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Advanced Maritime Technologies to Support Manoeuvring in Case of Emergencies - a Contribution to E-navigation Development

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ABSTRACT: Safe ship handling in every situation and under all prevailing circumstances of ship status and the environment is a core element contributing to the safety of the maritime transportation system. Especially in case of emergencies, there is a need for quick and reliable information to safely manoeuvre a ship e.g. to quickly return to the position of a Person-overboard (PoB) accident. Within this paper investigations into onboard manoeuvring support for Person-overboard accidents will be presented. Based on the analysis of selected accident case studies and existing solutions representing the technical state-of-the-art, shortcomings will be identified and discussed and a potential approach for advanced manoeuvring support in the context of e-Navigation based requirements will be introduced and discussed.

1 INTRODUCTION

One substantial contribution to safety of the maritime transportation system is safe ship handling. It has to be realised in every situation and under all potential prevailing circumstances of the ship status (i.a. characterised by ship type and shape, draught etc.) and the environment (as, e.g., water depth, wind, current etc.). In the case of certain dangers or concrete emergencies there is an urgent need for quick and reliable information in order to safely manoeuvre a ship e.g. to quickly return to the position of a Person-overboard (PoB) accident. Especially in such situations, manoeuvring information provided by standard wheelhouse posters or the required standard manoeuvring booklet are inconvenient and insufficient.

According to the definitions given by IMO/IALA, e-Navigation is the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth-to-berth navigation and related services, for safety and security at sea and protection of the marine environment. Within this concept new approaches to provide advanced manoeuvring support in case of emergencies can also be developed.

There are ongoing investigations into potential enhancements for onboard manoeuvring support and assistance for the specific case of Person-overboard accidents. Among others motivated by the introduction of new information and communication technologies and their potentials for more sophisticated solutions, research and development activities taking also into account the latest e-Navigation initiative of IMO and IALA have been started. Based on analysis of selected accident case studies and existing solutions, representing the technical state-of-the-art, lacks and shortcomings will be identified and discussed in the next chapter followed by development of a concept for advanced situation-dependent manoeuvring support. Relations to and requirement derived from IMO's and IALA's e-Navigation initiative will be introduced and discussed.

2 PERSON OVERBOARD CASE STUDIES

2.1 *Container ship in heavy seas*

A fully laden containership was on a voyage from port of Rotterdam sailing to a port in the Baltic Sea. The actual speed was reduced due to deteriorating weather conditions with strong winds and increasing wave heights.

Some bunker room alarms occurred during night time and the ship command decided to send a team to investigate the situation and the source of alarms.

A team of two engineers went to the bunker room between cargo holds but one of them was hit by a wave and washed overboard. Although his immersion suit was without a floating device, it kept him warm and a fender which had been torn loose kept him afloat.

The ship's command immediately informed shore-based traffic centre and requested assistance but decided not to conduct a return manoeuvre such as a SCHARNOW- or WILLIAMSON-Turn and, as documented in the official accident investigation report, continued her voyage without changing course or speed at all.

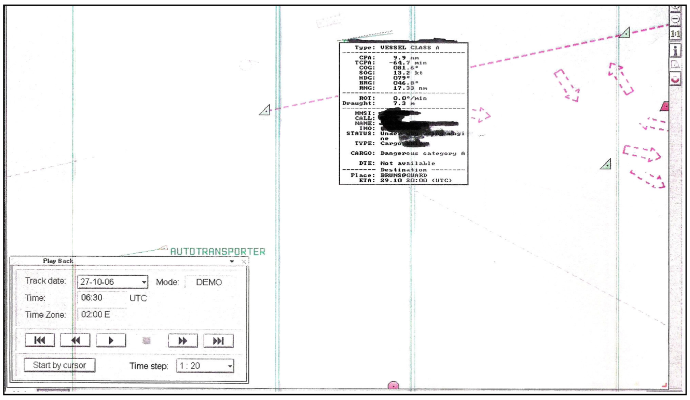

Figure 1. Snapshot from ECDIS record – continuation of the voyage without conduction any manoeuvre (taken from accident investigation report)

The person overboard was several hours later rescued by a SAR vessel and brought to a hospital, where he was recovered and was able to resume his work a few days later.

2.2 *Person-overboard in open sea area*

A container ship was en route from Mexico to Japan in winter. The ship's route had to lead through a sea area behind a hurricane. However, the average wind condition during the time of the accident was Bft 5 with corresponding sea state and with significant wave heights of approximately 5m. In the sea area 300 nm off the Japanese coast a team of four crew members performed various tasks on the bow. In the course of their work several strong waves washed over the deck, hitting three seamen and sweeping overboard one of the mariners.

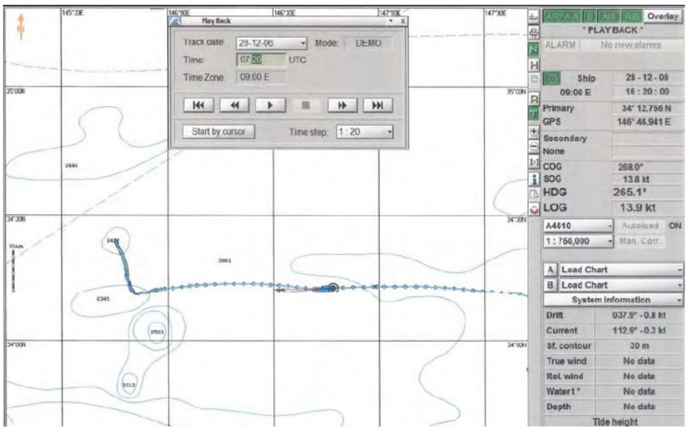

Figure 2. Manoeuvre track during person overboard accident (taken from official accident investigation report)

According to the official accident investigation report, which also includes an analysis of the manoeuvre log and ECDIS records, there were no manoeuvres in compliance with or at least similar to one of the known return manoeuvres to bring the ship back to the accident's position, or on a opposite course along the original track.

While some crew members attempted resuscitation, others were involved in search measures initiated by the ship command. The resuscitation efforts in connection with the seriously injured mariner were unsuccessful. Darkness started to fall as early as 1700 hours. Although there were supporting search efforts by Japanese Coast Guard (JCG) aircraft, the seaman who had been gone overboard could not be found. In addition at around 2100 hours rain began to fall. The search was ultimately suspended six hours after the accident due to continuously deteriorating weather, and resumed the next day by the JCG.

The vessel finally continued its journey to Japan, where two injured mariners recovered in hospital. The mariner who had been swept overboard was never found.

3 INVESTIGATIONS INTO THE PRESENT SITUATION AND STATE OF THE ART

As demonstrated in the cases studies above, even today a person overboard accident in most cases unfortunately ends with the death of the concerned person. Available statistics from national Marine Accident Investigation branches all over the world show that in up to 75% (see e.g. Annual Marine Incident Report 2003, Queensland) of such cases a mariner or passenger overboard finally died. Several publications refer to an average number of 1,000 dead worldwide per year due to person overboard accidents. According to the latest information about cruise and ferry passengers and crew overboard accidents only of North American passenger shipping companies, compiled by KLEIN for the period from 2000 to 2010, there were over 150 PoB accidents.

Compared to groundings and collisions, person overboard accidents are rarer events but in terms of risk assessment have much greater consequences. A person overboard accident requires immediate decision making and prompt action. Every second is important and influences the success of the actions to rescue the person overboard.

There are standard plans available which can be visualised, e.g., as flow chart diagram as exemplarily shown in the figure below.

But the poor success rate of rescue actions begins already with the difficulties of recognising the event immediately. The first task of the bridge team is to mark the position, release a life ring with safety buoy (smoke and light signal), keep sharp look out and turn the ship back to the position of the accident to pick up the person overboard.

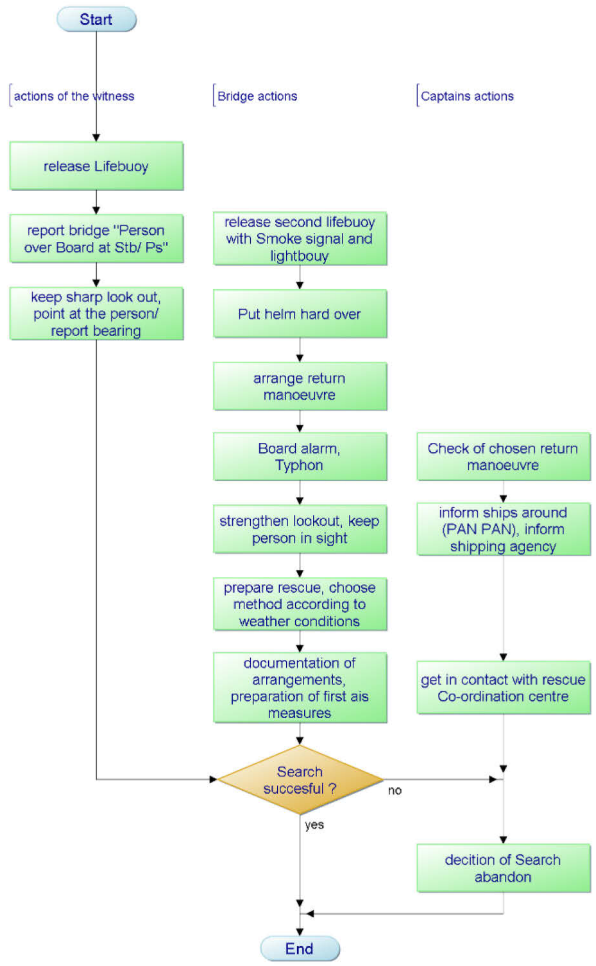

Figure 3. Sample of a Person-overboard action plan addressing actions of witness, captain and members of the bridge team (according to HAHNE)

The crucial action is to bring the ship back to the position of the accident. In literature, several manoeuvres for person-overboard accidents are described. However, there is no single standard procedure recommended, as the effectiveness of a manoeuvre depends on the type of the ship and the prevailing circumstances of the particular situation. The guidance given therefore basically takes into account only the amount of time passed after the accident. According to the IAMSAR (International Aeronautical and Maritime Search and Rescue) / MERSAR (Merchant Ship Search and Rescue) Manual, firstly published by IMO in 1970, threefold action cases for manoeuvring are described:

– "Immediate action" situation,
– "Delayed action" situation and
– "Person missing" situation.

Referring to the experiences and proven effectiveness in many person-overboard casualties the SINGLE-TURN, the WILLIAMSON-Turn as well as the so called SCHARNOW-Turn are mentioned in the MERSAR manual. However, there are further turns which are rarely used in commercial shipping as knowledge and/or experience is limited. In case of real accidents, almost no experience is available for most of the ship officers; they never or seldom have experienced such an accident personally.

The mandatory training procedures, including the conduct of return manoeuvres, are normally executed under good conditions in order to keep a safe environment for persons involved in the training routine. Contrary to this, in accidents the conditions, especially the wind and waves, are worse. Action plans according to the International Safety Management (ISM) Code are available, but in the case of real situations the use of these plans is often limited because plans are made to give more general guidance. No technical means, or only unsuitable ones, are available e.g. for the immediate selection and planning of the manoeuvre in the respective situation.

Today ECDIS and GPS or other systems are available to allow for marking the position of an accident electronically. However, it has to be done manually. As accident investigations have shown in such stressful situation the crew member may fail to do so.

Most Radar/ECDIS equipment available on the market (i.a. Transas NaviSailor or Furuno ECDIS EC 1000) allows the display of a marked position and may provide information about distance and Time To Go (TTG) to the marked position on basis of calculation using actual course/speed information.

Some more enhanced systems (e.g. latest Visionmaster FT systems of Sperry Marine) even allow for the display of search patterns – but this is needed later, if the immediate measures for finding the person right after the accident have failed.

The consideration of external factors, such as wind influence on the ship's track, is possible only on the basis of the mental model of the ship officer on watch; no computer-based support is available when it is most urgently needed.

Like all other maritime accidents, person-overboard and search and rescue cases are rare events. Immediate actions are necessary and have to take into account the prevailing circumstances of the environment and the manoeuvring characteristics of the ship. The general guidelines and information for manoeuvring have to be adapted to the actual situation. However, the manoeuvring data displayed on paper on the bridge to assist the captain and navigating officers are of a general character only and of limited use in the case of real accidents. Manoeuvring assistance regarding optimised conduction adapted to the specific hydrodynamic and the actual environmental conditions are urgently needed.

Although new and highly sophisticated equipment and integrated navigation and bridge systems (INS / IBS) have great potential to provide enhanced assistance, situation-dependent manoeuvring information and recommendation are not available yet. The same is true for SAR actions. Optimisation and coordination of all involved parties is needed, taking into account e-Navigation related concepts.

Finally, the related training courses need to be enhanced, especially by means of the use of full-mission ship-handling simulation facilities.

4 INTEGRATED MARITIME TECHNOLOGIES FOR ADVANCED MANOEUVRING ASSISTANCE

4.1 *Selected Aspects of Manoeuvring*

Ship manoeuvres can be divided into routine manoeuvring and manoeuvring in safety-critical and emergency situations. This division can be developed further by considering different sea areas where manoeuvres have to be performed: e.g. in open seas, in coastal waters and fairways as well as in harbour approaches and basins. Routine manoeuvring in open seas covers ship-handling under normal conditions, e.g. in order to follow a planned route from the port of departure to the port of destination, and include simple course change manoeuvres, speed adaptations according to the voyage plan etc.

Manoeuvring in coastal areas, at entrances to ports and in harbour basins include manoeuvres, e.g. to embark and disembark a pilot, to pass fairways and channels and even berthing manoeuvres with or without tug assistance.

Manoeuvring in safety-critical and emergency situations deals with operational risk management and includes manoeuvres to avoid a collision or a grounding, to avoid dangerous rolling in heavy seas, or to manoeuvre in the case of an real accident e.g. return manoeuvres in case of a person overboard accident or when involved in Search-and-Rescue operations.

Taking the case studies described in the second section it can be concluded that there is a strong need to improve and support the ship command with more sophisticated situation-dependent manoeuvring information, especially in an emergency. It is worthwhile to use the potential of e-Navigation and the related new technology in order to generate such assistance to the human operator when a person has fallen overboard.

4.2 *Situation dependent manoeuvring assistance by dynamic wheelhouse poster and electronic manoeuvring booklet*

As earlier investigations (Baldauf & Motz, 2006) into the field of collision and grounding avoidance have shown, there is an unsatisfactory exchange of information which is already available on a ship's navigational bridge from different sensors and sources.

Until today the change of manoeuvring characteristics, e.g. with respect to their dependencies on speed and loading conditions, as well as on environmental conditions (e.g. water depth, wind and current) has not yet been sufficiently considered. High sophisticated Integrated navigation systems (INS – see also IMO, 2009) are installed on board but do not provide the bridge team with situation-dependent manoeuvring data e.g. turning circle diameter, stopping distances etc. for the actual situation. However, the ongoing developments under the IMO's and IALA's e-Navigation initiative with the application of new technologies and data might allow exactly this in the future. In the context of the e-Navigation concept and its definition, the introduction of a dynamic wheelhouse poster and an electronic manoeuvring booklet are suggested. Up-to-date manoeuvring information adapted to specific purposes and situations can be provided by using enhanced integrated simulation technologies.

For that purpose a first generic concept has been drafted to combine own ship status and environmental information from different sensors and manoeuvring information that, e.g., could be gained via a mandatory Voyage Data Recorder or from ECDIS recordings.

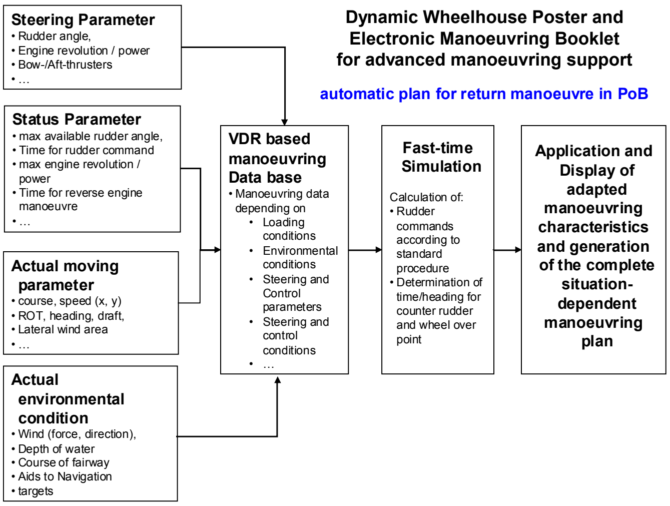

Figure 4. Principal structure and data-flow for generating a dynamic wheelhouse poster and manoeuvring booklet to provide situation dependent manoeuvring support for return manoeuvre

For a person overboard accident the mandatory wheelhouse poster should contain information about return manoeuvres. Spotlight analyses have shown that in most cases this information is incomplete and only partly or not available in the documents, even for the basic cases of deep and shallow waters as well as for loaded and ballast conditions.

4.3 *Application of fast-time simulation techniques for Manoeuvring Assistance*

The following equation of motion is used as the model for the ships dynamic and implemented in software modules for fast time simulation:

$$
\begin{aligned}
X &= m\left(\dot{u} - rv - x_G r^2\right) \\
Y &= m\left(\dot{v} + ru + x_G \dot{r}\right) \\
N &= I_z \dot{r} + m x_G \left(\dot{v} + ru\right)
\end{aligned}
\tag{1}
$$

On the right side are the effects of inertia where u and v represent the speed components in longitudinal and transverse direction x and y, and r is the rate of turn of the ship. The ship's mass is m, and x_G is the distance of the centre of gravity from the origin of the coordinate system, I_z is the moment of inertia around the z-axis. The ship's hull forces X and Y as well as the yawing moment N around the z-axis are on the left side. Their dimensionless coefficients are normally represented by polynomials based on dimensionless parameters, for instance in the equation for transverse force Y and yaw moment N given as the sum of terms with linear components N_r, N_v, Y_r and Y_v and additional non-linear terms. Other forces, such as rudder forces and wind forces are expressed as look-up tables. There are additional equations for the engine model, and also look-up tables to represent automation systems characteristics. The solution of this set of differential equations is calculated every second; some internal calculations are even done at a higher frequency. Further detailed descriptions can be found in Benedict (2010).

The inputs for the simulation module consist of controls, the states and the data for the environmental conditions. Additionally, there is an input of the ship's condition parameters. They are normally fixed but in case of malfunctions they might change, e.g. reducing the rudder turning rate or maximum angle. The results from the simulation module are transferred to be stored or directly displayed on demand in the dynamic wheelhouse poster or the electronic booklet.

The module is used to perform calculations to predict the path for specific actual or planned commands. In this way the module can be applied to plan and optimise the return manoeuvre and automatically produce the complete situation-dependent manoeuvring plan for a return manoeuvre.

5 SITUATION-DEPENDENT MANOEUVRING PLAN FOR RETURN MANOEUVRE

5.1 *Aim and Objective of the Planning Process*

The objective of the simulation-based manoeuvre planning and optimisation process is to find a suitable procedure which can be used in a particular situation for the actual status of a real ship.

There are standard files for manoeuvre control settings for simulating specific manoeuvres. By means of the fast time simulations, various results of manoeuvres will be generated. The final goal is to achieve the sequence for an optimised manoeuvre control setting adapted to the actual situation parameter. Presently, the biggest problem is that there are many options possible and the effect of the changes of the parameters used in the models is not very clear; some changes may even have effects which counteract the results of the others. Therefore it is very important to know which parameters which have a clear impact on the manoeuvring characteristic.

An example is given below to indicate the need and the effect of manoeuvring optimisation by means of an Emergency Return Manoeuvre.

5.2 *Planning of an Emergency Return Manoeuvre*

The example discussed in the following extract is the emergency return manoeuvre using the well known “Scharnow-Turn”.

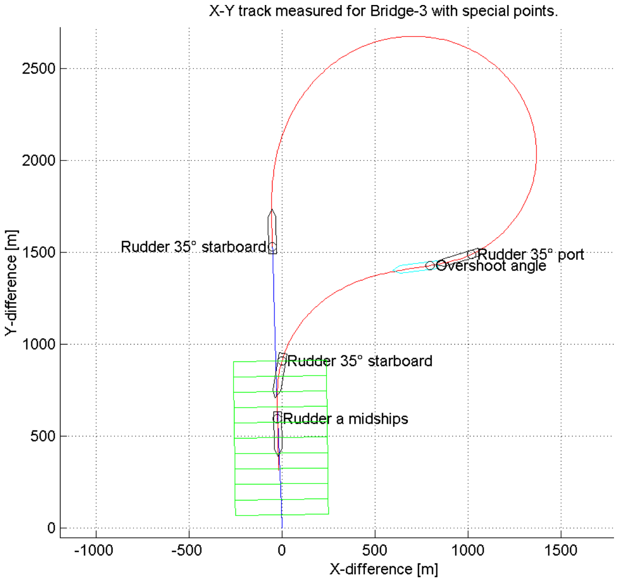

Figure 5. Reference outline for the Scharnow–Turn

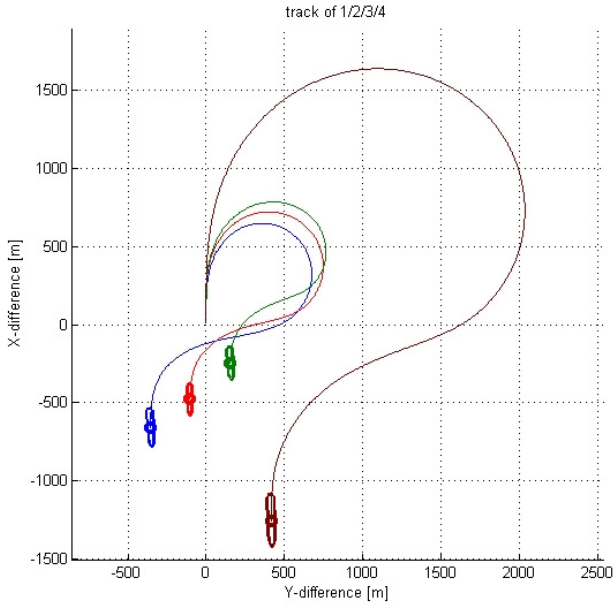

Figure 6. Comparison of the outline of standardised Scharnow–Turn for four different types of ships

As with all other emergency return manoeuvres, the fundamental aim is to return the vessel to the original track by the shortest route and with minimum loss of time. In practice the vessel initially follows the turning circle, and after shifting the rudder by a course change of about 240°, finally turns to counter rudder and amidships. The vessel then swings back to the opposite course at a certain measurable distance from the original track, at a certain distance from the reference manoeuvre.

The first problem is how to get the "Optimal reference manoeuvre" because the heading change of 240° is an average only and can differ among ships from 225° up to 260° or even more, as can the Williamson Turn which can vary from 25° to 80° instead of the standard average value of 60°.

The following figure demonstrates the wide variety of the outcome of the standard course of rudder commands compared for a container vessel, a cruise ship (blue), roro-passenger ferry (brown) and two container feeder vessels (green and red).

Beside this basic variance according to the ship type, there are other more important dependencies that have a substantial impact on the outlined path of a return manoeuvre.

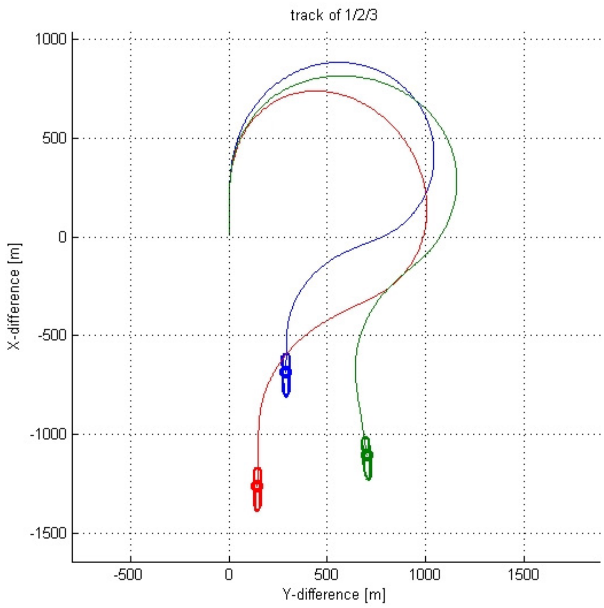

Figure 7. Comparison of the outline of standardised Scharnow–Turn for a 7.500 TEU container ship in ballast condition for three different wind conditions (no wind- blue and wind Bft 6 from north (red) and north-west (green) respectively)

Further samples are given in Fig. 7, which demonstrates the dependency of the final outcome of the return manoeuvre on the loading condition as well as on wind force and wind direction. Of course, the outline would change again if the ship is fully laden or if shallow water effects occur.

Finally, for reasons of completeness, it should be mentioned that there are dependencies on the initial ship speed and on the available water depth. It is clearly to be seen that adaptation of the manoeuvre plan has to be performed for each single varied situation parameter. On the other hand, the simulation software module is able to provide the corresponding data accordingly.

The next step after having simulated the standard manoeuvre procedure for the prevailing environmental circumstances is then to determine the best manoeuvre sequence.

Using the simulation software module there are two principal ways available in order to determine the optimal sequence for the situation dependent manoeuvre plan:

- The first option is to simulate series of manoeuvres using standard „SCHARNOW-Turn“ (or WILLIAMSON-Turn) manoeuvring commands in automated simulation series. This method can be seen in Fig. 8 below, where several heading changes were used as parameters to vary the final result of the distance between the initial track and return track.

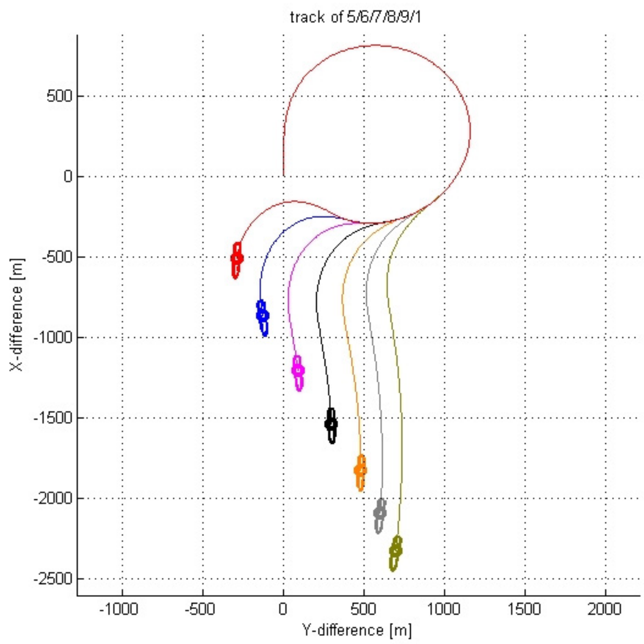

Figure 8. Optimisation of a emergency return manoeuvre by series with different heading changes from 240° up to 300° (with increasing steps of 10°) for counter rudder

The results presented in Figure 8 are for the 7.500 TEU container ship in ballast conditions and taking into account northerly winds of Bft 6.

- The second option is to start with a standard „SCHARNOW-Turn“ manoeuvring command series for automated simulation, combined with an optimisation procedure.

An optimising algorithm is applied to find a suitable heading change for counter rudder as parameter to achieve smallest distance (limit=10m) between initial track and return track on opposite heading (limit=2°). The Optimal track is indicated by yellow colour in Fig. 9. The main parameters of the optimised manoeuvre procedure are given in the table format.

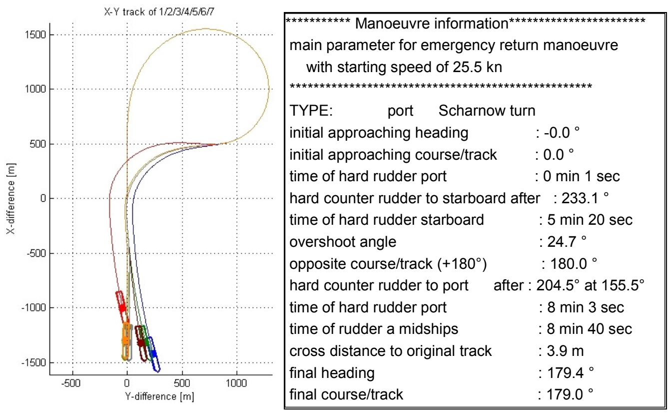

Figure 9. Emergency return manoeuvre optimisation procedure (left) and display of manoeuvring details for optimised manoeuvre (right)

An optimising algorithm is used to find the suitable heading change for counter rudder as parameter to achieve smallest distance (limit=10m) between initial track and return track on opposite heading (limit=2°). The optimal track is indicated by yellow colour in Fig. 9. The main parameters of the optimised manoeuvre procedure are given in the table format.

6 SUMMARY, CONCLUSIONS AND OUTLOOK

Investigations into the overall situation regarding onboard manoeuvring assistance and into the integration of new maritime technologies onboard ships are performed. The ongoing investigations have shown that there is potential to increase operational safety in shipping.

Taking into account the availability of new technologies and new equipment, situation dependent manoeuvring information should be provided to the navigators on the bridge rather than continuing to provide them with static manoeuvring data which often are incomplete and inconvenient in use.

For these purposes, the introduction of a dynamic wheelhouse poster and an electronic manoeuvring booklet is suggested, to provide ship's command with up-to-date information about the manoeuvring characteristics of their ship, adapted to the prevailing environmental conditions.

A concept is developed and exemplarily applied in order to support the accomplishment of manoeuvring tasks in case of a person overboard accident. The fundamental element of this concept is based on innovative fast-time simulation technologies. It is applied for the purpose of providing situation-dependent manoeuvring data by taking into account actual environmental conditions and actual ship status information. The use is also demonstrated exemplarily for the generation of optimised situation dependent manoeuvring plan for an emergency return manoeuvre.

Future investigations, i.a., will deal with enhancement and validation of suitable visualization of the fast-time simulation results to support decision-making in an ECDIS environment. Therefore, human factor related investigations dealing with a user-centered design of the human-machine interface have to be performed.

Additionally, investigations into the application of the concept on other situations will be carried out.

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