INVESTIGATIONS INTO ENHANCED ALERT MANAGEMENT FOR COLLISION AVOIDANCE IN SHIP-BORNE INTEGRATED NAVIGATION SYSTEMS

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Abstract: High sophisticated integrated navigation systems are installed on the ship navigational bridges to support the operator of modern container ships. The integrated systems should assist the captains, navigation officers and the pilots to avoid any dangerous situation when sailing from port of departure to the port of destination. Numerous Human Machine Interfaces require interaction to control the voyage in every situation under all possible circumstances. However, with respect to shipping statistics collisions and groundings are major risks. This paper deals with investigations into the alert management on board modern ships and potential approach to reduce the number of alarms. Results gained during several field studies on board ships are presented. Based on these results the draft of a concept for reducing the high frequency of collision warnings to be implemented into the navigation systems on board is discussed. First preliminary results are introduced.

1 INTRODUCTION

In February 2008 the Norwegian classification society Det Norske Veritas (DNV) published new statistical figures on sea accidents. The figures clearly showed that the number of accidents has doubled over the last five years. DNV concluded that this is caused mainly by the continued growth of the world fleet and a shortage of officers with right skills. On the other hand, technical failures were mentioned more seldom.

It can be seen as another sample for Ironies of Automation as described by Bainbridge (1983) – that the majority of total losses in shipping is due to collisions, groundings and contacts although there are highly automated systems installed onboard seagoing vessels to support the Officer of the Watch (OOW) on the ships navigational bridge. Especially with respect to the level of integration of the sensors, equipment, displays and assistance systems those navigational bridges can undoubtedly be defined as highly-complex man-machine systems. Sherwood Jones et al. (2006) discuss the management of alarm systems and come to the conclusion that the role of the OOW seems to become more an observer of the navigational equipment instead of their situation awareness being improved by such systems.

Recent field studies (Motz, Baldauf & Höckel, 2008) showed a lack of alert management. There are superfluous alarms from several systems under conditions of high traffic density especially in sea areas near the coast and at harbour entrances. With respect to implemented collision warnings there is a lack of adjustment of the thresholds. In order to better and effectively support the mariner onboard a task- and situation-dependent representation of encounter situation's parameter and information basing on sufficient acquisition of reliable data and

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its processing is an urgent demand and an actual challenge for research and development.

To approach the problem a number of field studies were performed on board of ships to investigate the situation with respect to the occurrence of alarms and their handling by the bridge team. Based on the outcome of these studies lacks and shortcomings of navigation systems presently in use were identified and an approach to reduce the number of false alarms is developed as suggestion, taking into consideration available technical system as e.g. ARPA (Automatic Radar Plotting Aid) and AIS (Automatic Identification System) information as well as new GNSS (Global Navigation Satellite System) facilities. Within this paper the used methods and selected results for samples of the investigations are presented.

The investigations were performed under the framework of two national research and development projects funded by German Federal Ministry of Education and Research and the German Federal Ministry of Transport, Building and Urban Affairs. The results of the studies are used to directly support the work of the International Maritime Organization regarding the development of new performance standards for Bridge Alert Management and to contribute to the further development of the e-Navigation concept.

2 ONBOARD COLLISION AVOIDANCE – PRESENT SITUATION

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

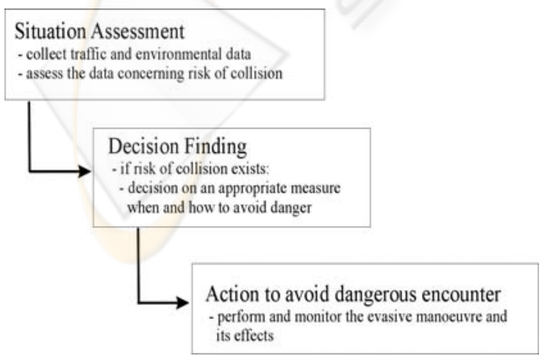

Figure 1: Simplified model of the on board process of collision avoidance.

During the process of situation assessment the OOW has 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 case of a situation with developing or existing risk of collision, the OOW has to decide when and by which initiated measure – usually a manoeuvre to increase the expected passing distance in due time – 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 controlled and, if necessary, to be corrected or adjusted.

A detailed analysis of the investigation reports dealing with collisions performed by the Nautical Institute (Patraiko, 2008) showed that nearly 50% of all collisions happened, because one of the involved vessels had not recognised the other vessel.

3 INVESTIGATIONS AND SELECTED RESULTS

A series of field studies was conducted on board of ships to investigate the situation with respect to the occurrence of alarms and their handling by the bridge team. 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 (Baldauf & Motz, 2006), 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 situation onboard with respect to the alert occurrence and handling. Within the context of this paper, the focus is laid on results related to collisions warnings triggered by and displayed at the ARPA-Radar Human Machine Interface with integrated AIS targets and superimposed by information of ECDIS (Electronic Chart Display and Information System).

The timely distribution of alarms reflects the dependence of the numbers of alarms from the sea area. This hypothesis is further confirmed when analyzing the registered alarms in relation to the navigational situation.

The field studies were carried out on board of six vessels, which were two ferries operating in the Baltic Sea, three container vessels (with container capacities of 6.200 TEU, 5.500 TEU and 7.500 TEU) and a cruise vessel operating in the Mediterranean Sea. All vessels were built or reconstructed within the time span from 2001 until 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 on different times of the year, usually good weather conditions were experienced with low winds and calm sea. 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 by Motz, Baldauf and Höckel (2008).

An important result of the analysed records was that collision warnings form a major part of all types of alarms registered during the studies. Figure 1 depicts the average percentage of the types of alarms registered for the six vessels and highlights this outcome. For all vessels investigated the majorities of alarms are collision avoidance alarms together with lost target alarms. Summed up they have a portion of approximately 50%.

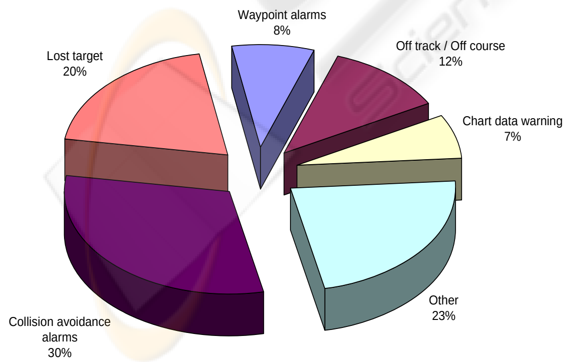

Figure 2: Average percentage for types of alarms for all six vessels.

Additionally Figure 3 shows the average percentages of the sources initiating 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 vessel 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.

This result is to be 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.

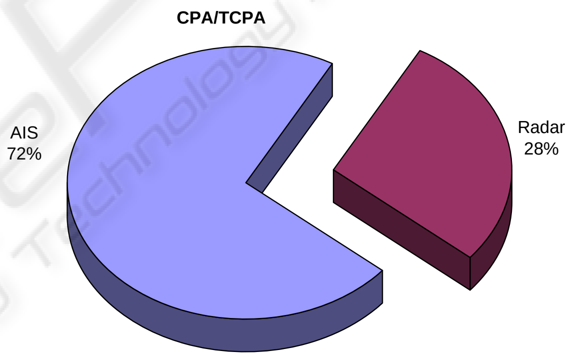

Figure 3: Sources of collision warnings for all vessels of the field studies.

Usual threshold configuration for CPA is from 0,5 to 1,0 nm and for TCPA from 12 to 15 min. During the 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 the results of personal interviews 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).

4 APPROACH TO REDUCE THE NUMBER OF COLLISION WARNINGS

To guarantee the high safety standard in maritime transport, as described above, there is a need to reduce the number of alarms on board vessels. It is necessary because the high frequency of occurring alarms, obviously, do not contribute to a better situation awareness of the watch keeping officers on the ship's navigational bridge. Alarms should only occur, if a real dangerous situation is developing and the announcement confirms the mental risk assessment of a well skilled and experienced navigating officer.

This goal can be reached by combination and pre-processing of available information to generate and apply situation dependent thresholds for example for the purposes of collision avoidance. In this way, enhanced alert management of future Integrated Navigation Systems (INS) will be able to trigger more reliable collision warnings, but only in that cases in which a navigator usually would have to react.

For that specific purpose a first generic concept is drafted. It is aimed to combine target information from different sensors and manoeuvring information that will be provided by Voyage Data Recorders (VDR) and from ECDIS as well. A visualisation is given in Figure 4.

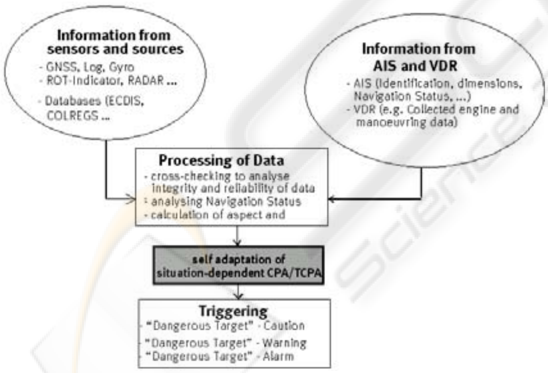

Figure 4: Generic concept for combined use of information provided by INS to self-adapting and triggering situation dependent collision warnings

Presently, modern anti-collision-systems triggering alarms, when the calculated passing distance at the closest point of approach (CPA) and the time to CPA (TCPA) are less then the limits freely configured by the navigator.

Core element of the approach for reducing the number of collision alarms is a risk model for situation assessment. This model differs between three types of encounter situations (head-on encounter, overtaking and meeting on crossing courses) and is considering the two conditions of visibility as they are laid down in the International Rules for Preventing Collisions at Sea (Cockcroft & Lameijer, 2004). Furthermore the concept is applied to the new IMO definition of alerts given in the new performance standards for INS (IMO, 2007) and allows for introducing situation dependent collision alert categories "Caution", "Warning" and "Alarm" as well. Cautions and warnings may be switched off by the operator, but alarms may not.

For self adaptation of thresholds, different CPA limits are foreseen, which will be set according to the hydrodynamic safe passing distance related to the dimensions of the involved ships, the actual sea area as well as visibility conditions.

As suggestion for initial basic values CPA limits were determined by a detailed field study. To ensure a wide range of user acceptance one emphasis was laid on the navigators' behaviour. From the point of view of well experienced navigators it is rather more practical to determine the safe passing distance with respect to usual data. Under pragmatic aspects and according to the investigations performed it can be assumed that the nominal safe passing distance has to be in relation to the ship's length of the largest vessel L_{max} involved in an encounter situation (L_{max} . should not be less than 1 cbl). Taking into account different kinds of encounter situations as defined by the COLREGs a factor "f_x" is necessary which depends on the kind of situation "x" (Safe Passing Distance (nominal) = $f_x \cdot L_{max}$).

Table 1: Recommendation for basic values to calculate situation dependent threshold.

kind of encounter situation	f_x (good visibility)	f_x (restricted visibility)
head-on situation meeting port/port-side	2.5	5
Overtaking	2.5	5
head-on situation meeting stb/stb	5	10
crossing situation	5	10

The values, given in the table above, are derived from several investigations and are suggested for the four main kinds of encounter situations. These values were proved by simulation studies and are valid under the conditions "open sea" for good (column 2) and restricted visibility (column 3).

The values derived here and used for this approach are similar to values found by several other studies (e.g. by Pietrzykowski & Uriasz (2009)) to support safe manoeuvring in case of collision avoidance.

On the other hand recorded manoeuvring data will be used for automatic adaptation of the TCPA related limits of the dangerous target alarms, either by taking them directly from a database or by calculations using fast time simulation algorithms (Benedict et al, 2006). The response time for turning manoeuvre is a fundamental value to avoid a collision. Such response times are only available to captains on board for some standard manoeuvres and they are usually neither exactly known nor applicable to the prevailing circumstances of a concrete dangerous situation to be solved. A sample of a standard set of response times for a normal sized container vessel with a capacity of 5.000 TEUs is given in the following table.

Table 2: Response times for turning manoeuvre depending on own ships speed and rudder angles.

Own speed (kt)	Rudder angle (°)	time for course alteration of 90° $t_{90°}$ (min)	covered distance $t_{90°}$ d_{OS} (nm)
24	hard a-starboard	2,42 (2 min 25 sec)	0,97
24	starboard 15	3,85 (3 min 51 sec)	1,54
22	starboard 20	3,40 (3 min 24 sec)	1,25
22	starboard 15	4,17 (4 min 10 sec)	1,53

As stated before, when applying the drafted concept for situation dependent alarm thresholds those values maybe be determined from direct recordings of the continuously working VDR. The principal application's structure and the relevant data flows are given in the figure below.

Again the values suggested here roughly corresponds with values coming from ship domain studies (Goodwin (1975)) but also with results applying new concepts to determine critical distance for manoeuvring according to the COLREGs (e.g. Rymarz (2007).

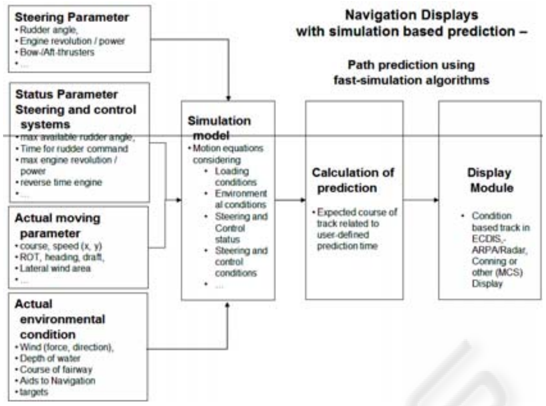

Figure 5: Principal application structure and data flow for self-adaptation of thresholds for collision alerts.

First studies applying the situation dependent thresholds for detection of dangerous encounter situations in overall traffic scenarios in sea areas off the coast monitored by VTS leads to a reduction of the number of collision alerts by 40%.

5 SUMMARY AND OUTLOOK

Investigations into ship borne Alert Management were performed and are continuously ongoing to improve the situation on board. Investigations into the present situation on board have shown that there is an urgent need for the reduction of the high frequency of alerts. Presently collision alerts have a major portion of all alerts occurring during normal ship operation. That is why a concept for situation dependent thresholds for collision alerts is developed. The concept considers the situation assessment of experienced navigating officers by allowing different values according the type of encounter situation and visibility conditions as well. Combining available information and data from different sensors of modern Integrated Navigation Systems it is suggested to determine the situation dependent thresholds taking into account the ship dimensions of the involved ships and the manoeuvring characteristics valid for the concrete situation. First studies performed for purposes of shore based detection of dangerous encounter situations have shown that a significant reduction (up to 40%) of the collision alerts frequency is possible.

The investigations were part of projects funded by the German Ministry of Transport, Building and Urban Affairs and the German Ministry of Education and Research. The results directly support

the work of the International Maritime Organization developing new performance standards for Bridge Alert Management and contribute to the e-Navigation concept.

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