A perfect warning to avoid collisions at sea?

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Abstract

Avoidance of collisions is one of the most important tasks for the officer of the watch on a ship's bridge. Measures and actions required to avoid such accidents are described in the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) adopted by the International Maritime Organization (IMO) in 1972 and still valid, with several minor amendments, since then. On the basis of a proper look-out at all times, by sight and hearing, and the use of all available means, also including technical equipment installed on-board as well as information provided by a Vessel Traffic Service (VTS), the navigating officer collects traffic and environmental data and combines them with their own ship data to construct a mental traffic image for the assessment of risk of collision with other objects in the vicinity. In the case wherre there is an unacceptable risk she or he has to decide on taking action.

In most of the cases decision making is appropriate to the prevailing circumstances and ships maneuver and pass at a safe distance. Only in very rare cases, due to whatever reasons, watch officers fail in taking appropriate actions in good time. It is assumed that, if effective alerting algorithms would be available, a substantial number of collisions at sea, and especially in coastal waters, can be avoided by making the watch officer aware that the 'last line of defence' for taking action is close to come. It is assumed that there is potential in applying the principle of the resolution advisory alert of an ACAS (Airborne Collision Avoidance System)/TCAS (Traffic Alert and Collision Avoidance System) in aviation and adapt it to the needs of maritime traffic.

In this paper, the authors introduce a method for triggering collision warnings by focusing specifically on the critical last phase of an encounter and taking into account the maneuvering characteristics of the navigating ship. They comprehensively explore the application using scenario studies discussing the operational aspects of varying implementation states (one ship only, SOLAS ships only).

Introduction

Rapidly increasing numbers of ships and ship sizes pose an ever-growing challenge to the maritime industry. Although statistics indicate improved levels of safety in the industry which carries 90% of the world trade, the risk of navigational accidents remains a prime concern and priority (among others EMSA, 2014; 2015).

Collisions and groundings are the two major types of accidents in maritime transportation. Therefore, most essential navigational tasks are route planning and monitoring as well as collision avoidance. For both the mentioned tasks specific equipment is mandatorily required to be installed on ships' bridges in order to support the officer of the watch (OOW) and the bridge team respectively to improve situational awareness. Even though if a collision or a grounding happens this is often the cause of human error. One of the authors' hypotheses is, that this is, inter alia, due to insufficient alarms and warnings that fail to compensate the human elements unawareness of a risky situation that requires immediate action.

It is one of the central tasks of bridge officers to maintain safe navigation while realizing the voyage planning. Crews are mainly successful in ensuring a sufficient safety level and shipping is considered a safe mode of transport, in general. However, sometimes ships collide or run aground, indicating that the crew was unable to maintain safety. In such cases incomplete or incorrect execution of tasks is often identified in the sequence of events leading to a collision or grounding. Usually investigation reports indicate errors of the OOW. In (Liu & Wu, 2004 a representative number of collision cases was investigated and came to the conclusion that "there is a major lack in situational awareness". Another study conducted by the Nautical Institute (Gale & Patraiko, 2007) stated that in almost 60 per cent of considered collision cases, the OOW of one of the ships involved in a collision was not aware of the other vessel and may even have not seen that the vessel was on a collision course. Recognizing the lack of situational awareness, the authors, however, are of the opinion that it is too simple to just blame only the human operator, e.g. the OOW or the bridge team. Insufficient design of the user interfaces, e.g. of support systems like Radar-ARPA (Automatic Radar Plotting Aids), Automatic Identification System (AIS) or Electronic Chart Display and Information System (ECDIS) etc. and its integration need to be taken into account as well. Systems triggering warnings are too often lacking in the areas such as the provision of practically suitable configuration of thresholds according to the needs and demands of the users.

Using the IMO's approach of defining alerts as the term including cautions, warnings and alarms (IMO, 2007), a "perfect" alarm can be defined as an alert that only occurs, when, from whatever reason the human operator, who most of the time has taken correct action in time, has overseen a situation or passed the right time she or he usually has to take action to avoid a threat and urge him to immediately take an action.

Applying this definition for the purpose of collision avoidance, it seems to be obvious and reasonable, that such an anti-collision alarm shall occur, when the time to take immediate action is coming. This point in time is characterized by the fact that only a limited number of maneuvering options remain, materialized by rudder and/or engine commands to be initiated in order to avoid damages by the impacting of the ships' hulls. Consequently, the key for a 'perfect' collision alarm is the connection between the navigating ship's maneuvering characteristics according to the prevailing circumstances of a concrete situation (mainly environmental parameters) and the accuracy of the encounter parameters of this concrete situation.

However, existing technical systems to support the OOW in detecting dangerous encounter situations, with a risk of collision, do not provide such considerations and trigger a warning on the basis of static limit values configured by the user for the distance at the Closest Point of Approach (CPA) and the time to reach the CPA (TCPA). The set limits are not only static, moreover, they apply for all situations, all ship status and all kinds of prevailing environmental conditions and therefore are unsuitable and inappropriate for triggering a 'perfect' anti-collision alarm. Therefore, the authors propose a perfect collision alarm has to be designed as a "Last Line of Defence" (LLoD) as it is used in airborne collision avoidance systems (ACAS) and may be applied as the "Ultimate Action Alarm" (UAA). Other similar approaches from a different perspective and technical background are ongoing (see e.g. Montewka & Prata, 2014; and others).

Taking the example of the 'resolution advisory' (RA) alarm in civil aviation, the authors suggests a new concept for triggering alarms and warnings in the maritime domain by applying the concept of potential areas of water (see Göhler, 1983; Inoue, 1990; Benedict et al., 1994). This concept is to be further developed by using, preferably, fast-time-simulation-based dynamic predictions of maneuvering areas to objectively identify the moment and position when immediate demand to take action is required to avoid a collision or a grounding in open sea and coastal areas.

As mentioned above, the innovation originates from application of ships' maneuvering data to the prevailing circumstances of concrete situation parameters and estimates remaining options to take action. While CPA/TCPA warnings have to be configured by the OOW manually and, if not switched off, function as a kind of a pre-warning, the UAA for collision avoidance shall be based on multi-sensor information about the situation and, as new element, on digitized maneuvering data, either recorded or calculated. If the OOW performs correctly the UAA shall not be triggered at all. Only when all other safety measures such as the route plan, the watch standing orders, Radar-ARPA, AIS warnings or VTS interventions have failed, this alarm shall occur as the "Last Line of Defence". This alarm corresponds to the moment when the amount of remaining options for maneuvers to successfully avoid a collision is getting close to a critical minimum.

Such a system will also enable new opportunities for traffic surveillance and interaction. Integrated Bridge and Navigation Systems (IBS/INS) on board modern ships will share data in a sophisticated e-Navigation environment (Patraiko, 2007) and allow for more advanced shore-based traffic monitoring and even allow for a re-thinking of existing regimes and procedures on traffic management. Consequently a sophisticated maneuvering support tool using fast-time simulation technology (Benedict, 2014) and its application for on board support as well as for its potential integration into enhanced shore-based monitoring processes when linked with a 'Maritime Data Cloud' will be introduced. Keeping up with these trends of ongoing technological developments, particularly in light of potential developments such as autonomous navigation and unmanned ships, the authors of this paper have further developed their concept (Krüger et al., 2014). Internal studies carried out by various aviation companies suggest that the introduction of ACAS has reduced the risk of mid-air collisions significantly. According to the European Organisation for the Safety of Air Navigation (EUROCONTROL), the latest version of ACAS – ACAS II – has reduced the risk of mid-air collisions by a factor of about 4, or approximately 50% alone (see e.g. EUROCONTROL, 2014).

In the following chapters the basic concept of ACAS and how the principle can be applied on board ships is explained and discussed. The authors present the first test application from on-going research into technical feasibility of the concept.

Collision avoidance at sea

As illustrated in the Figure 1 the process of collision avoidance, in principle, consists of three main elements: "Situation Assessment", "Decision Finding" and "Initiating and Control of a measure to avoid a dangerous encounter".

During the process of situation assessment (the three blue boxes) the OOW or an operator in a shore-based monitoring center has to merge all data into a mental traffic image to evaluate and assess the results of his permanent observations in order to detect any risk of collision with other objects in the vicinity of his own ship.

Today the additional information provided by AIS contributes to better situational awareness as it widely solves e.g. the problem of clear target identification. In the case of a situation with developing or existing risk of collision, the OOW has to decide when and by which initiated measure – usually a rudder
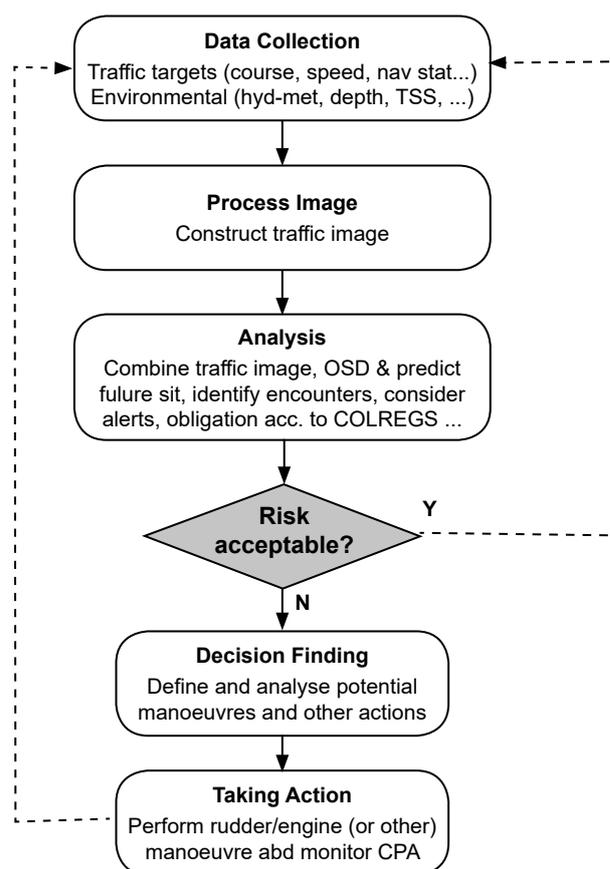

Figure 1. Applying Maritime Operational Risk Management to processes of on-board and shore-based collision avoidance

maneuver to change course in order to increase the expected passing distance in due time – she or he can avoid a potential danger. This decision making process should be supported by a suitable collision warning, e.g. especially in multiple encounters situations in areas with high traffic density or when the OOW – by whatever reason – has overseen such a developing situation. Finally, the action has to be taken, its consequences have to be monitored and controlled and, if necessary, to be corrected or adjusted in order to reach the ultimate goal to pass the other ship or object at a safe distance.

Collision avoidance in air traffic

In civil aviation, the support available for collision avoidance differs from the current approaches available in the maritime domain. Particularly in air traffic there are clearly defined, commonly accepted and homogeneously used minimal time and space standards separating aircraft at all times. The separation criteria represent quantified risk values to ensure safety and efficiency in the air transport sector. It is generally recognized that this contributes to the high

safety level in civil aviation and has prevented conflictions and collisions.

The functioning of ACAS is based on the information provided by secondary surveillance radar and transponder signals. The prime idea behind ACAS is to construct two virtual 3D zones around an aircraft. These zones – which collectively form a 'protected volume' of airspace around an aircraft are dynamic, and are referred to as the 'Caution Area' and the 'Warning Area' respectively.

If the ACAS system detects an 'intruder' – i.e. – another aircraft in either of the two well-defined virtual zones, it provides warnings and/or instructions to pilots of both aircraft to take certain precautionary or emergency measures. If an intruder is detected in the 'Caution Area', the ACAS system will provide a Traffic Advisory (TA) to indicate a potential threat. On the other hand, if the system detects an intruder in the 'Warning Area', it will provide a Resolution Advisory (RA). It is not necessary for a RA to be announced by a preceding TA.

There are generally two types of RA's. A corrective RA, which requires the pilot to perform certain maneuvers and deviate from the current flight path, whereas a preventive RA, which gives a recommendation to the pilot to maintain the current flight path, and not perform certain manoeuvres. RA's generally try to provide a vertical separation of between 300 to 700 ft, in case the threat of a collision is detected.

Should an RA alert occur, the pilot has to follow clear instructions to climb or to descend, generated by the TCAS and this is given as a voice alarm. This alert cannot be switched off and the alarm thresholds cannot be changed by the pilot.

The 'Caution Area' and the 'Warning Area' are dynamic in the sense that their dimensions can vary depending on the altitude, speed and heading of the aircraft involved in an encounter.

The vertical limits above and below are between 850 and 1200 ft. for a TA (Caution Area), and between 600 and 800 ft for RA (Warning Area) alert. As a general rule, the 'dimension' of the 'Caution Area' varies from 20 to 48 seconds, whereas the 'Warning Area' has a smaller 'dimension' of between 15 to 20 seconds – both are in the direction of the flight path of the aircraft.

In some cases, the time limits for the warning areas are not sufficient or feasible. If this occurs, the ACAS relies on 'DMOD (Distance Modification)' defined dimension values of between 0.3 NM and 1.30 NM for TA regions, and between 0.2 NM and 1.10 NM for RA regions.

ACAS, to summarize, acts as a "last line of defense system" providing two types of alerts – firstly the so called "Traffic Advisory" and secondly the "Resolution Advisory". The first assists the pilot in his visual detection of conflicts, while the second gives inviolable clear advice to the pilot on how to maneuver to avoid a collision with an intruder. Figure 2 demonstrates the horizontal and vertical alert regions of an ACAS.

This principle difference in the approaches leads to a rather inconvenient situation in respect to the occurrence of alarms and warnings during usual ship navigation.

Alerts on ships' navigational bridge

In the frame of earlier investigations into the development of new performance standards for Integrated Navigation and Integrated Bridge Systems (INS/IBS), a series of field studies was conducted on board of ships to investigate the situation with respect to the occurrence of alerts (cautions, warnings and alarms) and their handling by the bridge teams. As the management and presentation of alarms is influenced by the type of ship, the year of construction, the installed equipment and grade of integration, the sea area, the training and education of the crew as well as by the safety standards of the shipping company (Motz, Baldauf & Höckel, 2008), these factors were taken into account to obtain a profound database.

The investigations aimed at several technical, operational and human factors related aspects of the
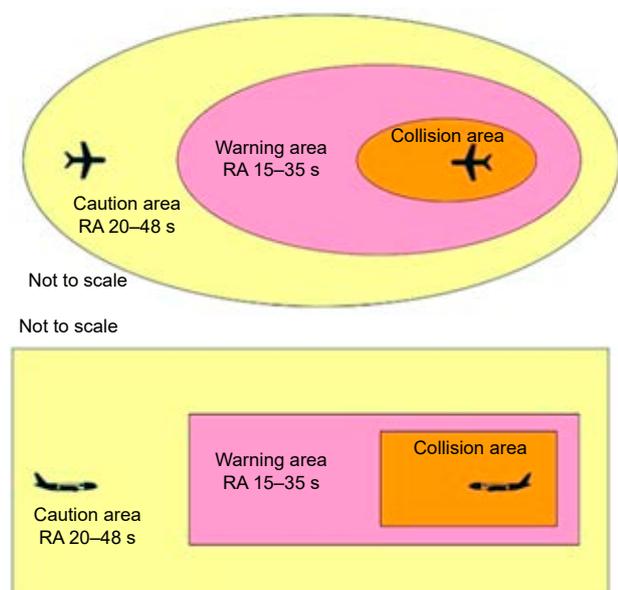

Figure 2. Time/Range regions for ACAS alerts (adapted from EUROCONTROL, 2014)

situation onboard with respect to the alert occurrence and handling. Within the context of this paper, the focus is laid on results related to collision warnings triggered by and displayed at the ARPA-Radar Human Machine Interface with integrated AIS targets and superimposed by information from the ECDIS.

The timely distribution of alarms reflects the dependence of the number of alarms from the sea area. This hypothesis was further proved when analyzing the registered alarms in relation to the navigational situation.

The field studies were carried out on board six vessels, which were two ferries operating in the Baltic Sea, three container vessels (with container capacities of 5.500 TEU, 6.200 TEU and 7.500 TEU) and a cruise vessel operating in the Mediterranean Sea. All vessels were built or refitted between 2001 and 2007. The ships' bridges were equipped differently; the equipment (among others AIS devices) was integrated on a medium or high integration level.

The investigations were conducted during voyages in the Baltic Sea, in the Western Mediterranean Sea, in the North Sea and in the English Channel. The average time of observation was 19 hours, with a minimum of 11 hours and a maximum of 27 hours. Even though the investigations took place during different times of the year, usually good weather conditions were experienced with low winds and calm seas. During one voyage temporary rain showers were encountered during the night. Another vessel was sailing through fog banks with restricted visibility up to 200m for two hours of its voyage. Comprehensive analysis of alarm recordings were performed and are described in more detail in (Motz, Baldauf & Höckel, 2008).

An important result of the analyzed records was that collision warnings form a major part of all types of alarms registered during the studies. Figure 3
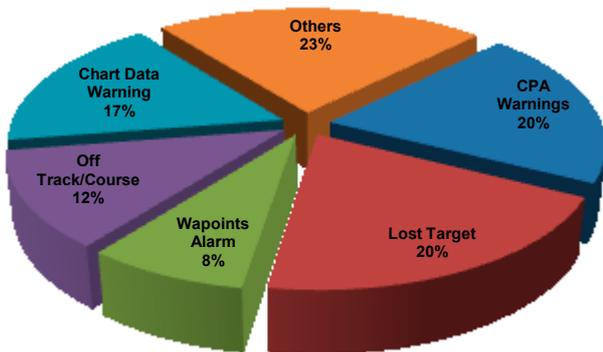
depicts the average percentage of the types of alarms registered for the six vessels and highlights this outcome. For all vessels investigated the majority of alarms are collision avoidance alarms together with lost target alarms. Summed up they have a portion of approximately 50%.

Additionally Figure 4 shows the average percentages of the sources triggering collision warnings (CPA – (distance at) Closest Point of Approach)/ TCPA – Time to CPA) for all vessels investigated. Both kinds of alarms were predominantly caused by AIS information. This percentage could have been even higher, if the bridge team of one of the container vessels had not chosen a radar setting without integration of AIS information, which caused all CPA/TCPA and lost target alarms to be initiated by radar information.
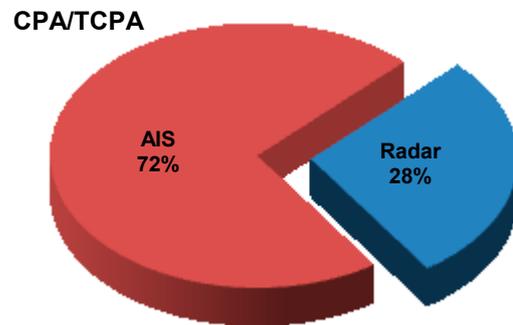

Figure 4. Sources of collision warnings for all vessels of the field studies

This result has been expected because of the technical configuration and the use of the automatic alarm functions. For AIS, according to IMO regulations, the same limit values have to be applied as for tracked radar targets and the option for CPA/ TCPA calculation was switched on to sleeping AIS targets by default. On the other hand a critical fact is that 20% of all registered alarms are "Lost target alarms", mainly caused by AIS. This is critical as "Lost targets" are of minor importance compared to safety-relevant collision warnings. Accordingly their occurrence occupies the operator's attention and workload capacity.

Usual threshold configuration for CPA is from 0.5 to 1.0 NM and for TCPA from 12 to 15 min. During empirical studies it was observed that the crew adapted the thresholds for CPA and TCPA only very seldom. Moreover the navigating officers often prefer to switch off the alarm by setting the thresholds to zero. As investigated in former studies (Baldauf, 1999) and confirmed by participating observations and the results of personal interviews
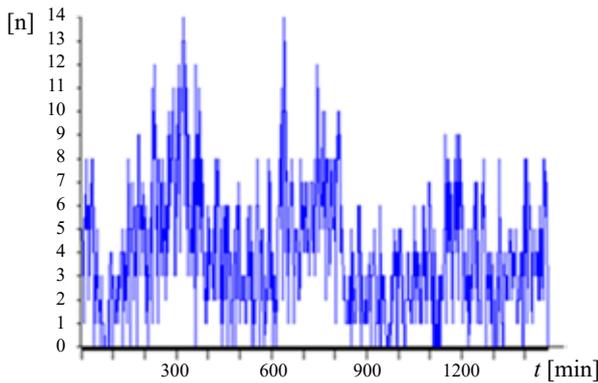

Figure 3. Average percentage for types of alarms for all six vessels

Figure 5. Frequency of CPA/TCPA-warnings for a sample of 24 hours recording period of VTS traffic in the German Bight area

based on structured questionnaires, the navigators mentally use different CPA limit values and adapt them especially according to different types of situations (meeting on opposite courses, overtaking or encounter on crossing courses).

Studies using historical traffic data recorded in a shore-based VTS station have shown similar shortcomings (Baldauf, 1999). Applying standard CPA-limit of 900m and TCPA-Limit of 8 min for the traffic in a monitored area resulted in a permanent high alarm rate (see Figure 5).

In this spotlight analysis of a 24 hours recording period there were, up to 14 collision warnings at the same time, which is difficult to handle with only one operator.

The onboard and shore-based investigations, however, clearly show the need for situation dependent variable thresholds to be applied for triggering warnings that may support the operators' situational awareness and help him to detect dangerous situations and respond to them accordingly.

The concept of the Last Line of Defence and the ultimate action alarm

Similar to air traffic the framework for collision avoidance in maritime traffic in open seas is laid down in IMO's Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), from 1972 (see Cockcroft & Lameijer, 2012; IMO, 1972). However, although COLREGs contain a specific rule on 'Risk of Collision' (Rule 7) there is only generic guidance given for how such a risk may be determined. Besides a constant compass bearing there are no clear parameters and criteria mentioned that shall be used for the determination of a risk of collision. Numerous comments, scientific studies and academic articles

are available discussing this situation and suggesting amendments and clarifications for a more harmonized, concrete and detailed procedure for how to determine the risk of collision and when and how to take what action.

Contrary to air traffic, the rules and regulations, as well as all mandatory technical systems for collision avoidance in shipping, do not provide any clearly defined safety limit nor ranges or times when a navigator has to take action to avoid a collision. Technical systems to support decision making as Radar ARPA, also integrated with AIS, provide options to alert the OOW if a dangerous situation, in terms of an expected encounter with a passing distance less than a configured limit value, is likely to occur in a certain time, freely configured by the OOW as well. Modern Integrated Navigation Systems (INS) usually provide further alerts, however, most of them can be completely switched off – a fundamental difference to ACAS in air traffic.

In maritime traffic the situation is moreover characterized by the use of 'fuzzy-like' definitions. A vessel shall take action to pass at a safe distance – but there is no value given as to what distance is safe. Action shall be taken 'in ample time' but there is no concrete time period mentioned. Furthermore there are no rules or regulations which clearly define any separation zone around a ship to be kept free of any other vessel (intruder).

However, the COLREGs were found to be good and sufficient as they were and so withstand all those attempts of modifying, changing or further developing these rules. Consequently, in the light of the introduction of so many new technologies into shipping since 1977, when the COLREGs entered into force, one may give compliments and credits to this legal framework that is still functioning but space should be made to allow the application of enhanced and sophisticated tools, computer- and simulation-based decision support and other systems.

The possibility exists for harmonizing and to further improve maritime collision avoidance thus making it similar to aviation, in the past a number of concepts and methods have been developed (see e.g. Benedict, 1994). Among which was the suggestion of the introduction and application of the concept of potential area of water (PAW). Among others Göhler (Göhler, 1983) introduced a so called 'expectation area'. He defined it as the area covering all potential positions that a ship theoretically may reach in a certain time period by using the control options of the maneuvering handles. Further Inoue (Inoue, 1990) developed a similar approach and proposed

using the PAW as an index for risk assessment in ship handling.

While one concept takes into account the complete range of all maneuvers to both sides, the other concept was looking into probability related aspects and was focusing only on one side. However, the principle concept is obviously the same and takes into account all combinations of maneuvering options of a ship. Besides a number of qualitative approaches there are a number of further studies dealing with the quantification of the risk of collision using similar terms as the PAW, expectation area, maneuvering area and so on (see in more detail Baldauf et al., 2011; 2015).

One of the challenges of the approach is the provision of suitably fitting methods for the provision of the dimensions and expansion of the area by predicting the maneuvering characteristics of a ship in terms of its hydrodynamic behavior when responding to a rudder, engine or other maneuvering controls. This means on the one hand calculations of satisfying accuracy are required, meeting a minimum level of reliability. On the other, especially for real-time-support, the availability of reliable measurement data is a compelling need but will not be discussed in this paper. A simplified application of the PAW concept is shown in Figure 6.
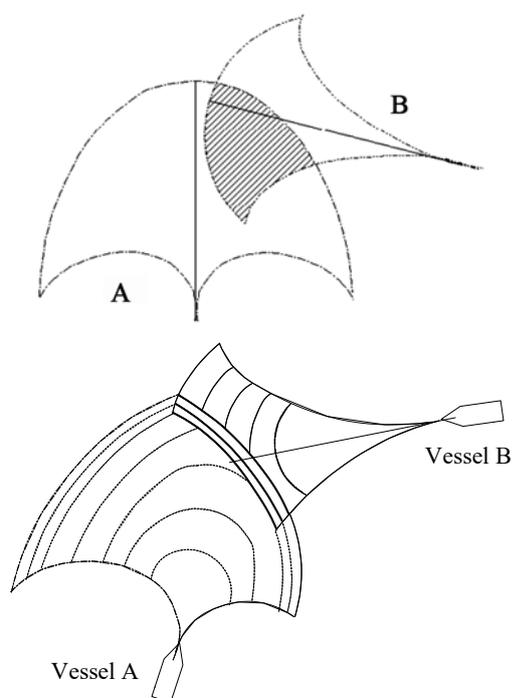

Figure 6. Top: Principle of overlapping maneuvering areas as an estimate risk of collision taking into account dynamic aspects of maneuvering; Bottom: Principle sketch highlighting Lines of same time as potential collision points when both vessels decide and conduct a fatal maneuver

Assuming the aforementioned prerequisites are fulfilled, in earlier presentations, it was suggested quantifying the risk of collision by estimating the level of the overlap of both ships' maneuvering areas for a given time period as an expression of the probability of the potential hazardous event of a damaging contact between the two ships (see Figure 6 top).

The underlying idea for this method is that the overlap of the maneuvering areas can be taken as an initial simplified expression of the remaining options of taking those actions that successfully prevent a damaging contact with the other vessel.

The simplification is based on the fact that the overlap does not exactly describe all the options for steering sequences of the involved vessels that will lead to a collision. The exact determination would require the determination of the positions both the vessels would reach as a result of any steering sequence at the same time – lines of the same time or isochrones (Figure 6, bottom). However, the overlap can be taken as a good estimation for quantifying the risk of collision during the course of any encounter situation.

For triggering the 'perfect' collision alarm a sophisticated probability consideration is not necessarily a prerequisite as long as a ship-centric approach is aimed for. What is needed is a comprehensive network of sensors providing sufficiently accurate and reliable own ship data, data of the marine environment and traffic data (targets in the vicinity of the own ship). A principle structure of the required elements of a module that provides calculation of the "Last Line of Defence" and triggering the "Ultimate Action Alarm" is given in the Figure 7.

The core element of such a module will be the unit that provides the maneuvering characteristics according to the prevailing circumstances. Two options are under development.

The first approach is a data collecting and analysis method and is based on the continuous recording of maneuvering data during normal routine and even emergency navigation processes. The use of the steering controls will be recorded and the response of the ship in terms of rate of turn, course- and or speed changes will be analyzed and stored according to a sophisticated system that records actual water depth, current, wind, ship draughts (fore and aft) according to and depending on available sensor inputs. It is assumed that during the life time of a ship a database can be developed that will contain, if not exactly, at least similar conditions of the environment and the ship status in which a collision avoidance maneuver needs to be executed. Using enhanced search algorithms in such a maneuver
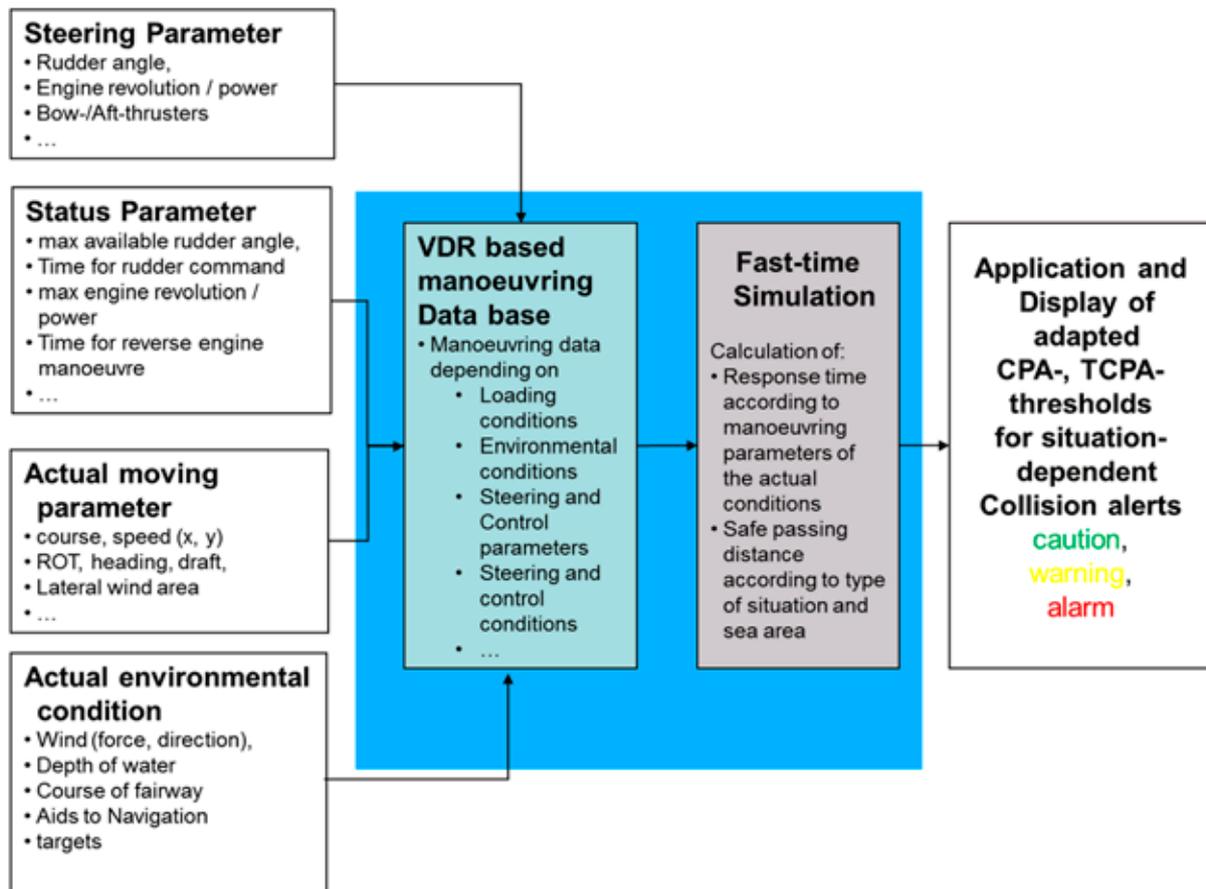
Figure 7. Elements of a Collision Avoidance Module providing calculation of the LLoD and triggering the "Ultimate Action Alarm"

database will allow the determination of the remaining options for an evasive maneuver and can provide the most suitable maneuver and the time at which the specific command has to be initiated.

The second approach applies the Fast-Time-Simulation (FTS) technology. In very general terms any simulation module can be applied that appropriately provides for the prediction of the response of the vessel in given circumstances. For such kinds of predictions, including all available steering options, a number of methods can be applied.

A rough estimation could be realized by applying IMO resolution on "Standards for Ship Maneuverability" (MSC.137 (76), 2002). The standard aims at defining minimum performance standards for maneuvering. This standard requires e.g. in regards to the turning ability that the advance shall not exceed 4.5 ship lengths and the tactical diameter of the turning circle shall not exceed 5 ship lengths. Regarding the stopping ability it is required that a full astern stopping track shall not exceed 15 ship lengths, with exemptions for ships with large displacement and impracticability of the criterion (shall not exceed 20 ship lengths).

It is obvious that this rough estimation as a rule of thumb might only be supportive for a kind of preliminary situation assessment of the risk of collision. The ship status and the prevailing environmental conditions and even more so a change in draught and trim may significantly affect turning and stopping abilities.

A more enhanced estimation of the maneuvering characteristics can be performed using sophisticated calculation methods and simulation facilities using equations describing the maneuvering behavior of a ship. There are two basic approaches: on the one hand response models and on the other hand hydrodynamic force models.

With the rapid development of computer technology, the increased power and performance of computers and their growing memory capacity it is nowadays possible to implement sophisticated models and develop and apply more and more comprehensive and advanced models for the prediction of ships' maneuvers. In first experimental studies the authors have applied the NOMOTO model and for application in an online support tool, a 3DoF-model of hydrodynamic forces. NOMOTO commenced

his study on the application of frequency response approach to the steering motion of ships, and then attempted to express the manoeuvrability of ships as a whole in terms of two indices. First one "K" indicates the turning ability and the second one "T" indicates the course stability or quick responsibility. The NOMOTO equation is the simplest mathematical model for ship manoeuvrability. It is used to calculate ship trajectories for each angel between 0 and 35 degree for the same speed, time and hydrodynamic indices, the results shows that the model is feasible for the concept of maneuvering area. However, due to the absence of drift angles there is no speed drop in this model. That is why a correction is added to take this into account (for further details see e.g. (Nakano & Hasegawa, 2012).

A more sophisticated option is the use the simulation augmented maneuver design and monitoring (SAMMON) fast time simulation (FTS). This is specifically developed for online support in almost real-time. Real-time simulation calculates per second computing time reflecting one-second of simulation time and is, preferably used for ship-handling simulations in education and training (see among others Benedict et al., 2014). Opposite to this FTS calculates future positions and status of the ship by means of complex models quicker than in real-time. The module developed is able to provide in one second calculation time predictions for up to 24 minutes in advance. The predictions even include use of steering sequences of the handles (rudder, thrusters, and engine) as input values for path predictions.
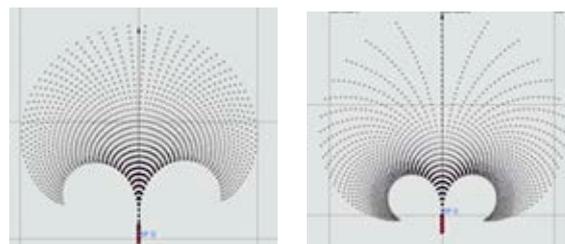

Figure 8. Samples of maneuvering areas for a container (left) and a passenger cruise ship (right) for series of rudder maneuvers (engine at 80% in deep water with no disturbance from wind and current)

In respect to the triggering of the 'perfect' alarm such a simulation module can provide the needed parameters for the "LLoD" either by direct calculation or by filling the related database with the relevant maneuvering characteristics for numerous alternative maneuvering options. Figure 8 shows examples of such FTS based calculations for maneuvering areas of a container and a passenger cruise ship.

An important result of these performed experimental trials for the determination of the coordinates and times of the "LLoD" is that depending on the ship loading conditions it is not in every case that a hardover rudder maneuver is the maneuver that is the last remaining evasive action, as best turning rates and smaller turning circle diameters may sometimes appear at other rudder angles than the hard angles. The following Figure 9 shows a visualization of an encounter situation for two ships on crossing courses in an ECDIS environment (own ship marked by the red shape in the top middle of the screenshot).
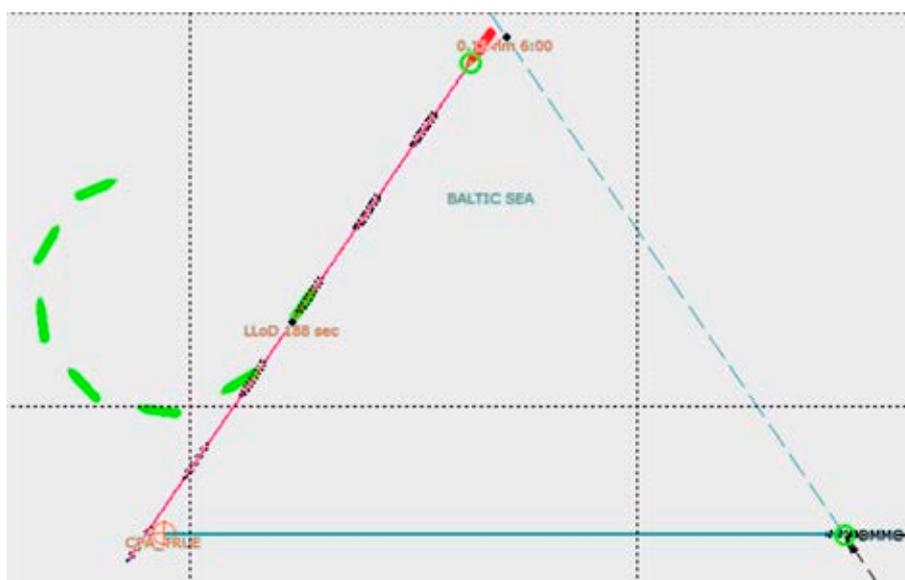

Figure 9. Sample of a freely constructed encounter situation of two ships on crossing courses and visualization of a chosen starboard turn maneuver
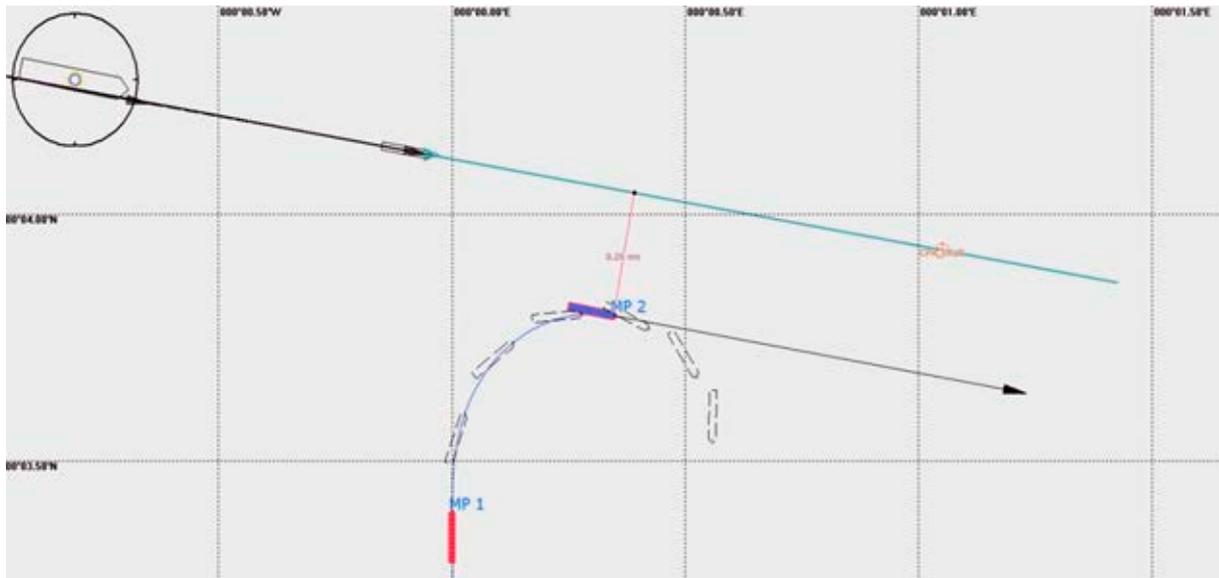
Figure 10. Sample of calculation results for another encounter situation on crossing courses with intended passing distance of 0.25 NM for a turning maneuver at maximum turning rate

In this scenario the own ship is on a southwesterly course and has another ship on her port-side. A very close CPA is detected and indicated by Radar-AR-PA calculations accompanied by AIS data. In good visibility the vessel "which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel". In a rather generalized way this means the own ship would have to be the stand on vessel and keep course and speed until it becomes apparent that the give way vessel is not following the rules. Detailed discussions of obligations of each the vessels can be found among others in (Cockcroft & Lameijer, 2012).

However, it is not intended to discuss obligations according to COLREGs, but for demonstration purposes it is assumed that the vessels have tried to contact each other but without success. In case none of the vessels, no matter if stand-on or give way, take action, a collision would occur in less than six minutes. Focusing only on the own ship and taking into account her maneuvering capabilities at the actual environmental conditions, the time for initiating a maneuver to realize a passing distance of 3 cable from ship's hull to ship's hull shall be determined.

For the depicted situation the time to the LLoD, assuming a rudder angle of 30° can be used, the FTS-module calculates this time to approximately 3 minutes (188 seconds). The position, when this maneuver has to be started by turning over the wheel is indicated by the green ship shape ahead of the own heading line and the green ship shapes indicate the predicted ship status of initiating the maneuver for pre-selected time steps.

In the same manner the system may simultaneously provide the remaining time until reaching the LLoD for other (smaller) rudder angles (e.g. in the demonstrated scenario 2:52 min (20°) and 2:14 min (10°)).

A visualization of another encounter situation on crossing courses in an ECDIS environment is shown below. The calculation of the LLoD in this case is based on the maneuver with the maximum possible turning rate. This is because of the fact, that there are often constraints from ship operation, especially avoiding the use of hard rudder for instance.

Here it is also highlighted, that the closest approach will be reached when the heading of the own ship equals to the course over ground of the target ship.

The fundamental difference of triggering a "LLoD – Ultimate Action Alarm" (UAA) compared to the conventional CPA/TCPA warnings is, that for the very first time, a direct connection of alarming and maneuvering characteristics have been realized. The OOW is no longer informed about the remaining time to a potential collision or the passing at whatever "safe" or "unsafe" distance, but she or he will get a clear indication of the time remaining to take action and maneuver to avoid the collision. With the support of the fast-time simulation different maneuvering options can of course be calculated. Those alternative options can not only include different rudder angles but even provide combined engine- and rudder maneuvers.

The system may suggest a maneuver on the basis of the simulation module or on the basis of recorded maneuvering data matching to the environmental conditions and the ship status. The minimum passing distance needs to be defined and shall always be greater than the hydrodynamic safe passing distance. Domain areas (see a.o. Szlapczyński & Szlapczyńska, 2017) are considered to not really be suitable for this UAA concept. Domain areas seems to be more suitable for more enhanced CPA calculations. However, the minimum passing distance value is qualitatively defined as the distance at which hydrodynamic interaction between two overtaking vessels will not lead to contact between the ships' hulls. A quantification of this distance needs further research. However, the hydrodynamic safe passing distance for an overtaking situation is considered safe for head-on and crossing situations as well.

Summary and conclusions

Investigations are ongoing to explore potential transfer and application of solutions from aviation into the maritime domain in order to develop a perfect alarm that only occurs when really needed. This is the case when the options for actions (maneuvers) to avoid potential damage by a collision are becoming less.

A system similar to ACAS can feasibly be adapted for use in maritime traffic. An originally implemented method using FTS technology to predict the hydrodynamic behavior of the ship has been further developed to determine the "Last Line of Defence" for a maneuver to successfully avoid a collision on the basis of the own ship maneuvering characteristics. For the prediction of the maneuver options a concept containing two basic approaches to provide data have been introduced and their principle structures and functioning have been described. Finally a first application case has been demonstrated.

The approach of triggering situation-dependent variable alarming is a fundamentally new approach to trigger a collision alarm and certainly requires further investigation and research in a number of areas among which are design of the user interface (what and how to present situation parameters) and how to provide accurate and reliable predictions respectively.

The authors are of the opinion that the chosen approach, the applied method and technologies clearly demonstrate the potential to allow the development and introduction of a completely new quality of alarms and warnings for collision avoidance systems in shipping. Such alarms may have the potential for generating at least a similar effect of risk reduction as ACAS/TCAS in air traffic.

Acknowledgments

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