

Assessing Safety Effects of Digitization with the European Maritime Simulator Network EMSN: The Sea Traffic Management Case

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ABSTRACT: This paper will give an intro into the technical backbone of the EMSN and derive necessary specifications to allow for objective testing in large scale. Further, it will demonstrate the potential of EMSN as a maritime safety test-bed on the STM case. Therefore, the simulations executed within the EMSN are evaluated regarding their safety level in order to demonstrate the effects of various measures to improve safety. Based on a fuzzy logic approach, numerical Data from the EMSN Data-Tracker is used as an input to assess a present traffic situation from the perspective of a specific ship and outputs a comprehensive safety index developed by expert opinions. The safety index is used to further analyze navigators' behavior and decisions in different maritime traffic scenarios that are executed within the EMSN.

1 INTRODUCTION

Digitization and automation will have a great effect on shipping in the future. Hereby, not only navigation or single ship operation is affected, but in most cases, large-scale effects on sea traffic and marine processes are expected. Depending on the concrete digitization and automation project, those are potentially also addressing safety related issues.

As soon as digitization and automation affects safety, the legal framework and thus the requirement for a Formal Safety Assessment (FSA) is often touched as well. A FSA is *"a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs"* (IMO, 2007).

A critical step in safety assessments and in the FSA in general is the transition from the hazard identification to the quantitative risk analyses. While international studies agree, that the human factor is the key component behind most marine accidents (Sanquist, 1992), (Rothblum, n.d.) recommended risk assessment methods are mostly classical fault tree analyses or expert reviews (IMO, 2007), which are potentially too restricted to fully cover safety effects of those future technology, as the human element is hard to assess. Especially regarding the human element, ship-handling simulation is the only known method to fully incorporate this into a scientific set-up and thus *"the results, conclusions and recommendations can be based on a thorough review of technical aspects, as well as the important human factors, such as response times and communication"* (PIANC, 2014).

So far, SHS was limited to a small number of simulated vessels in a joint exercise, thus organizational affects or large scale changes to waterborne processes, procedures and technology

could barely be assessed. Thus, the European Maritime Simulator Network (EMSN) has been developed to provide a large-scale test environment for maritime safety (Rizvanolli, et al., 2015).

Chapter 2 will give an overview about the backbone and technical features of the EMSN as implemented today, before Chapter 3 outlines the Sea Traffic Management (STM) case and how this concept was assessed with the help of EMSN. Chapter 4 draws conclusion regarding the usage of EMSN as well as about its further potentials for maritime training and research.

2 THE EUROPEAN MARITIME SIMULATOR NETWORK

The EMSN is a network that connects numerous ship handling simulators (SHS) from different simulation sites across Europe. Enabling joint exercises between this remote locations with different simulation manufacturers requires a joint understanding of the logical and technical connectivity between the SHS (John, et al., 2014), which is ensured within the EMSN by the IEEE Standard 1278.1-1995 as well as some EMSN-specific joint agreements (IEEE, 1995), (Poschmann & Burmeister, 2017).

This set-up enables users to operate individual ship bridges in configurable scenarios and to interact in real time with each other in a simulated environment.

At the end of 2018, 13 simulation centers in 7 European countries with a total of more than 30 bridges were connected to the EMSN.

In principle, EMSN ensures alignment between SHS within the following areas:

- Exchange of simulation data (ground truth)
- Exchange of communication data
- Centralized data tracking
- Synchronization of simulation management

2.1 Topology

The mentioned exchange services are deployed in IP networks and implemented as Virtual Private Networks (VPN). For this purpose, VPN tunnels are set up between EMSN simulation sites to provide confidential and authenticated connections with integrity over the public Internet. For realization, a hub-and-spoke topology was selected. Its general structure is shown in Figure 1 (John, et al., 2014).

Thereby, the DIS interface guarantees the so-called common ground truth exchange, whose functionality is described in the section 2.2. As seen in Figure 2, this interface connects each SHS to the EMSN infrastructure. NMEA-interfaces at each SHS do further allow integration of innovative marine equipment based on standard interfaces, as also used within the STM project.

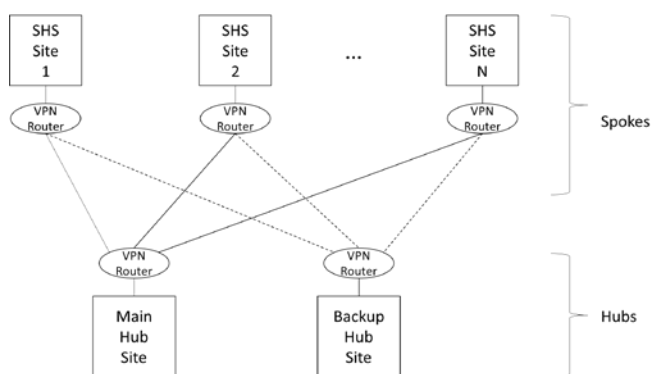


Figure 1. Overview of the VPN technology of EMSN.

At each site, the SHS has different interfaces to allow for an easy integration of EMSN as well as potential digitization and automation prototypes to be tested.

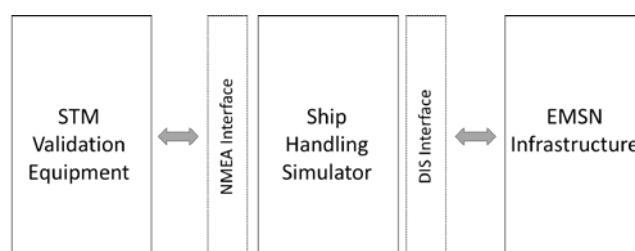


Figure 2. Overview of SHS interfaces within EMSN. (according to (Poschmann & Burmeister, 2017))

2.2 Ground truth and communication

The ground truth exchange basically ensures that all manually controlled own-ships of one center are represented by a remote-controlled traffic ship at all other centers (Rizvanolli, et al., 2015). This is based on a so called Entity State PDU of the IEEE standard (IEEE, 1995). Hereby, not only the position and type of vessels are exchanged, but also the used light and shape signals, which are currently the only mandatory way to indicate the own ship navigational status. Among others, EMSN thus enables an interactive exchange navigational status, as e.g. (Poschmann & Burmeister, 2017):

- Not under command
- Restricted ability to maneuver
- Constrained by her draught
- Fishing and
- Anchoring.

Out of the standard marine communication channels, voice communication by VHF as well as the Automated Identification System AIS is fully integrated into the EMSN to allow for realistic scenarios. VHF is implemented based using a separate TeamSpeak-Server within the EMSN, while AIS is fully integrated into the DIS concept as Signal PDU. Thereby not just the most frequently used position report (AIS message type 1,2,3) and the Static and Voyage related data report (AIS message type 5) is implemented, but also addressed and broadcasted binary message exchanges (AIS message type 6, 8, 12, and 14) (Poschmann & Burmeister, 2017), (ITU, 2014). Besides those standard channels, application specific channels and communication systems for the digitization and automation system to be tested can be integrated into the network.

2.3 Central data tracking and simulation management

By using the DIS-standards Data PDU a wide variety of data can be centrally recorded in customized simulation environments and scenarios. This can serve as the basis for the evaluation of scientific problems, as in the risk assessment of STM Validation.

An overview of the data types recorded during the simulation runs in STM Validation is shown below.

- Ship Data
General information describing specifications of the vessels used in the simulation scenarios, for example length overall, breadth overall, IMO number, MMSI, etc.
- Motion Data
Variety of information describing the movement of a vessel under consideration, e.g. heading, speed over ground, engine order telegraph, etc.
- Environmental data
Environmental information that influences the vessel's movement or voyage, such as wind direction and speed, current direction and speed as well as visibility.
- General data
General simulation information and identifiers for the assignment of centers and ships, for example simulation id, site id, timestamp, etc.

Besides, central simulation management tools like the Start/Resume PDU as well as the Stop/Freeze PDU enable synchronization of local simulations (IEEE, 1995).

3 EVALUATION

The STM concept contains several functions whose effects on the navigation behavior of seafarers involved have been investigated within the EMSN. These include the following services.

- Chat function
Real-time communication via a stand-alone chat program on the ECDIS client. It allows the exchange of simple text messages between vessels and shore center.
- Receiving navigational warning
Notifying seafarers about the occurrence of new navigational warnings. Direct presentation of the area to be avoided on the ECDIS.
- Receiving route suggestion from Shore Center
Submission of a recommended route from a Shore Center to a ship concerned, to be checked by the bridge team. At the discretion of the captain, the route recommendation can either be accepted or rejected.
- Rendezvous function
Display of the intersection between the routes of considered vessels using the AIS-based Closest Point of Approach (CPA) and Time to Closest Point of Approach (TCPA) on the ECDIS.
- Ship-to-Ship-route-exchange
Display of the next 7 waypoints of a monitored vessel on the ECDIS.

3.1 EMSN Methodology

The main objective of the EMSN tests is to provide a further validated input to the FSA risk assessment, especially concerning the evolvement of situational awareness and traffic patterns by applying STM. Hereby, the test methodology itself consists of four individual stages:

- Selection of appropriate scenarios
- Simulation of scenarios with and without STM equipment
- Safety assessment of encounters of each scenario
- Comparison of safety assessments.

This study is not attempting to make a comparative analysis of the possible effects of each individual STM service on traffic safety separately. Rather, this study is an attempt to capture the possible effects of several STM services being available at the time of the simulation runs based on numerical data collected during the simulation trials in the EMSN. Other factors which may have an influence when analyzing possible effects of introducing STM services such as usability of ECDIS in general, the familiarization and training in the use of the services, the experience of the test participants, etc. have not been considered in this study. In addition, it should be emphasized that within the numerical data analysis only two runs have been analyzed (one with STM services and one without). This fact is conformal, since the depicted runs are considered as representatives of all executed simulation runs.

3.2 Scenario Selection

The English Channel and the Southern Baltic were selected as they are good examples of heavily trafficked areas. The Baltic scenario was created within the Fehmarn Belt representing one of the worlds' busiest traffic corridors with numerous recommended routes, junction areas and crossing ferry routes, but no Traffic Separation Scheme in place. For the STM runs, a simulated Shore Centre "Baltic Shore Centre" was established. The English Channel scenario was created for the south coast of England with the port of Southampton playing the major port of interest and a fictitious "Shore Centre Southampton" on the Isle of Wight was established for the STM runs.

Eight scenarios were specified based on the combination of three variables: location, time of day, and visibility. Each scenario was executed several times with and without the availability of STM services. The simulations were conducted in the EMSN consisting of up to 30 manned bridges during four sessions.

For the later evaluation, the simulation data was used, which was recorded using the data tracker described in section 2.3. For each run, around 210,000 movement data were available at a distance of one second from the 30 ships.

3.3 Maritime Safety Index

In order to assess the safety of different encounter situations and thus the validity of the available STM

services, a Safety Index (SI) was developed. The SI is used to further analyze navigators' behavior and decisions in different maritime traffic scenarios that are conducted within the EMSN. For the assessment of navigators' behavior in encounter situations between ships, it is required to develop an approach that accounts for the full complexity of the task. While most assessment methods conventionally used depend to a large degree on expert opinions, this study aims for a more objective and quantitative approach.

The most widely used approach for the assessment of ship handling simulation is rating by expert opinion. An obvious disadvantage of this methodology is the high influence of subjective judgement. This means that the same simulation results can receive totally divergent ratings when being assessed by different experts. To compensate this drawback, an alternative approach will be used for analyzing and evaluating the impact of the available services at the time of the simulations in the STM concept on ship traffic.

Within the STM Validation project, the level of safety of different traffic situations will be measured based on a fuzzy logic approach, cf. (Bai & Wang, 2006), (Kozłowska, 2012), (Mamdani & Assilion, 1975), (Perera, et al., 2011) and (Zadeh, 1965). The SI may be used within the Formal Safety Assessment (FSA) to assess the potential risk reduction by the implementation of the STM and its various operational services.

Overall, the safety index consists of a collision index, a grounding index and an environmental index, which parameters are presented in Figure 3.

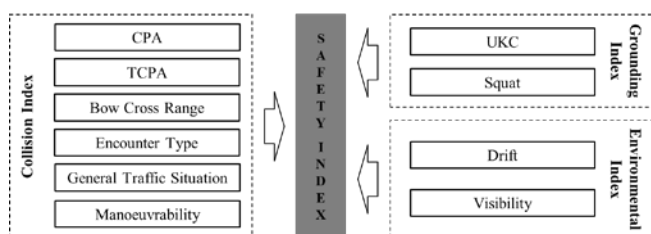


Figure 1. Structure of the safety index for the evaluation of the EMSN runs.

Following the definition of the input variables, the membership functions for the fuzzy models estimating a collision index are created based on the results of pre-conducted instructor surveys and/or a comprehensive literature research. In the following a maritime traffic situation is given by one own ship (OS) and one or multiple target ships (TS) encountering in different situations: head-on, crossing or overtaking.

The maneuverability of a ship is determined by the block coefficient of length and breadth and the type of ship transmitted via AIS. If the block coefficient is small, then there is no good ability to maneuver, the larger it becomes, the better the ability to maneuver the ship (American Bureau of Shipping, 2006). A poor maneuverability causes a deterioration of the Safety Index. The maneuverability of a vessel strongly depends on its maneuvering devices. This includes the rudder, fixed lateral areas, transverse thrusters, propeller (with fixed pitch or controllable pitch, Voith

Schneider propeller or azimuth thruster). In addition, the engine has an influence on the maneuverability of the vessel (two or four stroke engine or electrically driven). Since AIS does not include this type of information the maneuverability of a ship has to be estimated. Thus, the maneuverability is according to the AIS data a function of the following variables.

$$f(Vessel\ type, L, B) = [good, poor, none] \quad (1)$$

The main idea is to give every ship type a classification of the maneuverability. For passenger ships, cargo ships, tanker and tugs an additional factor will be considered. The ratio length to breadth will change maneuverability index of the actual ship. The larger the ratio, the slender the ship. This is good for speed and course keeping, but rather bad for maneuvering. For this ship types good L/B ratios will be estimated. If a ship has a greater L/B ratio than the estimated one, the estimated maneuverability will be improved one level and vice versa.

The grounding index is determined by specifying the squat of each vessel, which represents the decrease of a ship's under keel clearance due to vessel's movement in shallow waters. A small squat has a small grounding probability. Given the block coefficient c_B and the actual speed through water v of a ship, the squat is given by (Serban & Panaitescu, 2016)

$$squat = \frac{c_B * v^2}{100} \quad (2)$$

To determine the environmental conditions, two fuzzy systems will be used: within a first one, the drift of a ship given the current, wind and sea state will be developed. The drift will be used to estimate the maneuverability later on. The output of the linguistic variable visibility will be directly used to define the EI. The drift of a vessel is determined by the environmental parameters current, wind and sea state.

For more details on the mathematical backgrounds of the indices, it is referred to (Olinderson, et al., 2017).

3.4 EMSN Safety Assessment

To evaluate the effects of STM services, the safety indices of runs without STM equipment ("base runs") and runs with equipment ("STM runs") are determined. For this purpose, each combination of owned and foreign ships was considered and the corresponding safety index was determined for each point in time.

The histograms in Figure 4 and Figure 5 depict the safety indices for baseline and STM runs. The results indicate that no significant effect of these combined STM services on maritime traffic safety could be observed. If all SI of the runs are compared, it is verified that both the runs without STM and those with STM equipment are in a similar range.



Figure 4. Histogram of the safety indices of baseline runs. (Scheidweiler & Weber, 2018)

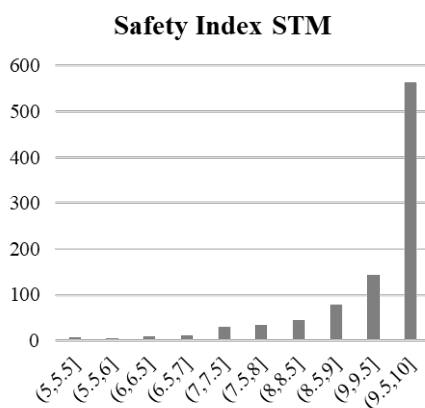


Figure 5. Histogram of the safety indices of STM runs. (Scheidweiler & Weber, 2018)

However, no separate analysis of the effect of individual services on maritime traffic safety has been made nor any analysis on usability and/or human factors assessment. Therefore, the effect of the STM services reported here should be compared with the results of other evaluation methods to confirm it.

Due to the ongoing development of the EMSN, scenario simulations had some sort of irregularity. Most of the regularities have been ships freezing, disappearing, and re-appearing, which reduced throughout the EMSN maturity increased. As those irregularity were also seldom and mostly of a short duration of less than ten seconds, the authors considered that these irregularities were unlikely to have a large effect on the results of the numerical analysis regarding the SI.

The results show that these combined STM services do not significantly improve maritime safety for a selection of simulation runs. However, neither a separate analysis of the impact of individual services on maritime safety nor an analysis of usability and/or human factor assessment was carried out. Therefore, the effect of the STM services listed here should be compared with the results of other assessment methods (Scheidweiler & Weber, 2018).

Additionally, it must be stressed that even if the data itself does not significantly indicate an improvement, the perceived safety benefits by the test participants was rather positive. With an exemption

of the chat function, all tested services received more positive than negative comments by the investigated 227 marines (Aylward, et al., 2018). Thus, a resilient human factor assessment, which is now based on first experiences and not solely on expert opinions, can be derived from the EMSN setup providing input to an objective FSA.

4 CONCLUSION AND OUTLOOK

This paper briefly showed the capabilities of the EMSN and how it can be used to assess objectively and human factor oriented the effects of marine digitization and automation on safety based on the STM example. In general, the use of the simulator network EMSN to validate nautical research hypotheses offers many advantages over large-scale field tests, which are briefly outlined below.

- Saving money & time
- Focus on relevant research field
- Reduction of noise
- Risk-free investigation
- No impact on environment.

For the future, assessing additional STM services, which have not yet been incorporated into the EMSN is recommended and aspired before rolling them out to shipping. Beyond STM, there are further marine digitization and automation projects on the horizon, where proper, simulation-based safety assessments are required, that fully incorporate the human factor, like e.g. the development of Maritime Autonomous Surface Ships. According to the EU Directorate-General for Research and Innovation, large-scale virtual test facilities like the European Maritime Simulator Network are required here to bridge “major gaps with regards to development of safe waterborne connected and automated transport” (European Commission, 2017).

Besides applying the EMSN in research projects, it is intended to broaden the use of the EMSN for joint training of nautical cadets and officers during their studies by incorporation real international training between cross-border institutes. Therefore, the EMSN now became project independent by the EMSN Connect initiative, which ensures further usage and maintenance of the EMSN beyond STM (Jahn, 2018).

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