations and safety with the addition of questions regarding future technologies. Using a semi-structured interview mitigated the chance of interviewees answering out of the scope of this project.

Thirteen active officers were interviewed at a place and time they were best able to concentrate for a high performance. Four of them were pilots having ten to twenty years of experience. Three masters from ten to thirty years of experience. One first officer, sixteen years in cruise-vessels. The rest five, were second officers with an experience from a couple of months up to six years. All the above officers had been serving in all the different type of vessels.

4.1.1 *Interview structure*

The interview structure consisted of three parts: the introduction questions to the project, evaluation of the matrices of six different traffic scenarios and concluded with the excluded factors to the defined traffic scenarios.

4.1.1.1 *Introduction to the interview*

The introduction part of the interview consisted of nine questions. Interviewees were asked to present themselves. After the interviewees presented themselves, they were introduced to the aim of the interview, a general overview over situational awareness in traffic situations.

4.1.1.2 *Matrices with traffic scenarios*

Coming to the core discussion, which was the main part of the project, where the officers evaluated six different traffic scenarios with a collision safety index for each and every one. The following six scenarios were presented:

- Head-on situation
- Crossing from starboard side
- Overtaking from starboard side
- Overtaking from stern
- Overtaking from port side
- Crossing from port side

It was assumed that the officers were on a 200-meter long power-driven vessel with a speed of 15 knots. Another vessel with the same size with different CPAs and TCPAs according to the matrices was passing from the six different angles as listed above with the same speed. An exception to these conditions was the overtaking scenarios where the overtaking vessel had a speed of 17 knots. The officers were asked to assign a safety index value from 1 to 10 where zero indicates collision, 1 indicates immediate danger, 5: medium risk of collision and 10 indicates a totally safe situation. They were often reminded that they needed only to evaluate the safety of the present situation, not the manoeuvring action to avoid a collision.

A matrix from the crossing from the starboard side scenario is presented below. The other matrices are included in the Result section.

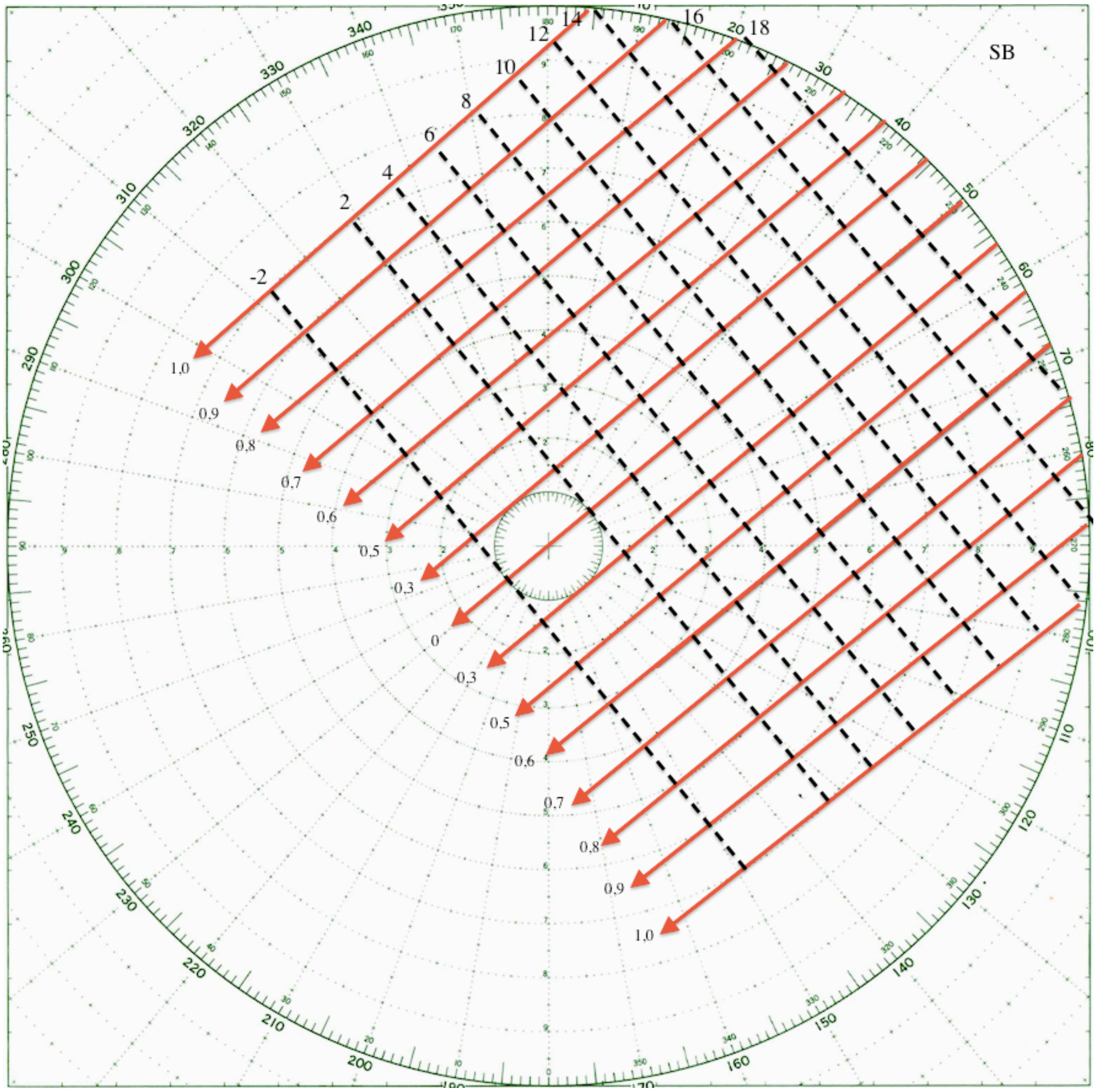


Figure 4*. Second scenario, crossing from the starboard side, own ship head up*

4.1.1.3 Conclusion and exclusions

To conclude the interview the officers were asked eight questions with excluded factors that were not taken in consideration in the matrices. There were also further discussions about present and future tools. The questionnaire is attached at the Appendix 1.

4.2 Simulation

To validate the results of the collision safety index from the interviews, the results were applied in a simulation of three multi-vessel scenarios that were made at the bridge simulator at Chalmers University of Technology. Six experienced simulator instructors were assigned to evaluate a collision safety index every minute from the perspective of the own ship. The simulator instructors had been working as instructors at the simulator of Chalmers University of Technology up to 18 years. They have been from second officers to masters with up to 20 years at sea. The three multi-vessel scenarios are shown in Appendix 3.

4.2.1 Multi-vessel scenario one

In the first scenario, four vessels were approaching; the own ship is the north-going vessel. Target one was crossing on her starboard bow with a CPA of one M, target two on the port bow with a CPA of one M and the third target was overtaking her on the starboard side with a CPA of 0.5 M.

4.2.2 Multi-vessel scenario two

In the second scenario, three vessels were approaching, and the own ship is likewise the north going vessel. Target one was a head on vessel with a CPA of zero M and target two a port crossing with a CPA of zero M.

- 14th minute target one change course to starboard
- 15th minute target two changes course to starboard
- 16th minute target one goes back to original course
- 19th minute the own ship alter course to starboard
- 24th minute the own ship goes back to original course

4.2.3 Multi-vessel scenario three

In the last scenario, three vessels were approaching. The focus was on the own ship that is the north-going vessel as in the previous scenarios. Target one was crossing from the starboard with a CPA of one M and target two was overtaking on the port side with a CPA of 0.5 M. In the eighth minute, the own ship altered course to starboard.

The mean values from the two-vessel scenarios that are presented in the appendix 2 were applied in the evaluation of the instructors' multi-vessel scenarios in consideration to CPA and TCPA. This was done by splitting up the multi-vessel scenario into each and one individual traffic encounter between the own ship and one target at the time. Then, the least safe traffic encounter between the two vessels was chosen and was compared to the safety index given by the instructors in their every minute evaluation of the whole scenario being on the own ship.

5 Result

5.1 Introduction questions

The officers were asked at the first phase of the interview what makes them insecure in a traffic situation. The factors of insecurity when being at the bridge and having to make decisions are listed below; the most common where when the other vessel does not follow the COLREG, being in restricted waters, unexpected intentions by the other vessel and the unexpected manoeuvrings of fishing vessels.

<u>Regulation factors:</u>

- Unexpected intentions
- Confined waters
- Meetings in strange angles
- Crossings in front of the own vessel
- The other vessel does not follow COLREG.
- Many other vessels have to give way to the own ship at the same time

<u>Human factors:</u>

- Fishing vessels
- Miscommunication on VHF
- The other vessel alters course too late
- The other vessel suddenly speeds up rapidly
- Hesitant if the other vessel has seen the own ship

<u>Environmental factors:</u>

- Rough weather

5.2 Evaluation of the matrices

Respondents assigned a collision safety index to each intersection between CPA and TCPA in the matrices shown below in the Figures: 5, 7, 9, 11, 13 and 15. To estimate the collision safety index the mean values of all data was used. Three colours were chosen to easily distinguish the zones. For more accuracy the results are presented in the Appendix 2. Red colour was chosen to indicate the most dangerous area with a safety collision index between 1 and 3.5 inclusively. Yellow colour indicates a relatively safe area with a safety collision index between 3.5 and 6.5 inclusively. Green colour indicates the safest area with a safety collision index greater than or equal to 7. The colour scale division is based on the parameters of the safety index scale from 0 to 10 as given in the beginning of the interview. The results are shown in the following Tables: 6, 8, 10, 12, 14 and 16.

5.2.1 Scenario one, head-on situation

The most unsafe zone according to the first scenario in Figure 5, when two vessels are meeting on a counter and nearly counter course, is when the other vessel is right ahead, on a counter course, and it is six minutes left for a collision. The most unsafe zone is also when the head-on vessel on a nearly counter course is passing the own vessel with a CPA of 0.3 M at a TCPA of two minutes at her starboard side. According to COLREG rule 14 regarding head-on situations: "When two power-driven vessels are meeting on counter or nearly counter courses so as to involve risk of collision, both vessels shall alter course to starboard so that each shall pass on the port side of the other". This is clearly shown the figure 6 where the most unsafe zone is shown to be on the starboard side of the own vessel when the nearly counter-coursed vessel is passing her starboard side since the right passage according to the rule is on the port side. It is stated to be less safe when the passing is done at the starboard side. The safe zone is indicated to be when the head on vessel is passing the own ship at 0.5 M CPA on her port side and 0.6 M on her starboard side.

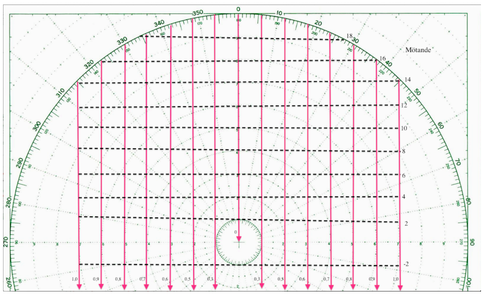


Figure 5. ***Traffic scenario one, head on situation***

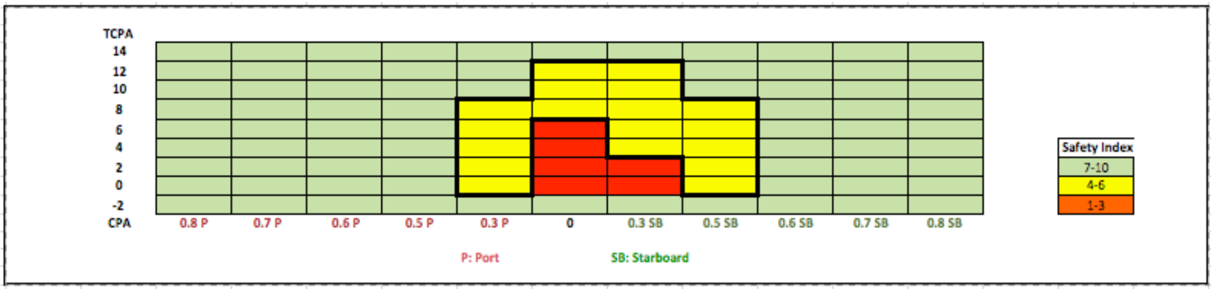


Figure 6. Results from the collision safety index after evaluated the on head on scenario

5.2.2 Scenario two, crossing from starboard side

The second scenario was a crossing vessel from the starboard side to the own ship shown in Figure 7. The most unsafe zone, shown in Figure 8 is when the starboard vessel is crossing the own ship´s bow on a CPA of zero and a TCPA up to six minutes. The most unsafe zone is also when the starboard vessel is crossing the bow of the own ship at a CPA of 0.3 M and a TCPA up to four minutes. Referring to COLREG rule 15 about crossing situations: "When two power-driven vessels are crossing so that risk of collision can be involved, the vessel which has the other on her own starboard side, shall keep out of the way and shall, if the circumstances permit it, avoid crossing ahead of the other vessel." According to Figure 8, the unsafe zone is ahead of a vessel, which proves the rule; It also shows that the minor unsafe zone is stretching more stern of the crossed vessel when the crossing vessel is passing the stern of the other vessel. Safe zone is indicated to be when the starboard vessel is crossing 0.7 M CPA ahead and stern of the own ship.

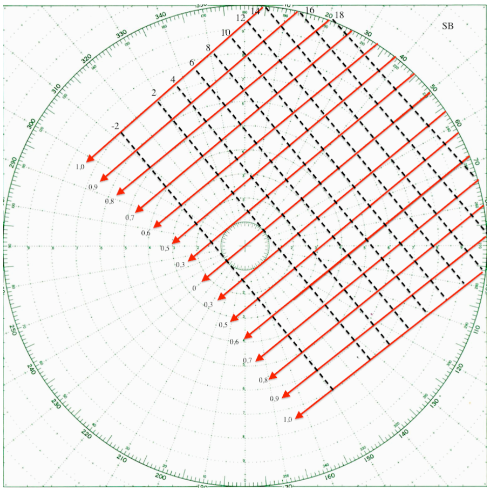


Figure 7. Traffic scenario two, crossing from Starboard side, own ship head up

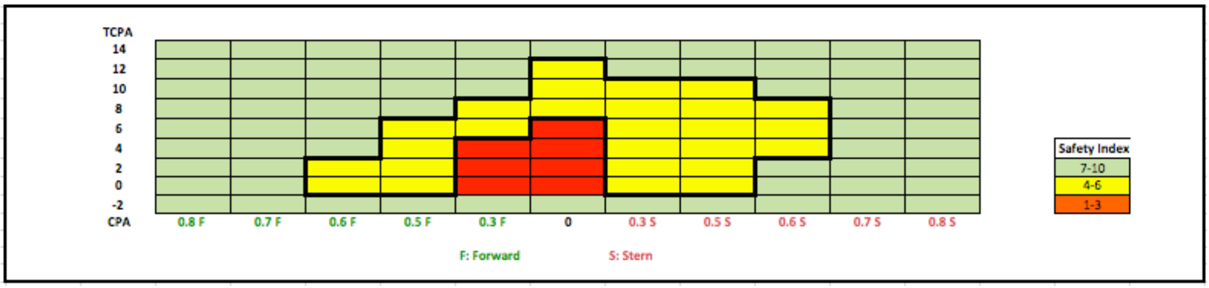


Figure 8. Results from the collision safety index after evaluated the on crossing from the starboard side scenario

5.2.3 Scenario three, overtaking from starboard side

The third scenario was an overtaking vessel from the starboard side of the own ship as shown in Figure 9. In Figure 10, it is shown that the most unsafe zone is at a CPA of zero M, a TCPA up to four minutes and when the starboard vessel is overtaking the own ship on her stern with a CPA of 0.3 M and a TCPA of up to minutes. The minor unsafe zone is shown to be stretching more stern of the own ship that is being overtaken. The safe zone is when the overtaking vessel is crossing the owns' ship bow in 0.5 M CPA and when crossing the own ship stern at a CPA of 0.7 M.

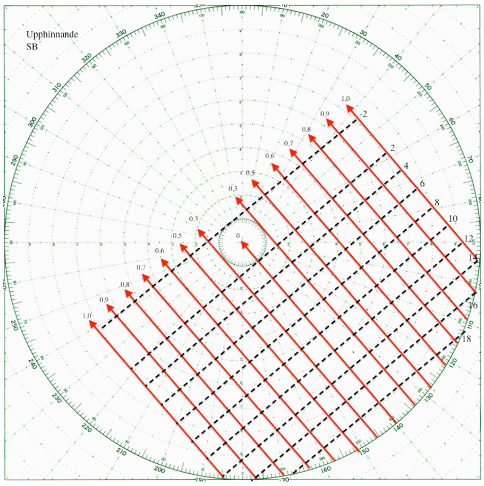


Figure 9. Traffic scenario three, overtaking from starboard side, own ship heap up

Figure 10. Results from the collision safety index after evaluated the overtaking from starboard scenario

5.2.4 Scenario four, overtaking from astern

The fourth scenario was an overtaking situation from stern as shown in Figure 11. When a vessel is overtaking the own ship on her stern, the unsafe zone is when the overtaking vessel passes her starboard side as shown in Figure 12. Specifically, the most unsafe zones are: zero M CPA up to six minutes TCPA, 0.3 M CPA on the own ship's starboard side up to four minutes TCPA and 0.3 M CPA on the port side up to two minutes TCPA. The safe zones are when the vessel is passing the own ship's port side on 0.5 M CPA and 0.6 M CPA on her starboard side.

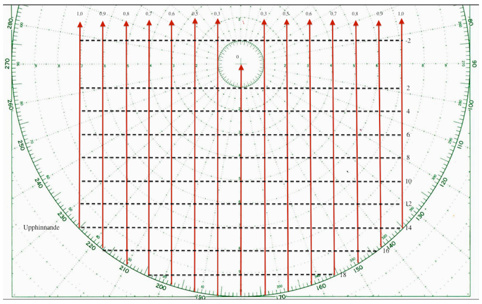


Figure 11. Traffic scenario four, overtaking from astern, own ship heap up

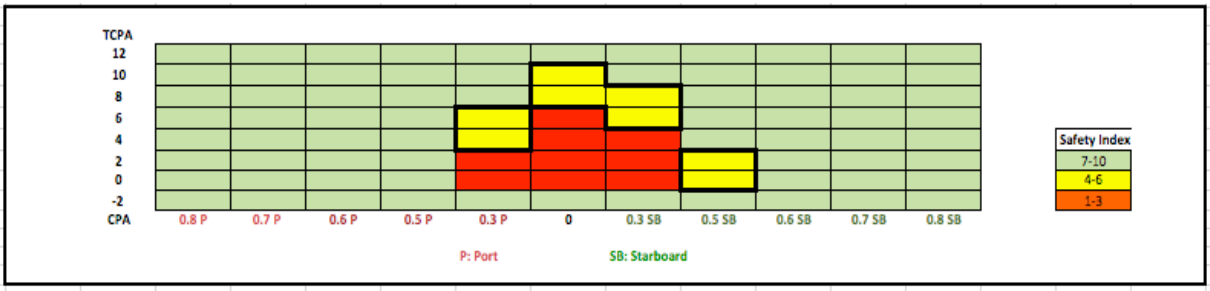


Figure 12: Results from the collision safety index after evaluated the overtaking from astern on scenario

5.2.5 Scenario five, overtaking from port side

The fifth scenario was an overtaking situation from the port side of the own ship as shown in Figure 13. In an overtaking situation from the port side, the unsafe zone according to the Figure 14 is when the overtaking vessel is passing the overtaken vessels bow. According to COLREG rule 13 regarding overtaking and rule 15 regarding crossing situations, it is clearly stated that an overtaking and a crossing vessel from the port side should give way. The most unsafe zones are: at a CPA of zero M with a TCPA up to six minutes, when the overtaking vessel is passing the bow of the own ship's at CPA of 0.3 M with a TCPA up to four minutes when the overtaking vessel is passing the own ship's stern at a CPA of 0.3 M up to minutes of TCPA. The safe zones are 0.5 M a CPA on the starboard side of the own ship and 0.8 M CPA on the port side of the own ship. It is also shown that a minor unsafe zone is at 0.3 M of CPA after the overtaking vessel has passed the own ship´s bow.

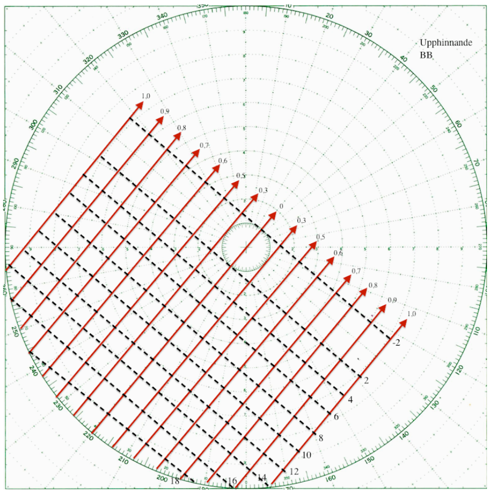


Figure 13. Traffic scenario five, overtaking from port side, own ship head up

Figure 14. Results from the collision safety index after evaluated the overtaking from the port side scenario

5.2.6 Scenario six, crossing from portside

The sixth and final scenario, shown in Figure 15, was a crossing situation from the port side of the own ship. As indicated in Figure 16, the most unsafe zones are: zero M CPA up to 8 minutes of TCPA, when the port vessel is crossing the own ship's bow with a CPA of 0.3 M up with a CPA to six minutes of TCPA and when the crossing vessel is passing stern the own ship at a CPA of 0.3 M up to four minutes TCPA. According to COLREG rule 15, a vessel crossing from the port side shall alter her course to starboard and follow the stern of the other vessel. When that rule is violated the safety risk increases. The safe zones are indicated to be when the port-crossing vessel crosses the stern of the own ship at a CPA of 0.6 M and 0.8 M CPA in front of the own ship.

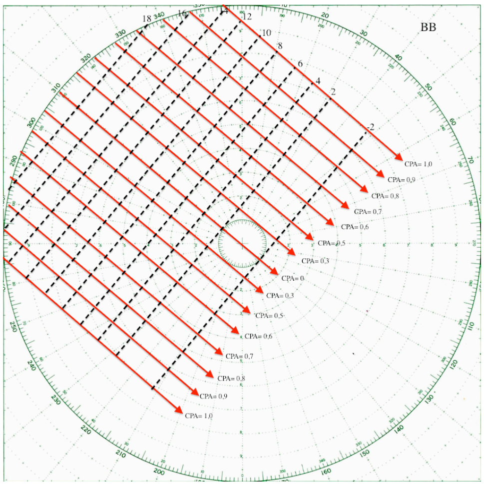


Figure 15. Traffic scenario six, crossing from port side, own ship heap up

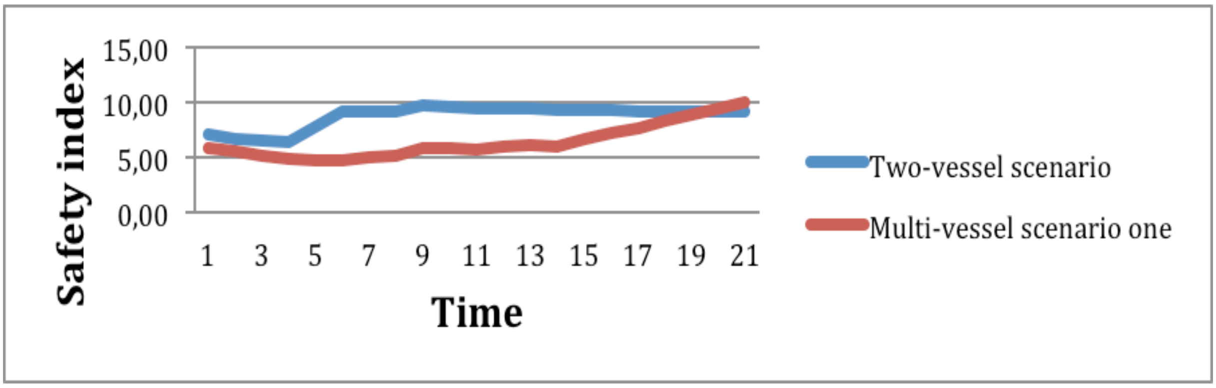
Figure 16. Results from the collision safety index after evaluated the crossing from the port side scenario

5.3 Excluded factors from the matrices

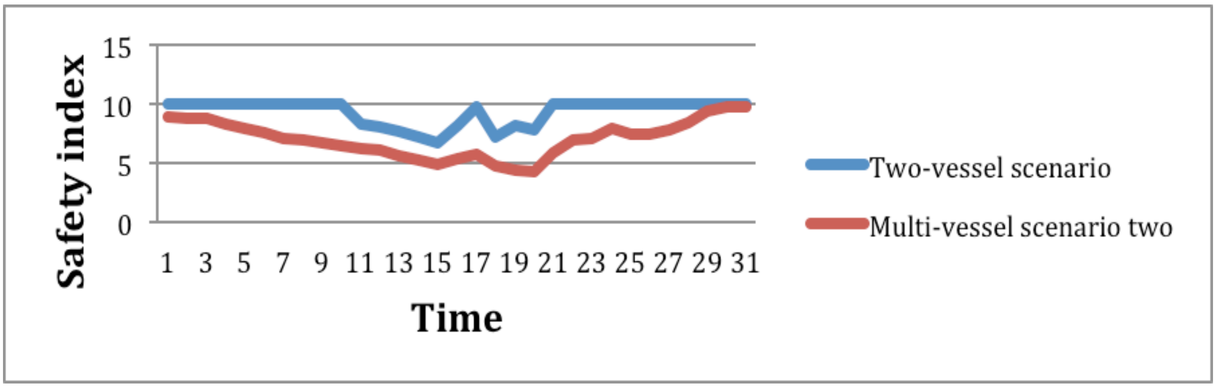
The officers made it clear that they would assign a lower collision safety index value if the following preference factors would influence the scenarios: rough environmental conditions, heavy traffic, confined waters and technical issues; for example, restricted ability to manoeuvre or not being able to communicate with the other vessel.

5.4 Appliance of the two-vessel scenarios in three multi-vessel scenarios

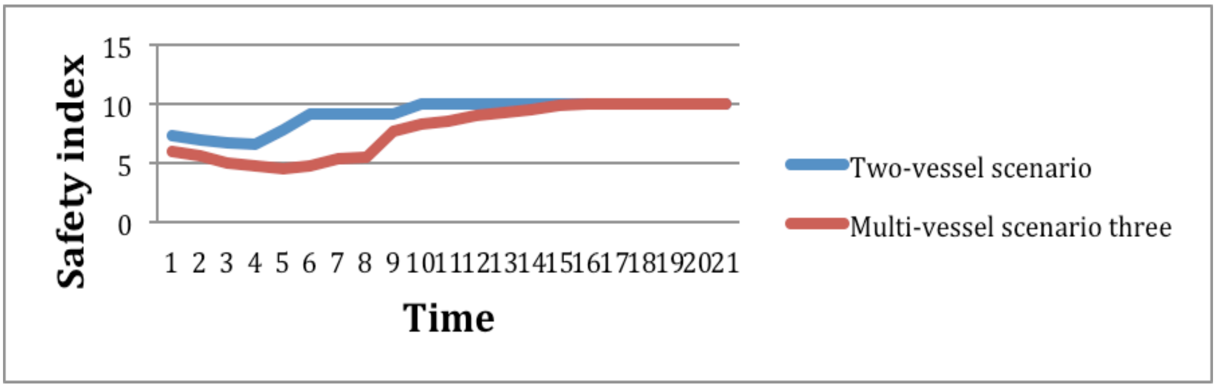
The mean values of the result from the two-vessel scenarios that are presented in the Appendix 2 were applied in the every minute evaluation of the instructors' multi-vessel scenarios in consideration to CPA and TCPA. The result is shown in Graphs 1, 2, 3 below. It is clearly shown that they follow a similar tendency except that the interviewees have a quicker tendency to favour the maximum collision safety index.



Graph 1. Appliance of the two-vessel scenarios in multi-vessel scenario one



Graph 2. Appliance of the two-vessel scenarios in multi-vessel scenario two



Graph 3. Appliance of the two-vessel scenarios in multi-vessel scenario three

6 Discussion

The discussion of the results is divided in three parts; the first part is the results from the interviews with the 13 officers. The second part is the simulation of the three scenarios that was run by the six experienced instructors of the simulator at Chalmers University of Technology and was compared to the officers' evaluation of the six defines matrices. The last part is a discussion about the method chosen for this project.

6.1 Scenarios

The scenarios required considerable concentration and effort from the officers; it usually took up to an hour for each interview. Evaluating the matrices was challenging for the officers because they normally would never allow close quarter situations to occur. Through the questionnaire it was clearly shown that they all wanted to have control of the situation.

The overall evaluation of the six matrices conducted according to COLREG rules 14 and 15 when having a vessel on counter course or a vessel on the starboard side, alteration to the starboard side shall be made. The officers were assertive that they wanted their starboard side always free in case of a required manoeuver. That is why passing at the "wrong side" gave a lower collision safety index.

In a crossing situation from the starboard side it was illustrated that the minor risky zone is stretching more stern of the own ship when the crossing vessel is passing the stern of the own ship. In this situation the own ship is on the others starboard side, so the officers indicated a lower collision safety index compared to the vessel that had already crossed their bow. According to the COLREG, even though the traffic situations are listed between two vessels, in real life we have to take the whole contest into consideration.

According to Olindersson et al. (2017), the following is verified:

- Crossings situations from the port are considered to be less safe than crossings from the starboard.

- Overtaking situations are considered to be less safe if the target vessel is located on the starboard side of the ship.
- In a head-on situation with a CPA of zero it is assessed to be safer than a crossing situation from the port side.
- If an avoiding manoeuver has been made by a target vessel on the port side of the own ship, the situation is assessed to be safer than if the give way vessel did not make that manoeuvre.
- When the starboard side is occupied with another vessel that makes an avoiding manoeuver difficult, a lower collision safety index is indicated.

In a crossing situation when a vessel is passing ahead of the own ship with a CPA of one M, the less safe situation is when the target vessel still has to pass the heading line within a TCPA of four minutes according to Olindersson et al. (2017). In the results of the evaluation scenarios, a crossing from the starboard and the port side with a vessel passing ahead of the own ship, with a CPA of one M, the officers evaluated the situations as safe. The less safe situation on crossing from the starboard side was indicated at a CPA of 0.3 M and two minutes TCPA. The less safe situation in a crossing situation from the port side was however indicated to be a CPA of 0.3 M and four minutes TCPA. Having a limited CPA scale on the matrices up to one M, in comparison to the Olinderssons et al. (2017) project where the maximum CPA was three M, makes it reasonable to evaluate the maximum CPA of one as the safest.

A recurring sentiment from the officers as indicated at their evaluation results of the matrices was that they wanted to have their starboard side free, to be able to do an avoidance manoeuvre if needed. This is likewise confirmed in the Goodwin design, where as shown in Figure 1a, the starboard arc is stretching with the largest area, which includes the ships domain, an area of the ship that should not be violated. According to Wang et al. (2009) the starboard arc of the Goodwin design is up to 0.85 M, after that, the situation is safe since it is out of the ships domain. Compared to the matrix number two, crossing of the starboard side is shown to be totally safe with a CPA of 0.7 M and greater. Zhao et al. later introduced a fuzzy ship domain where the safety boundary of the ship domain was unclear. That was also shown through the interview that the answers in the evaluation were dependent on their experience and the navigating area. The pilots and the officers that frequently navigated in heavy traffic were more certain and quick on their evaluation answers (Wang et al., 2009). The elliptical ship domain that was introduced later can also be compared to the results from the matrices one and two, the head-on and the crossing from the starboard situation. The safe zone in a head on situation is 0.5 M CPA on the port side and 0.6 M on the starboard side. In the crossing situation though, the safe CPA when crossing in front of the bow is 0.7 m CPA. (Wang et al., 2009).

The officers were questioned if TSS would affect the evaluation of the collision safety index in the defined scenarios and on average the officers stated that they would make the same evaluation. Even though the TSS is assessed to be a safer and more controlled area, it was stated that this could be taken as a “fake security”. The OOW should never rely on others and instead be in control of the situation.

6.2 Simulation

The validation of the project through the simulation of the three multi-vessels scenarios showed a clear shared tendency except that the officers evaluation was at a higher level on the collision safety index. This can be confirmed by the Olindersson et al. (2017) project where it was stated that: “In multi-vessel situations the safety index is always equal or lower than the individually each of one situation.” Even in the COLREG, the basis in the traffic situations are adapted between two vessels, whilst in real life where more vessels are involved you shall adjust to the specific situation and according to situational awareness.

Validation of scenario one shows a deviation from this tendency. The instructors’ evaluation resulted in a safer level compared to the officers, which instead showed a decreasing safety index. The reason for this deviation is speed differences in the overtaking scenarios. Although in the two-vessel scenario we have chosen to take the most risky situation; where the speed difference between the own ship and the overtaking one is just 2 knots more whilst in the validation scenario number one the speed difference is 11.8 knots.

6.3 Method discussion

The methodology of a project is a constant process, where many aspects are evaluated in the end and the accuracy is challenged. Thirteen persons have been interviewed and that is neither a major amount in comparison to the whole number of the active officers in the marine industry. However, the advantage of the chosen face-to-face interview method was successful due to qualitative time with the interviewees and prevented misinterpretation of the matrices that could otherwise occur if a questionnaire survey was chosen instead. This project is assessed to be a quantitative research study where numerical values of collision safety index have been used as an analytical unit, with CPA and TCPA, as specific variables. According to Denscombe, (2017) a quantitative research study is referred to when the data analysis happens after the data collection. It tends also to be associated with the researcher´s impartiality. Concluded, as the word: quantitative is in itself, quantitate data is more advantageous given greater quantities of data since the results would be more reliable and can be statistically generalized.

6.3.1 Generalisation

This project provided a sufficient result of the collision safety index but cannot be generalized over all possible traffic situations. However, under the same circumstances the results of the collision safety index can be generalized. Navigation in rough environmental conditions, heavy traffic, confined waters and when having technical issues as shown in the project would give a lower value to the collision safety index. Concerning these cases, additional parameters affecting the traffic situation would affect the method in an uncertain way.

6.3.2 Validation

As shown in this project, there are more parameters that affect the assessment of the method than just CPA and TCPA. It is though possible to measure relative safety in this way. Literature studies frequently link the values of CPA and TCPA in relation to situational awareness in maritime safety as well as the deficient factors not considered in this project. Regarding traffic density, manoeuvrability, environmental conditions and geographical aspects the safest circumstances have been taken into consideration to the chosen scenarios. The above-mentioned circumstances that were not taken into account could result in lower collision safety index values, but their tendency would be the same. The compared results between the evaluation model and the values from the matrices confirm this assumption.

6.3.3 Reliability

To estimate a collision safety index, mean values of all data have been used. The standard deviation[1] of the data is relatively low, which means that the interviewed officers have a close approximation of estimating the collision safety index. The highest standard deviation in the matrices is shown to be in the overtaking situations, in minus two TCPA and especially in the lower CPA limits. The presented values for the collision safety index are not deterministic, but they are a sufficient estimation of real life traffic situations. Reliability of this project is sufficient, and the results would be similar if the same method were to be repeated. If other officers were interviewed under the same circumstances, there is a high probability that the result would be the same. The result also fits well with previous surveys and it is shown to be applicable. One exception has to be made for the fourth scenario overtaking from the stern. The officers could probably not have been certain of the situation when assessing the most unsafe zone for zero M CPA up to minutes six TCPA, where zero CPA is physically impossible.

6.3.4 Lacking factor

As it is said, many factors affect the validity, reliability, and the generalisation of a project. Taking into consideration the limited time, the lacking factor for this project was the lack of follow up in the scenarios to more negative values of TCPA.

[1] A quantity expressing by how much the members of a group differ from the mean value for the group (Katmath & Saurav, 2016, p 267)

7 Conclusion

Safe shipping is essential for today´s society, but how can a maritime collision safety index method be developed? Developing and evaluating a collision safety index method is not a simple task as both numerical values and human factors must be taken into consideration in order to get a sufficient safety level in a certain situation. In this project taking a statistical perspective of numerical values into account, a maritime collision safety index method in traffic situations has been introduced. Many simplifications have been done in the defined scenarios due to limited time and geographical disseminations.

The method has been developed by evaluating the safety in various angles of a two-vessel traffic situation taking the CPA and TCPA into consideration. That is a basis that can be used in a multi-vessel traffic scenario. It can be done by splitting up the multi-vessel scenario to each and one traffic encounter and choosing the collision safety index from the least safe encounter.

The result of this base method showed moreover that the tendency of the risky zones was observed when a vessel is crossing in front of the bow of another, manoeuvrings not according to the COLREG and when the starboard side of a vessel is occupied by a vessel so as no manoeuvre at that side is possible. The factors affecting the collision safety index to a lower value are: rough environmental conditions, heavy traffic, confined waters and technical issues.

In conclusion the project verifies that the values of CPA, TCPA and type of situation within two vessels, after our empirical research conducted on those factors, are a base though not enough to relate to a real traffic situation with multiple vessels involved in different circumstances.

7.1 Future fields of research

The collision safety index method that was developed in this project can act as basis but it needs further development to improve the model. For future research, it would give more accurate results if more factors were taken into consideration in the scenarios. The factors that could be investigated are: traffic density, navigation in TSS, manoeuvrability, confined and shallow waters, environmental conditions, negative TCPA and Bow Cross Range (BCR).

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9 Appendix

Appendix 1

Questionnaire though the interview:

Before the matrices:

1. Present of experience
- Name:
- Age:
- Current position:
- Vessel:

2. What types of traffic situations are: simple/tough?

3. Are you a person that has:
    a. Big margin?
    b. Sail straight to the destination?

4. What is a safe CPA for you?

5. When do you feel safe in a traffic situation? What does that require?

6. What CPA/TCPA is critical for you?

7. What CPA under 1 M makes you insecure and makes you act according to the situation.

8. What makes you insecure in a traffic situation?

9. Have you been involved in a close quarter situation/collision?

MATRICES

After the matrices:

1. Do you trust the Radar/ARPA?

2. What scenario from the ones we went though felt the most unsafe and why?
- Head on situation
- Crossing from starboard side
- Overtaking from: SB/P/Astern

- Crossing from port side

3. Under what other circumstances would those scenarios we went through, give different results on the safety index that you gave?

4. Would poor visibility affect your evaluations and how?

5. Would darkness affect your evaluations and why?

6. Would rough weather affect your evaluation and why?

7. Would you evaluate different if you were in a TSS, how?

8. What do you think about STM?

(The questions have been translated from Swedish.)

Appendix 2

Head on situation

RESULT SB

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	9,92	10	10	10	10	10	10	10
2	1,08	3,31	6,38	7,46	7,92	8,31	8,92	9,92	10
4	1,62	3,62	5,77	7	7,77	8,23	9	9,92	10
6	2,62	4,23	6,46	7,31	8,23	8,54	9,08	9,92	10
8	3,54	4,7	6,38	7,62	8,15	8,46	9,15	10	10
10	4,85	5,7	7	7,92	8,23	9	9,62	9,92	10
12	5,62	6,38	8,15	8,46	8,62	9,38	9,77	9,92	10
14	6,7	7,54	9	9,15	9,31	9,62	9,77	9,92	10
16	7,7	8	9,31	9,62	9,62	9,77	9,85	10	10
18	8,31	8,23	9,46	9,62	9,62	9,77	9,85	10	10
30	10	10	10	10	10	10	10	10	10

RESULT BB

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	9,85	10	10	10	10	10	10	10
2	1,08	4,62	7,15	7,85	8,23	8,23	9,15	10	10
4	1,62	5,08	7	7,54	8,15	8,62	9,31	10	10
6	2,62	5,24	7,23	7,92	8,62	8,92	9,38	10	10
8	3,54	5,7	7,53	8,31	8,7	9,08	9,54	10	10
10	4,85	6,85	8,23	8,85	8,77	9,08	9,92	10	10
12	5,62	7,54	8,85	9,15	9,23	9,77	9,92	10	10
14	6,7	8,23	9,15	9,54	9,62	9,85	10	10	10
16	7,7	8,62	9,54	9,7	9,77	9,85	10	10	10
18	8,31	8,7	9,62	9,77	9,77	9,85	10	10	10
30	10	10	10	10	10	10	10	10	10

Crossing from starboard

RESULT Forward

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	9,77	9,62	9,77	9,77	9,77	9,77	9	10
2	1,31	3,08	5,31	6,46	6,69	7,62	8	9,31	10
4	1,77	3,46	5,38	6,54	6,85	7,77	8,23	9,38	10
6	2,62	4,31	6,077	6,77	7,46	8,08	8,54	9,46	10
8	3,7	5,08	6,92	7,62	7,85	8,54	9	9,69	10
10	4,38	5,85	7,23	7,85	8,23	8,69	9,15	9,69	10
12	5,85	7,15	8,23	8,7	8,92	9,15	9,62	9,85	10
14	7,46	8	8,7	9,08	9,23	9,38	9,77	9,92	10
16	7,92	8,46	8,77	9,38	9,38	9,54	9,77	9,92	10
18	8,31	8,54	8,77	9,38	9,54	9,54	9,77	9,92	10
30	10	10	10	10	10	10	10	10	10

RESULT Astern

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	9,62	9,77	9,77	9,62	10	10	10	10
2	1,31	3,69	5,23	6,62	7,23	6,92	7,46	8,62	10
4	1,77	3,54	5,31	5,77	6,62	7,23	7,69	8,85	10
6	2,62	4	5,15	5,85	6,46	7,46	8,23	8,92	10
8	3,7	4,92	5,69	6,38	6,92	8,08	8,54	9	10
10	4,38	5,77	6,31	6,69	7,23	8,23	8,69	9	10
12	5,85	7,23	7,31	7,62	8	8,85	9,23	9,31	10
14	7,46	7,92	8	8,15	8,46	9,23	9,46	9,54	10
16	7,92	8,31	8,38	8,54	8,77	9,38	9,54	9,62	10
18	8,31	8,54	8,62	8,62	8,846	9,38	9,54	9,62	10
30	10	10	10	10	10	10	10	10	10

Overtaking from starboard

RESULT Forward

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	7,38	9,46	9,69	9,85	9,84	9,85	9,08	10
2	1,46	1,62	4,54	5,46	6,77	7,85	8,92	9,15	10
4	2,46	2,54	5	6,08	7,31	8,23	9,23	9,31	10
6	4,08	4,3	5,92	6,77	7,77	8,54	9,38	9,38	10
8	5,31	5,23	6,62	7,54	8,54	9,23	9,54	9,54	10
10	6,31	6,46	7,62	8,15	9,23	9,54	9,69	9,69	10
12	7,23	7,46	8,08	8,62	9,38	9,62	9,77	9,77	10
14	8,23	8,46	9,15	9,15	9,69	9,77	9,85	9,85	10
16	8,92	9,23	9,54	9,54	9,69	9,77	9,85	9,85	10
18	9,15	9,46	9,62	9,62	9,69	9,77	9,85	9,85	10
30	10	10	10	10	10	10	10	10	10

RESULT Astern

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	8,38	9,77	9,85	9,85	9,85	9,85	9,85	10
2	1,46	3,69	6,77	7,92	8,54	9,08	9,54	9,62	10
4	2,46	4,77	7,15	8,08	8,85	9,31	9,54	9,62	10
6	4,08	5,84	7,69	8,54	8,92	9,54	9,77	9,77	10
8	5,31	6,62	8,77	9,08	9,54	9,77	9,85	9,85	10
10	6,31	8	9,31	9,46	9,85	9,92	10	10	10
12	7,23	8,46	9,62	9,69	9,92	10	10	10	10
14	8,23	8,92	9,85	9,85	9,92	10	10	10	10
16	8,92	9,38	9,85	9,85	9,92	10	10	10	10
18	9,15	9,62	9,85	9,85	9,92	10	10	10	10
30	10	10	10	10	10	10	10	10	10

Overtaking from astern

RESULT SB

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	8,38	9,08	9,31	9,46	9,69	9,69	8,92	10
2	1,38	2,77	6,31	7,08	8,08	8,62	9,62	9,77	10
4	2	3,31	6,62	7,23	8,15	8,77	9,69	9,85	10
6	3,15	4,85	7,54	7,69	8,69	9	9,77	9,85	10
8	4,85	6,23	8	8,23	9,08	9,38	9,92	10	10
10	6,38	7,31	8,85	9	9,23	9,46	9,92	10	10
12	7,69	8,38	9,08	9,23	9,46	9,54	9,92	10	10
14	8,54	9	9,38	9,38	9,62	9,69	9,92	10	10
16	9,23	9,46	9,54	9,54	9,69	9,69	9,92	10	10
18	9,38	9,54	9,54	9,54	9,69	9,69	9,92	10	10
30	10	10	10	10	10	10	10	10	10

RESULT BB

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	8,31	9,15	9,46	9,54	9,69	9,69	9,69	10
2	1,38	3,23	6,62	7,46	8,54	9	9,54	9,62	10
4	2	3,69	6,92	7,69	8,69	9,15	9,62	9,69	10
6	3,15	5,08	7,77	8,15	9	9,31	9,69	9,69	10
8	4,85	6,85	8,69	8,85	9,38	9,85	10	10	10
10	6,38	7,85	9,15	9,31	9,46	9,85	10	10	10
12	7,69	8,54	9,46	9,54	9,69	9,92	10	10	10
14	8,54	9,08	9,62	9,62	9,77	9,92	10	10	10
16	9,23	9,46	9,77	9,77	9,77	9,92	10	10	10
18	9,38	9,54	9,77	9,77	9,85	9,92	10	10	10
30	10	10	10	10	10	10	10	10	10

Overtaking from port

RESULT Forward

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	5,85	8,31	8,54	8,92	9,23	9,38	8,69	10
2	1,46	1,92	4,08	5,38	6,38	7,46	8,62	9,15	10
4	2,08	2,62	4,69	5,85	6,85	7,62	8,69	9,23	10
6	3,23	3,69	5,69	6,62	7,46	8,15	9,31	9,46	10
8	4,77	4,54	6,92	7,62	8,23	8,92	9,69	9,77	10
10	6,31	6,69	8,15	8,62	9,23	9,46	9,92	10	10
12	7,31	7,62	8,85	9,08	9,46	9,69	9,92	10	10
14	8,54	8,69	9,31	9,31	9,77	9,77	9,92	10	10
16	8,92	9,15	9,69	9,69	9,85	9,85	9,92	10	10
18	9,23	9,54	9,77	9,77	9,85	9,85	9,92	10	10
30	10	10	10	10	10	10	10	10	10

RESULT Astern

	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	7,62	9,54	9,85	9,85	9,85	9,85	9,85	10
2	1,46	3,38	6,85	7,92	8,46	8,85	9,77	9,85	10
4	2,08	4,15	7,08	8	8,54	9	9,77	9,85	10
6	3,23	5,31	7,77	8,46	8,69	9,23	9,85	9,85	10
8	4,77	6,62	8,85	9	9,08	9,54	9,92	9,92	10
10	6,31	7,85	9,15	9,23	9,54	9,85	10	10	10
12	7,31	8,31	9,54	9,62	9,85	10	10	10	10
14	8,54	8,92	9,85	9,85	9,92	10	10	10	10
16	8,92	9,31	9,85	9,85	9,92	10	10	10	10
18	9,23	9,46	9,85	9,85	9,92	10	10	10	10
30	10	10	10	10	10	10	10	10	10

Crossing from port

RESULT SB

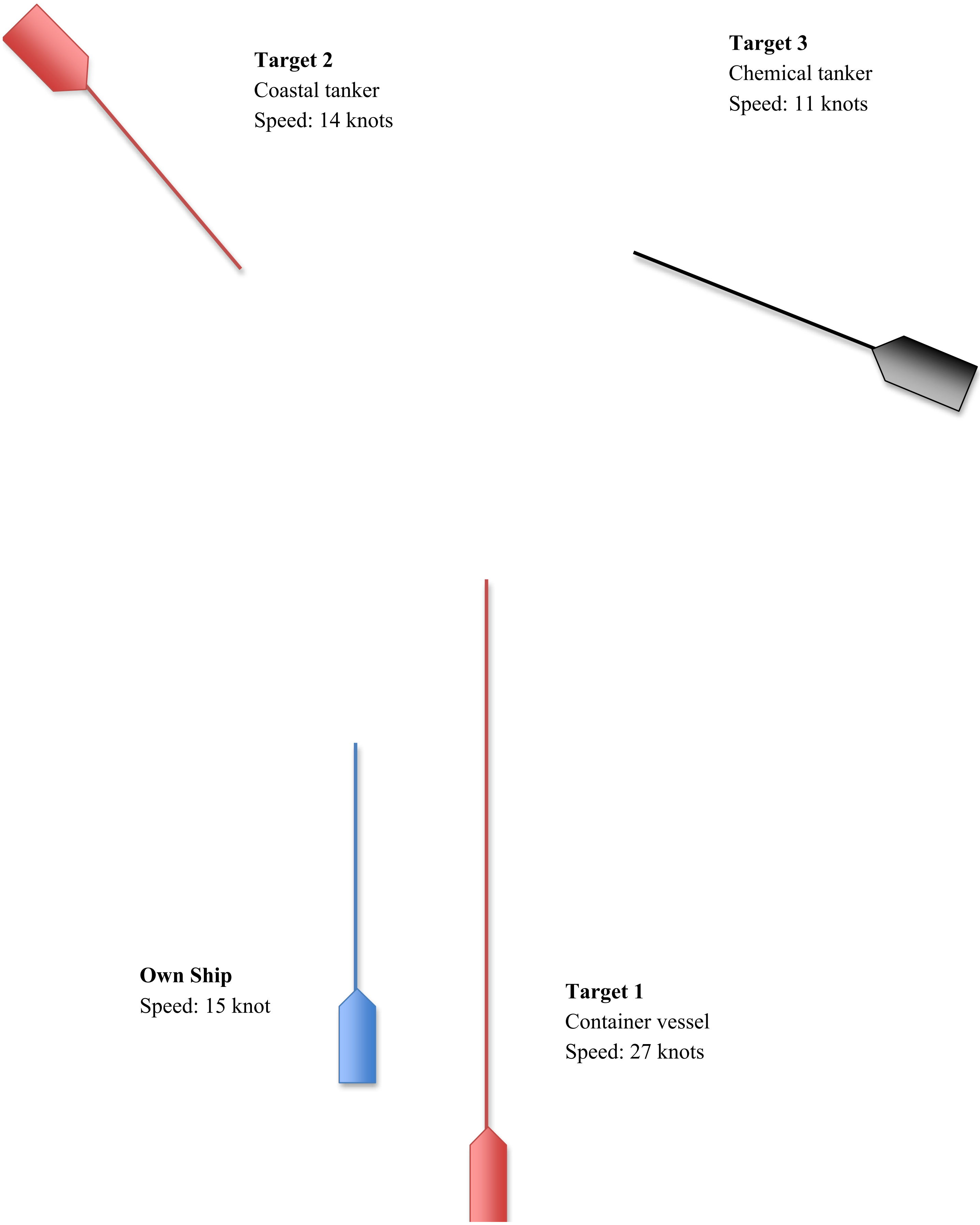
	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	6,62	8	8,69	8,69	8,92	9,69	8,92	10
2	1	1,85	4,08	5,69	6,38	6,77	8	9,23	10
4	1,54	1,69	3,85	5,92	6,62	7,15	8,69	9,38	10
6	2,23	2,38	4,31	5,77	6,46	7,31	8,77	9,38	10
8	3,38	3,92	5,08	6,15	7,23	8,15	9,23	9,69	10
10	5	5,46	6,62	7,54	8,46	8,77	9,54	9,85	10
12	6,31	6,38	7,62	8,15	8,62	9,08	9,77	10	10
14	7,69	7,62	8,15	8,54	8,92	9,31	9,77	10	10
16	8,38	8,38	8,54	8,92	9	9,31	9,85	10	10
18	8,69	8,69	8,69	9	9	9,38	9,85	10	10
30	10	10	10	10	10	10	10	10	10

RESULT BB

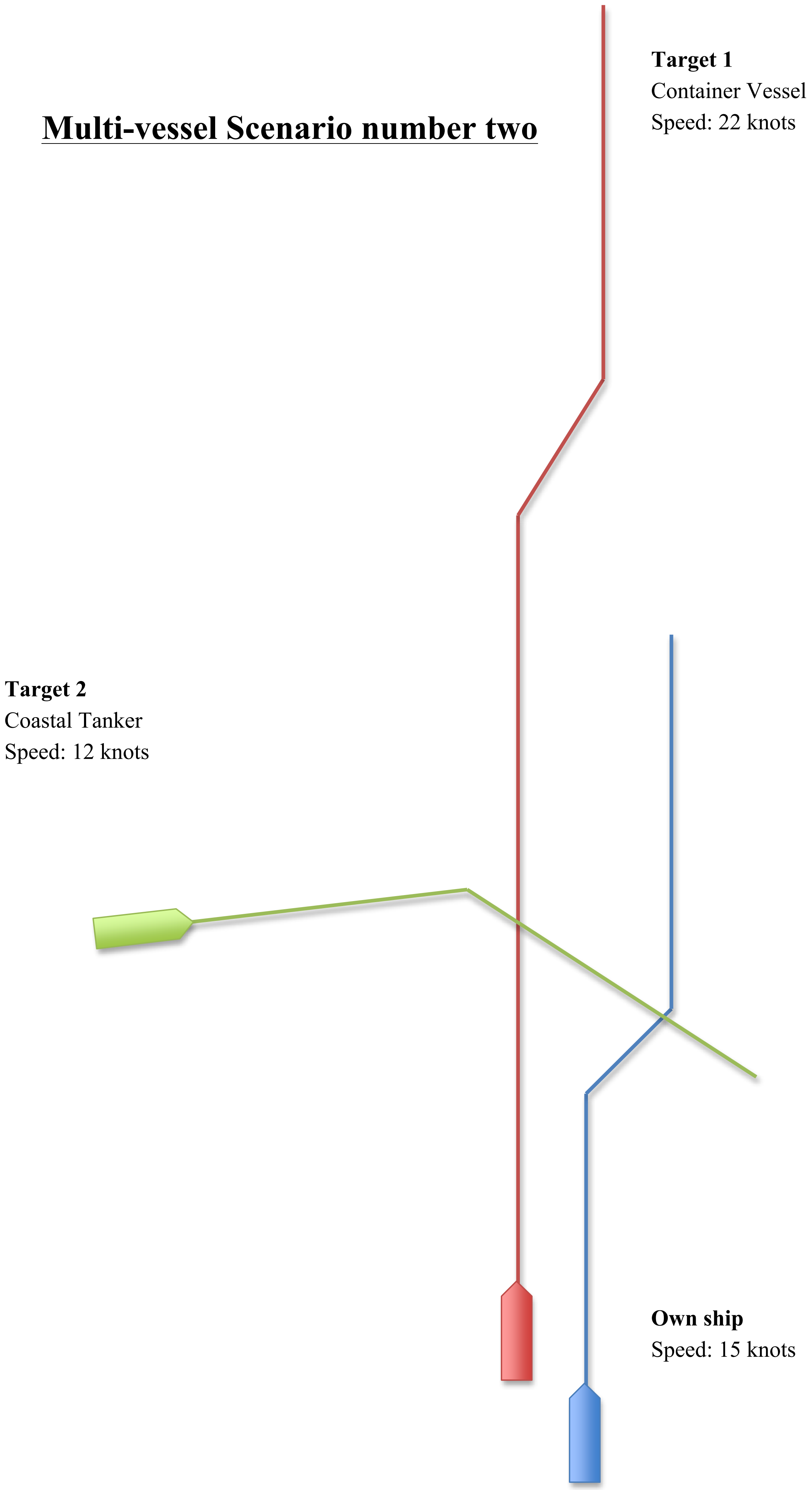
	0	0,3	0,5	0,6	0,7	0,8	0,9	1	3
-10	No Data	10	10	10	10	10	10	10	10
-2	No Data	8	9,54	9,69	9,69	9,69	9,69	9,69	10
2	1	2,77	6,23	7,15	7,77	8,31	9	9,46	10
4	1,54	3,15	6,62	7,38	8	8,46	9	9,46	10
6	2,23	4,46	7,15	7,69	8,15	8,62	9,08	9,46	10
8	3,38	5,62	7,85	8,31	8,54	9,08	9,62	9,85	10
10	5	6,77	8,23	8,54	8,85	9,23	9,85	9,85	10
12	6,31	7,77	8,69	8,92	9,08	9,69	10	10	10
14	7,69	8,46	9,23	9,38	9,38	9,77	10	10	10
16	8,38	8,85	9,31	9,46	9,38	9,77	10	10	10
18	8,69	9	9,31	9,54	9,38	9,77	10	10	10
30	10	10	10	10	10	10	10	10	10

Appendix 3

Multi-vessel Scenario number one



Multi-vessel Scenario number two



Multi-vessel Scenario number three