TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 8
Number 4
December 2014

DOI: 10.12716/1001.08.04.18

Potentials of e-Navigation – Enhanced Support for Collision Avoidance

M. Baldauf
World Maritime University, MaRiSa Research Group, Malmö, Sweden
Institute of Innovative Ship-Simulation and Maritime Systems (ISSIMS), Germany

K. Benedict & C. Krüger
University of Applied Sciences - Technology, Business and Design, Dept. of Maritime Studies Warnemuende - ISSIMS Germany

ABSTRACT: The e-Navigation initiative of IMO and IALA has stimulated and inspired a number of ambitious research projects and technological developments in the maritime field. The global transportation of goods is not only facing rapidly growing ship dimensions but also increasing industrial off shore activities, changing the relation between the need of areas for safe and reliable vessel traffic and its availability. Off shore activities is increasingly limiting the available navigable spaces and concentrating traffic flows, especially in coastal waters and port approaches.
Enhanced technical systems and equipment with numerous added functionalities are in use and under further development providing new opportunities for traffic surveillance and interaction. Integrated Bridge and Navigation Systems on board modern ships not only support the bridge teams and pilots on board, but also allow for more comprehensive shore-based traffic monitoring and even allow for re-thinking of existing regimes and procedures on traffic management.
A sophisticated manoeuvring support tool using fast real-time simulation technology and its application for on board support as well as for its potential integration into enhanced shore-based monitoring processes when linked with the 'Maritime Cloud' will be introduced. The potential for contribution to generate harmonized collision warnings will be discussed and explained. This paper is a reviewed and extended version of (Baldauf, Benedict & Gluch, 2014).

1 INTRODUCTION

The main commonly discussed features of maritime transport are usually its safety and effectiveness. Among them the ships safety issues are crucial from the operational point of view and they can be considered as one of the most prospective technical affairs. One of the most critical features of seagoing ships related to her safety is their stability.

The e-Navigation concept of the IMO as defined in (MSC 85/26/Add.1/Annex 21, IMO, 2009) has provided the impetus to a range of research projects focusing on the utilisation and integration of new solutions in ship–shore communication and information exchange and provide novel solutions to the challenges facing the industry today.

The ACCessibility for Shipping, Efficiency Advantages and Sustainability (ACCSEAS) project aims to advance maritime access in the North Sea region by developing intuitive tools to enable the seafarers to make safe and effective navigational decisions. The areas of shipping congestion and limitations are identified; in addition, novel solutions are developed, prototyped and demonstrated in e-Navigation test beds in the North Sea region. The aims are a.o. to harmonise Maritime information and

its exchange and in addition address training provision to support the real-world implementation of the solutions (Williams, 2014).

ACCSEAS works in tandem with the much larger MONALISA project that worked to develop Motorways of the Sea with ecologically efficient e-Navigation solutions supportive of EU strategy for the Baltic Sea region. The project laid the groundwork for future international deployment of innovative solutions. The follow-up MONALISA 2.0 seeks to develop the concept further by implementation of measures in line with EU transport policies.

Supportive of the vision of the e-Navigation concept is the so called 'Maritime Cloud' which could be utilised to populate pertinent data and information related e.g. to the ship domain (particularly manoeuvring characteristics beside length, breadth, draft, trim etc.); Voyage related details (voyage plan comprising waypoints, speed and course etc.) and environmental/hydro-meteorological information (wind, sea state, waves, visibility etc.). The information can be utilised both on-board the ship domain and by any shore based control centre like a VTS for information sharing and effective decision-making. The security and integrity of information would need to be addressed; however, the 'Maritime Cloud' can perform integral service for the implementation and achievement of future e-Navigation services.

2 PRESENT SITUATION

Beside the introduction of new technologies for sustainable shipping with reduced emissions, the growing of dimensions of cruise ships and container vessels are characterizing the present situation. Ship sizes range from a carrying capacity of 500-800 TEUs in the 1950s to today's 'CSCL Globe' and 'Triple E' types with capacities of over 18,000 TEU. According to statements of DNV- GL they have already planned container ships with a capacity of 22.000 up to 24.000 TEU with a length of 430m and breadth of 60m. On the one hand are the increasing ship sizes that defy imagination, while on the other we have ever increasing levels of offshore activity for oil exploration, drilling, installation of wind farms, Floating Production Storage and Offloading (FPSO) units, oil rigs and platforms etc. There is lack of harmonisation in the exclusion zones surrounding such installations which can range from as much as 10 miles to 500 m. Marine exclusion zones are set up and Particularly Sensitive Sea Areas (PSSA) are designated. The advancement of fishing activity further offshore also leads to the restriction of the navigable space available to seafarers.

Finally, the present situation is further compounded by a shortage of officers. The current and future availability of senior officers is also a cause for concern (BIMCO-ISF, 2010). Another aspect to be noted is, casualty statistics in shipping. Of the total number of accidents in 2013, 75% took place in 10 world regions, of which nearly 46% were related to European waters (AGCS, 2014).

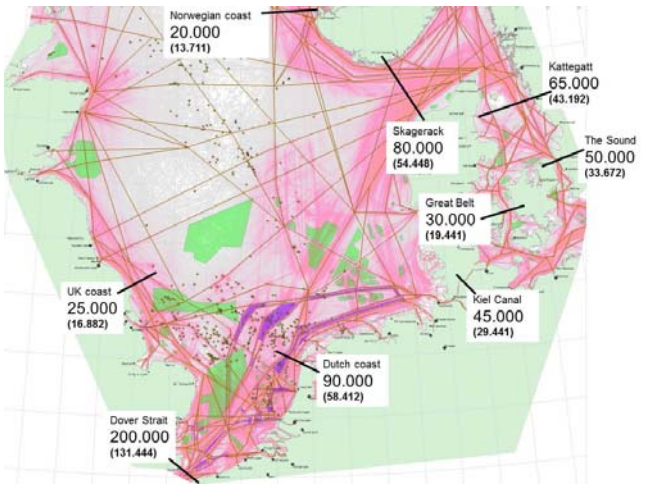

Figure 1: Snapshot of Vessel Traffic in the North Sea area, showing AIS-based indication of traffic situation in 2012 as well as prognosticated traffic figures for 2020+. Coloured areas indicating established and planned wind mill farm areas – clearly showing that they will impact present shipping routes (taken from (Williams, 2014))

The introduction of new and enhanced information and communication technologies is accompanying all these ongoing developments to allow efficient and sustainable operation of ships of all sizes and provide sufficient prerequisites for the safety of global sea transportation. e-Navigation the complete transportation process focussing not only on the situation onboard but also on shore has to play a crucial role in mitigating risk, particularly in collision and grounding accidents near the shore.

3 IMPROVED TECHNOLOGICAL SOLUTIONS AND NEW SERVICES AS ENHANCED RISK CONTROL OPTION

IMO has agreed and approved in a number of documents how to proceed with the further development of the e-Navigation activities. For instance, overarching e-Navigation architecture is provided; there is a proposed way how to develop a Common Maritime Data Structure (CMDS); using of the IHO's S-100 standard as the baseline. Furthermore there is an endorsed preliminary list of prioritized potential e-Navigation solutions namely improved, harmonized and user-friendly bridge design (S1); means for standardized and automated reporting (S2); improved reliability, resilience and integrity of bridge equipment and navigation information (S3); integration and presentation of available information in graphical displays received via communication equipment (S4) and improved communication of the VTS service portfolio (S9). Finally IMO identified on basis of a formal assessment a number of risk control options (RCO), which were found being most effective for risk reduction purposes. These options are:

- RCO 1: Integration of navigation information and equipment including improved software quality assurance
- RCO 2: Bridge alert management
- RCO 3: Standardized mode(s) for navigation equipment

- RCO 4: Automated and standardized ship -shore reporting
- RCO 5: Improved reliability and resilience of onboard PNT systems
- RCO 6: Improved shore-based services
- RCO 7: Bridge and workstation layout standardization

Further guidance that should be taken into account for research work and technological development is summarized in IMO's strategic implementation plan finalized by its correspondence group on e-Navigation.

In order to address these activities and contribute to the further materialization of the e-Navigation strategy, simulation trials were conducted to test the efficacy of innovative e-Navigation solutions as risk control options. As e.g., two pertinent functions related to the ship-port interface – 'shore based route suggestion' and 'display of intended route' were tested in simulation trials and are mentioned here exemplarily. Five different scenarios were designed and tested twice over the course of four consecutive days. At any one time, two bridge teams on simulation bridges participated in the simulation runs. The bridges were manned by experienced pilots as well as mariners and shore based support was provided by personnel from the Humber VTS. The bridge teams changed after two days after participating in all five scenarios. In a scenario pertaining to the approach to Humber, the VTS operator said that prior to the establishment of the Traffic Separation Scheme (TSS), vessels would approach from all directions like *"bees to a honey pot"* and would depart *"like a starburst"*. The VTS operator further went on to note that the functionality that enables them to see the intended route of vessels was extremely valuable to them as, based upon the route, they could suggest a suitable approach to the TSS if required. The Humber personnel added that they would miss the functionality upon their return to England. A very similar response was received from Danish Pilots referring to their area of operation (Skagen).

4 ENHANCED COLLISION AVOIDANCE USING FAST TIME SIMULATION AND DYNAMIC PREDICTIONS

Beside the studied route exchange functions mentioned above, investigations into improvement for collision avoidance taking into account both the aspects onboard and shore-based assistance are ongoing. Conventional shore-based services, as provided in the frame of a recognized VTS are based on traffic data collected and analysed in shore-based centres. Operators interact with the traffic from a shore-based centre by sending out information, warning or advice on a regular basis, on demand or when deemed necessary according to the operators' judgement and in accordance with established rules and procedures. In rare cases, e.g. when VTS operators have detected a certain danger requiring immediate action they may even send out instructions to vessels involved in such situations. The essential mean for exchange of information is VHF communication.

However, the rapid technological developments under the e-Navigation initiative will significantly change the landscape and the status quo of existing regimes of shore-based service provision. New information and communication technology (ICT) allows collection of extensive data which is expected to be more reliable and can provide almost real-time information. Voyage Data Recorders (VDR) and AIS were first options to collect and provide more data on the actual situation on-board SOLAS ships than information from only the radar and VHF. Today shipping companies seek to establish company fleet operation centres (FOC) ashore. VDR manufacturers have developed sophisticated solutions for data collection far beyond the minimum performance standard of VDRs and even provide data exchange to company owned FOCs via enhanced satellite data communication links, including even actual rudder, engine and thruster data as well as ordered steering values. Presently there is on-going research work making use of such data for dynamic path predictions for on-board decision making and shore-based monitoring (e.g. Baldauf et. al., 2012).

For onboard decision making the technology of fast time simulation can be applied for the introduction of more user-friendly alarm levels basing on dynamic ship's safety zones. IMO's Performance standards for Integrated Navigation Systems (MSC.252(83) were developed on the basis of a comprehensive task analysis and has provided the essential navigational tasks that needs to be supported by an INS. Two of which are collision avoidance and another essential is alert management.

Fast time simulation (FTS) is a technology using a mathematical model of a certain process and its influencing factors to estimate the future status of a system faster than in real time. While real time simulation is e.g. especially used for training purposes the FTS is specifically used for operational tasks and to support decision making (Benedict & Kirchhoff et. al., 2014). For the purposes of ship navigation FTS can be used for the prediction of the ship's path taking into account the immediate reaction on control settings (rudder, thrusters, engine etc.). Differently to static predictions as e.g. the vectors in ARPA radar, dynamic path predictions are taking into account e.g. inertial forces and moments in relation to actual environmental conditions (wind, currents but also water depth etc.). The reliability of the predictions is mainly dependent on the validity of the used model and the reliability of input data mainly provided by sensors. Ship navigation provides a number of use cases for FTS technology. FTS and dynamic path prediction can support onboard decision making when manoeuvring a ship in coastal waters or even when berthing in harbours. However it can also be used to enhance situation assessment with respect to existing risks of collision or grounding. The application of sophisticated algorithms providing predictions for a complete range of manoeuvring options can be used to qualify the triggering of warnings and alarms for bridge alert management (RCO 2).

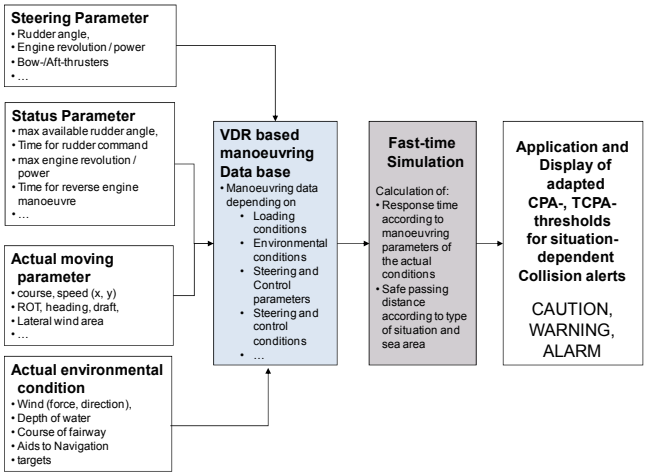

Figure 2: Generic Outline of an onboard Manoeuvring Support System applying Fast-Time-Simulation-Technology for triggering collision warnings according to IMO standards

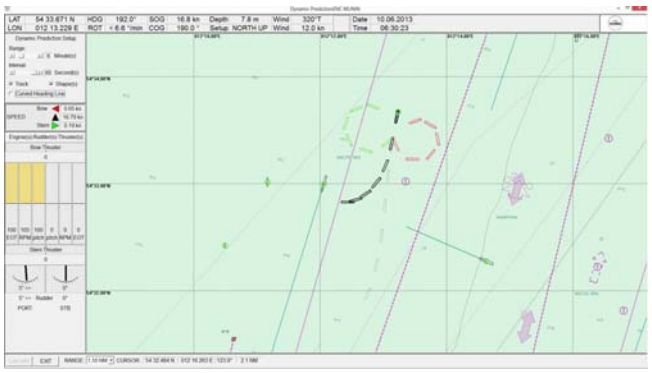

Figure 3: Operational (manoeuvring) limits of a ship visualized as dynamic path prediction on basis of fast time simulation technology and implemented in an ECDIS-based manoeuvring support tool for purposes of situation assessment regarding risk of collision or monitoring of safe and efficient conduction of manoeuvres for purposes of onboard assistance of the OOW and to support monitoring duties of an shore-based operator as well

In global terms alert management shall contribute to the harmonization of priorities and to the classification of alerts. It is to enhance their handling, distribution and presentation to the OOW. IMO has defined three levels of alerts – first is 'Caution' (lowest level; as a kind of a signal that there is a situation with certain deviation from usual (safe) conditions) secondly 'Warning' (requiring immediate attention of the bridge team) and finally, highest level of an alert 'Alarm' (requiring immediate action to avoid any dangerous situation.

In respect to the task of 'Collision Avoidance' there is similarity to the different stages of an encounter situation with risk of collision. Cockcroft and Lameijer suggested and discussed those stages in (Cockcroft & Lameijer, 2012) in respect to the obligations of a stand-on vessel in case of an encounter situation of two engine driven vessels on crossing courses according to rule 17. From this basic discussion, a more detailed and sophisticated model for situation assessment has been derived (Hilgert, Baldauf, 1997). This model takes into account further rules of COLREGs for other types of encounter situations under conditions of good and restricted visibility. This enhanced model concentrates on recommendations for action to be taken derived from COLREGs but also provides suggestions for the quantification of limit values for the situation dependent safe passing distances as a CPA threshold as well as for TCPA limits when to take those actions.

Table 1. Recommendation for lower limit of own ship safety zone (CPA-threshold) [dimension given as ship length of largest ship involved in the encounter situation]

Encounter situation	good visibility	restricted visibility
head-on situation meeting port/port-side	2,5	5
Overtaking	2,5	5
head-on situation meeting port/port-side	5	10
Crossing situation	5	10

Table 2. Applied simplified risk model for target alert prioritization

alert	limit values in case CPA > CPA-Limit for generating an alert
Caution	Manoeuvre in ample time < RNG ≤ Observation Range (e.g. 12 .. 16 min)
Warning	Lower Manoeuvring Limit ≤ RNG ≤ Manoeuvre in ample time (e.g. 6 min)
Alarm	RNG < Lower Manoeuvring Limit (time for a course change of 90° using Hard rudder acc. to actual conditions)

Taking into account the prevailing circumstances of a specific situation which needs to be characterized e.g. by input from sensor data about the environmental conditions (visibility, wind, sea state) as well as ship status (including the dimensions but moreover especially taking into account the actual manoeuvring characteristics of the involved vessels) it is possible to also harmonize the situation-dependent definition of safety zones around a ship and, in case of a potential violation of it, to prioritize collision alerts into the given levels 'caution', 'warning' and 'alarm' by ranking the level of risk of concerned targets in respect to the remaining time to take action to avoid a collision. In this way targets with risk of collision can be marked i.e. green (caution), yellow (warning) and red (alarm). Of course green level needs not necessarily to be visualized in the AR environment. However, the yellow level should be implemented and configured and switched on at the OOW's intentions. The red level alarm should be a fixed audible alarm which should not be able to be switched off.

For this purpose the proven TCAS concept, used for collision avoidance in aviation, has been transferred and adapted by (Baldauf, Benedict et. al., 2011). In TCAS, among others, a so called 'Resolution Advisory', requiring the pilot to follow a climb or descent instruction is implemented in TCAS as a 'last line of defence'. Applying this concept to collision avoidance in open sea, for instance a target, violating the safety zone of the own ship should generate a collision 'alarm' and be marked red, when it comes close to the lower manoeuvring limit, at which the own ship by its own manoeuvre alone is able to avoid a collision. This manoeuvre can be determined by using dynamic prediction using FTS of own

manoeuvring capabilities for the ship's evasive manoeuvre (Baldauf & Benedict et. al., 2012). This means in case the stand on vessel find herself so close to a give way vessel that a collision can only be avoided by her own manoeuvre alone (determined by fast time simulation-based dynamic prediction of a course change manoeuvre) than, finally, the red mark should appear in the augmented reality added by an audible alarm, to indicate and initiate necessary actions by the OOW accordingly.

The potential for improvement of shore-based support is well recognized. It is especially cruise and container shipping companies that are already using those enhanced capabilities and are aware of the potential of virtual online monitoring and decision support. This furthermore already includes route monitoring, keeping a certain corridor, not only a simple cross-track error but also considering actual ship status as well as weather forecasts and sea state data. Consequently the corridor is no longer the centre line of the corridor but the corridor is more enhanced by considering the drifting to a certain side.

The added shore-based monitoring acts as a kind of an additional safety barrier and moreover allows for optimization of the operational regimes of the company fleet. Taking those enhanced monitoring opportunities into account it seems that the existing services offered by VTS could also be improved accordingly. Compared to a VTS operator

5 CONCLUSION

Technological developments in the frame of the IMO's e-Navigation initiative allows for substantial improvement of regarding the support of the navigator onboard and operators monitoring traffic from a shore-based centre. The functionality of dynamic path prediction using fast-time-simulation technology can be utilised for calculating the operational limits of manoeuvring taking into account the prevailing circumstances of the environment and the ships status and that are needed for harmonized decision making and coordinated collision avoidance procedures.

Applications for onboard use will allow for a more precise estimation of the last time to take action to avoid a collision. For the implementation of enhanced application in shore-based monitoring facilities opens for a much more detailed surveillance of a ship's route and potential risks.

However, in relation to any enhanced future e-Navigation services, it is to be noted that the legal aspects of such services would need to be addressed as well as the training requirements from the point of view of involved stakeholders.

ACKNOWLEDGMENTS

Some of the results and parts of the investigations presented in this paper are presently performed under the European Interreg IVb-project – ACCSEAS Accessibility for Shipping, Efficiency Advantages and Sustainability and from the European FP 7 project MUNIN – Maritime Navigation Through Intelligence in Networks).

LITERATURE AND REFERENCES

AGCS. (2014). Safety and Shipping Review 2014 - An annual review of trends an developments in shipping losses and safety: Allianz Global Corporate & Specialty Communication.

Baldauf, M.; Benedict, K.; Gluch, M. (2014) Ensuring safety and efficiency by e-Navigation related traffic surveillance. Port & Technology International, Henley Media Group, London, 47(2) November 2014 p. 27-32

Baldauf, M., Klaes, S.; Benedict, K.; S. Fischer, M. Gluch, M. Kirchhoff, M. Schaub: (2012) Application of e-Navigation for Ship Operation Support in Emergency and Routine Situations. *European Journal of Navigation*; Volume 10: 2; 4 - 13.

Baldauf, M.; Benedict, K.; Fischer, S.; Motz, F.; Schröder-Hinrichs, J.-U. (2011): Collision avoidance systems in air and maritime traffic. Proc. IMechE Part O: *Journal of Risk and Reliability.* DOI: 10.1177/1748006X11408973;. 225 (3): 333-343

Benedict, K.; Kirchhoff, M.; Gluch, M.; S. Fischer, M. Schaub, M. Baldauf, S. Klaes (2014): Simulation Augmented Manoeuvring Design and Monitoring – a New Method for Advanced Ship Handling, *TransNav – International Journal on Marine Navigation and Safety of Sea Transportation*. 8:1, 131-141

Cockcroft A. N. and Lameijer J.N.F. (2012). A Guide to the Collision Avoidance Rules: International Regulations for Preventing Collisions at Sea. 7th Edition, Elsevier Butterworth-Heinemann, Oxford.

EMSA (2014). Annual Overview of Marine Casualties and Incidents. European Maritime Safety Agency . Lisbon (Portugal)

Hahn, A.; Bolles, A.; Benedict, K. (2014) Integrated Test Bed for Save and Efficient Maritime Systems. in Dev Ranmuthugala & Barrie Lewarn (eds.): *Looking Ahead - Innovation in Maritime Education Training & Research.* pp. 213-220, AMC, an Institute of University of Tasmania Local Executive Committee IAMU AGA15.

Hilgert, H., Baldauf, M. (1997), A common risk model for the assessment of encounter situations onboard ships. *Ocean Dynamics*, 1997, 49(4), 531–542., England.BIMCO-ISF. (2010). Manpower 2010 Update: The Worldwide Demand For and Supply of Seafarers - Highlights.

IMO. (2009). Report of the Maritime Safety Committee on its Eighty-Fifth Session. MSC 85/26/Add.1/Annex 21 - Framework for the implementation process for the E-navigation strategy. London: IMO. Online at: rntfnd.org/wp-content/uploads/IMO-E-Nav-Strategy.pdf.

Joy, R. (2014). Panamax and beyond: the story of ship sizes. *Port Technology, Edition 63: September 2014.*

Lindt, M.; Brödje, A.; Watson, R. Haraldson, S.; Holmberg, P.-E.; Hägg, M. (2014) Digital Infrastructures for Enabling Sea Traffic Management. Proceedings of the International Symposium Information on Ships. German Institute of Navigation. Bonn

Porathe, Th.; de Vries, L.& Prison, J. (2014). Ship voyage plan coordination in the MONALISA project: user tests of a prototype ship traffic management system. Paper presented at the Human Factors and Ergonomics Society Europe Chapter, 2013 Annual Conference, Torino, Italy.

Williams, A. (2014). *e-Navigation and the ACCSEAS project*. Paper presented at the IALA-AISM 2014 XVIII Conference, Spain.