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The Role of the European Maritime Simulator Network in Assessing Dynamic Sea Traffic Management Principles

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ABSTRACT: The MONALISA 2.0 (ML 2.0) project aims to define the Sea Traffic Management concept (STM), where information is shared amongst all stakeholders in the maritime transport chain, including nautical officers, ports, administrations, etc. Thus, a communication and information centered approach for data exchange by System Wide Information Management principles changing from surface-based- to voyage-based-operations has been proposed. Amongst others, testing and verifying the feasibility and benefits of STM and its solutions shall be done in the European Maritime Simulator Network (EMSN), a macro simulation environment for ship handling simulators. This is an open IEEE 1278 standard network protocol enabling interactive communication between distributed simulation environments. Based on an introduction into ML 2.0, the proposed STM concept is introduced, its expected impacts are listed and Key Performance Objectives are derived. The backgrounds on the EMSN are given and it is shown how it can assist in assessing the impact of STM's Key Performance Indicators.

1 AN INTRODUCTION TO THE MONALISA 2.0 PROJECT

Within the MONALISA 2.0 project operations and tools in the sectors dynamic and proactive route planning, route optimization, the exchanging of information about routes from ship to shore and ship to ship with the use of diverse technologies are important areas of development. Overarching goal is the enhanced response in case of accidents as well as a boosted ships performance. The all-encompassing vision compromise the real-time information availability to all authorized and interested stakeholders within the whole maritime transport chain. Among others involved partners could be ship owners, ship operators, pilots, flag states, port state controls, cargo owners, freight forwarder, port and terminal operators or P&I clubs.

The previous MONALISA project has shown how vessels, equipped with capability of seeing each other´s planned route, provide the master a more complete picture of how adjoining vessels are planning their upcoming voyage (Porate, De Vries & Prison 2014), (In De Waard et al. 2014). Correspondingly, shore side stakeholder and services are capable to query valuable information and in return to provide vessels with advices concerning their route or recommendations to avoid congestions in areas with high traffic areas. The primary approach, dynamic route exchange, had been achieved in order to increase the situational awareness on vessel´s bridge. This approach turned out to be an abundant basement for an overarching STM concept acknowledging the sea voyage as part of the larger, whole maritime logistic chain. The foundation for the aspired interoperable and comprehensive information sharing will be the Sea

Traffic Management concept, to be formed towards a common standardized information sharing environment and enables a holistic maritime information management (Jahn, et al. 2012).

2 THE SEA TRAFFIC MANAGEMENT CONCEPT

Today's bridge equipment gives the officer of the watch (OOW) a wide information basis about the actual traffic situation as well as about the historic traffic evolvement. The Automatic Identification System (AIS) gives the possibility to track other ships which were not detected by radar. For the establishment of a comprehensive and broad situational awareness a significant component is missing: the intentions of approaching vessels are still unknown. Decisions are made to primarily affect future traffic situation, which must be anticipated by the OOW when doing his actual decisions. Thus, there is actually a certain time gap before other vessels decisions become visible to the OOW due to the inertia of vessels, which might be critical in close quarter situations or restricted channels.

The majority of ships are using electronic charts, which contain their route. Instead of making assumptions, the existing navigational information could be compiled in a joint situation picture providing decision support for the bridge team of all vessels in a particular surrounding and related shore side parties. To make use of the vessels intentions is the nucleus of STM taking into account the principles of communication and information sharing.

The work in the STM definition phase is inspired from the SESAR program, which had Air Traffic Management as one of its outcomes. Despite that, STM will not be an adapted copy of the ATM for the sea traffic. It will provide facilities and services together with all parties and involved seabornes such that the traffic management on the sea and maritime space integrate dynamically. The development of STM takes into consideration that the intermodal sea transport is an irreplaceable part of the multimodal transport chain (Correa et al. 2014).

2.1 *The definition of STM*

The STM Concept is an information and communication centered approach enabling stakeholders in maritime domain to perform operations optimally for own purpose as well as sea traffic systems. In order to achieve safer and efficient sea transports, that will lead to a reduced environmental impact the Sea Traffic Management concept is being defined in the Mona Lisa 2.0 as following:

"Sea Traffic Management (STM) is a concept encompassing all actors, actions, and services assisting maritime traffic from port to port. STM is a part of the multimodal logistics supply chain, encompassing sea as well as shore based operations. The STM concept includes concepts for strategic and dynamic voyage management, flow management, port collaborative decision making, and the service based communication infrastructure concept SeaSWIM. STM puts an emphasis on interoperable and harmonized systems allowing a ship to operate in a safe and efficient manner from port to port with a minimal impact on the environment."

The development of STM should encompass in future all actors, actions and systems (infrastructure) assisting maritime transport from port to port. The following five concepts are the enabling ones for the holistic STM concept. The first four matches with the phases a voyage and the last one is the information sharing infrastructure that is missing in shipping.

- Strategic Voyage Management (SVM)
  The scope of this concept is to optimize the initial planning phase of a voyage. As the shipping company is planning the voyage in order to fulfill its own needs and requirement and with the scope to be successful, this phase is also called the strategic one. Giving the companies the possibility to check all the factors and constraints that affect the voyage is what strategic voyage management does. One of the factors may be the information from other parties connected to that voyage. SVM includes long and short time strategic planning of a voyage but the biggest advantages of using SVM related services is when it is applied at the earliest possible point in time before a voyage begins (Falnes unpubl.).
- Dynamic Voyage Management (DVM)
  Dynamic Voyage Management follows the earlier strategic voyage management. Within DVM a dynamic flow of information from ship to ship, ship to shore and vice versa will be established during an ongoing voyage. The information can be shared with other ships e.g. during a tactical action the ships can exchange their routes or with shore based service providers for the route optimization/validation.(Svedberg, unpubl.).
- Flow Management (FM)
  Unlike the strategic and dynamic voyage management, the flow management concentrates on the whole traffic flow. Nevertheless they are not independent from each other. The information needed for the route optimization during the voyage planning phases is generated from the flow management. On the other side the individual voyages are the building blocks of the whole traffic flow. As defined in (Flow Management Task Force, unpubl.) "the overall objective of the concept is to optimize and increase safety of the sea traffic flow during all planning and executing phases". Optimizing traffic is achieved by using a coordinating attitude, not control, hence leaving the final decision to the Master, and using STM technical enablers.
- Port Collaborative Decision Making (Port CDM)
  Port CDM as defined in (Port CDM Task Force, unpubl.) deals with improving the maritime transport as part of the multimodal supply chain by enabling the following collaborations:
  - Collaboration among actors operating within the port
  - Collaboration between the port and actors realizing sea voyages
  - Collaboration between the port and actors realizing inbound and outbound transportation (besides sea voyages)

  - Collaboration between ports within each collaborative arena
- Sea System wide information management (Sea SWIM)
  This concept is inspired by the SWIM concept in the aviation industry (SESAR, 2001), (Sea SWIM Task Force, unpubl.). The Sea SWIM concept is not a specific implementation of an information sharing environment. It will change the paradigm of how information is managed along its full lifecycle during a voyage. Sea SWIM can be technologically implemented in different ways covering one or different channels such that the information being shared will arrive in the right time to the right place with minimal costs. Sea SWIM will provide an information infrastructure that enables the implementation of STM and other services. It will be governed by a federation(s) and will be an enabler of the above described operational concepts.

2.2 *Potential paradigm shift of information management with STM*

Each created STM voyage plan will include a unique Single Voyage Identity (VoyageID). This VoyageID is used as the identifier of all information in the plan. The VoyageID will enable the connection of information in the network, making all involved parties able to stay up to date themselves, but also keep all other parties in the same state when they update the information they manage and control. The VoyageID will be created during the strategic and dynamic voyage planning phases and used during the whole voyage. As mentioned above it will be the key enabler and contributor for an efficient and clear information exchange during the whole voyage.

Different approaches for the creation of the VoyageID are being discussed in the project. They can be classified in centralized and decentralized approaches. The centralized one is inspired by the design approach for flight numbers in the air industry. The advantage of this approach is the quite easy implementation that allows fast tests. The benefits and costs of this approach can be recognized in short time and are easy to understand. One possible implementation approach of the VoyageID can be found in (Kula, 2015).

2.3 *Key Performance Areas (KPAs) and Key Performance Objects (KPOs)*

STM will potentially change sea traffic patterns and interactions between ships and shore. To measure the influence of STM of overall traffic flow, user and operating procedures the following key performance areas and objectives are recognized in the MONALISA 2.0 project (STM Performance Targets-Task Force, 2014.). The main key performance areas correspond to the goals of STM for a safer and efficient sea transport, with impacts in the environmental sustainability, cost effectiveness, predictability and interoperability of the information systems in the maritime world. The key performance objectives corresponding to these areas can be classified in qualitative and quantitative ones. The qualitative key performance objects can be further mapped in models and evaluated easier as the qualitative objects. Following classification of the KPOs is state of the art in the project:

Table 1. Key Performance Objectives for STM

Qualitative KPOs	Quantitative KPOs
Increase voyage safety	Minimize administrative burden
Reduce impact from accidents and incidents	Increase energy efficiency in voyage operations
Increase voyage security	Decrease spill marine pollution
Increase information exchange security	Decrease navigation within sensitive areas
Increase voyage situation awareness	Reduce total cost of ownership (TCO)
Increase In-Port Navigation safety	Reduce cost of port operation
Increase confidentiality and integrity of communication	Decrease integration complexity

Obviously are some of the objectives conflicting to each other. Decrease navigation within sensitive areas which can be reached by the flow management concept enabled by information sharing via Sea SWIM may sometimes, depending from the situation, conflict with increase energy efficiency in voyage operations. Dynamically changes on the route as result of no-go areas or weather conditions can sometimes lead to longer voyage, which implies more fuel consumption. Finding one or more compromise solution or furthermore analyzing by modeling this situation as multicriteria optimization problem will indicate clearly the benefits of STM. Furthermore, the tradeoff between the decisions can be analyzed and assessed. The model can be used as a reliable decision support tool.

3 THE EUROPEAN MARITIME SIMULATOR NETWORK

While proceeding from concept development towards implementation, testing of the concept and validating the intended safety and efficiency potentials is the important next step. Besides persuading maritime stakeholders by the benefits of the concept, the International Maritime Organization IMO as the global regulatory body adopt the concept laid out in the chapter before. Therefore, IMO 2007 requires conducting a Formal Safety Assessment FSA. However, there is a certain lack in applicable and trustworthy methods for conducting certain steps of the FSA for such groundbreaking concepts as STM, which is the reason why the outlined European Maritime Simulator Network EMSN is proposed.

3.1 *Limitations of FSA tools for STM evaluation*

A FSA in the meaning of the IMO is *"a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property"* (IMO 2007). It is conducted in five interdependent steps as outlined in Figure 1.

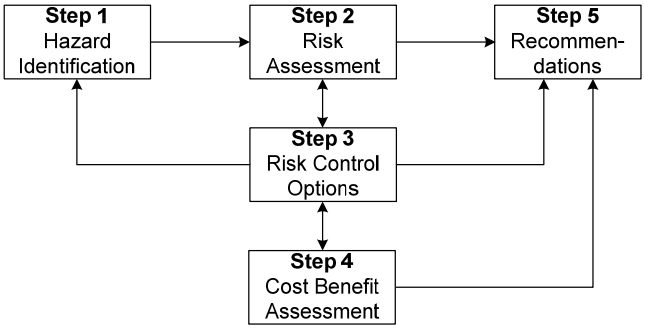

Figure 1. The FSA Process (IMO 2007)

With regards to the intended safety benefits of STM, especially the risk assessment step is of certain interest. Thereby, risk is commonly defined as:

$$Risk = \sum_i P_i\left(H_i C_i\right) \cdot U\left(C_i\right) \quad (1)$$

with $P_i(H_i, C_i)$ being the probability that the identified hazard H_i results in a consequence C_i and $U(C_i)$ being the expected monetary damage of C_i (IMO 2007, Pedersen 2010). Typical methods applied in a FSA's second step are (IMO 2007, IALA 2009):

- PAWSA (Port and Waterway Safety Assessment tool),
- IWRAP MkII (IALA Waterway Risk Assessment Programme),
- risk contribution trees and
- influence diagrams.

However, PAWSA only provides quantitative results and the latter two heavily rely on expert opinions which makes quantification rather subjective. In contrast, the IWRAP MkII provides a rather maritime specific approach based on frequency modelling based on the work of Fujii 1983 and Pedersen 1995 (John et al. 2014). Thereby, P_i can be quantified by:

$$P_i = N_A \cdot P_c \quad (2)$$

with N_A being the number of potential collision candidates and P_C the causation probability. By applying frequency models, N_A can now be derived from traffic pattern statistics and geometrical limitations of the sea area. Instead, P_C is in principal a probability indicating how many collision situations result in a real accident and thus include all technical and human error cases, which is derived either by accident statistics, expert opinion or Bayesian networks.

In contrast to e.g. introducing a traffic separation scheme, STM itself does neither change the sea area available nor directly the traffic pattern. Instead, it basically aims to improve situational awareness and reduces human error. In terms of IWRAP MkII, this should result in a change in P_C. However, P_C is not as strictly derived from measurable indicators like N_A.

Thus, assessing the effects of STM based on that tool again results in certain subjectivity about the expected change of the human error. As human error is involved in about 65-95% of all ship accidents (Sanquist 1992 & Rothblum n.d.) and as STM is primarily addressing this issue, a more objective way in assessing effects of regulatory and procedural changes is needed: The European Maritime Simulator Network (John et al 2014).

3.2 *EMSN technical specifications*

The EMSN is in principle an internet-based network connecting multiple individual ship handling simulators allowing them to interact and operate together in one joint scenario. Besides, it offers the possibility to add further IT-services and exchanges to implement new maritime concepts so that it can act as a virtual, full-scale navigational laboratory. Thus, the technical architecture of the EMSN consist of three different subnets (John et al 2014):

- Ground Truth exchange via DIS,
- Voice communication via TeamSpeak and
- Perceived Truth exchange via TCP/IP.

To ensure that all individual simulators operate on the same scenario basis, the EMSN uses the IEEE 1278 standard for Distributed Interactive Simulation DIS (IEEE 1278). Within EMSN, it basically ensures that the traffic related data are exchanged, e.g. the vessel's actual latitude φ, longitude λ, velocity SOG and heading TH. With the help of a common set of DIS entities, it is ensured that each ownship's movement, meaning the vessel directly controlled by one ship handing simulators, is correctly represented by a traffic ship in the other simulators (see figure 2). However, in the first version of the EMSN, further environmental data, like e.g. wind speed, wave direction or visibility, is not exchanged. Thus, it needs to be ensured by the overall EMSN management that all simulators work under common environmental conditions.

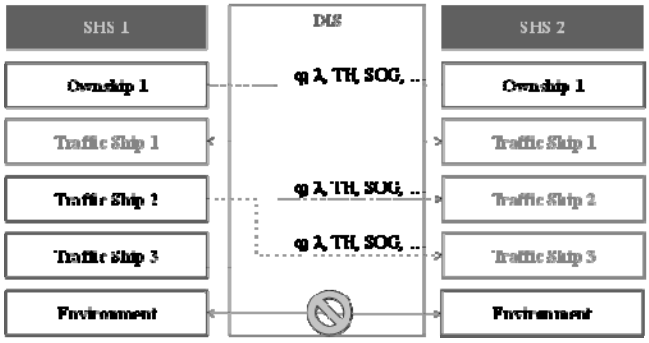

Figure 2. EMSN's ground truth exchange via DIS

For voice communication, a standard TeamSpeak-Server is used, which is state-of-the-art for voice communication in online gaming.[2] By connecting a push-to-talk-microphone and configuring the Client, the VHF maritime mobile band can be emulated. In comparison to the reality, TeamSpeak does however only provide duplex transmission and can't be directly reduced to marine typical simplex mode.

All other applications, e.g. the planned STM-services are then implemented in the perceived truth exchange, which is an extra TCP/IP-Layer. Additionally, the corresponding hardware is also

[2] See http://www.teamspeak.com/ for further details

connected to e.g. the bridge's NMEA-interfaces of the simulator, to get the normal ship data required.

3.3 *EMSN test methodology*

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

- Analyze current traffic patterns,
- Simulate traffic situation in EMSN and
- Analyze simulated traffic patterns.

Within the first step, a representative real-world situation is chosen, which should serve as a baseline for evaluating the benefits of STM. Recorded AIS-Data of areas of interest are beneficiary, to further analyze and investigate the safety and efficiency metrics in the as-is-situation. Possible metrics with regards to the KPOs are e.g. (Jahn et al. 2014):

- KPO Energy efficiency in voyage operations
  - Distances sailed (per vessel and overall),
  - Time sailed (per vessel and overall),
  - Average speed profiles (to indirectly assess fuel efficiency),
- KPO Cost of port operation
  - ETA predictability,
  - On time arrival
- KPO Voyage safety
  - Number of meeting situations arising,
  - Number of close-quarter situations,
  - Average passing distances,
  - Number of traffic regulation violations,
  - CPA/TCPA histograms,

As a test case for the STM evaluation, a situation in TSS Hattern in the Great Belt, Denmark has been chosen as baseline (Weber, unpubl.). Furthermore, as EMSN is applied for the first time in validating the STM, additional simulation runs have been made in that area without STM functionalities (so called baseline simulations). The purpose of these tests is to validate, if EMSN is producing traffic patterns and situations comparable to the real situation that has been occurred. This is an important characteristic, as otherwise the EMSN can't be used as a further risk assessment tool. During the first run, thirteen own-ships participated in this four days test series with promising results (see figure 3).

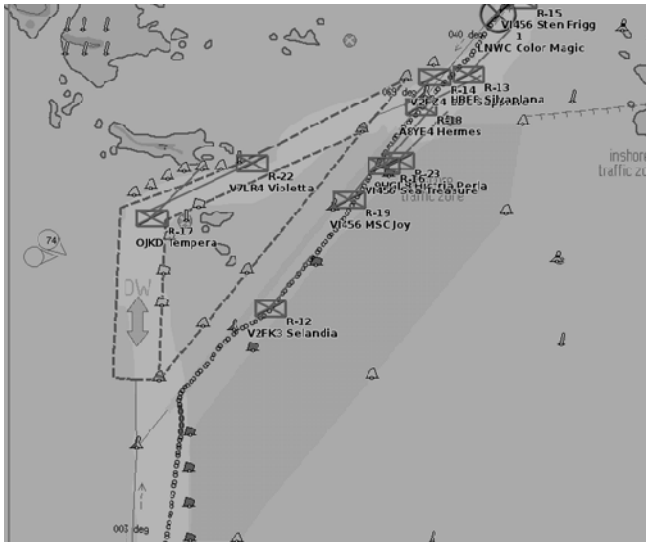

Figure 3. TSS Hattern during baseline test

In the second stage, parts of the dynamic STM functionalities are implemented and the same initial situation is simulated. Afterwards, baseline and STM-situation can be analyzed according to the predefined metrics set and conclusions are derived, which provides the input towards FSA's risk assessment, but also to the cost-benefit assessment steps.

4 CONCLUSION AND OUTLOOK

The Sea Traffic Management Concept (STM), which is still being developed in the MONALISA 2.0 project, is an information and communication centered approach amongst all stakeholders in the maritime transport chain. Within the STM the Dynamic Voyage Management concept is one main enabler for route exchange and route optimization in between ship and shore based services providers. An upcoming implementation of new STM procedures and services will involve potential impacts regarding interactions between ships and shore and overarching sea traffic patterns. The related qualitative and quantitative key performance objectives for safety, cost effectiveness and environmental sustainability in sea transport have been derived. On the way from a concept development to implementation testing and validation of aspired safety and efficiency objectives will be the crucial next task. Today, a Formal Safety Assessments is required by IMO prior the implementation process of new international regulations. It had been laid out that for more complex regulatory changes, like e.g. the implementation of STM, this methodology might be a bit restricted as certain impacts and human behavior cannot be accurately foreseen and quantified in a very changing and complex environment by modest assessment approaches. Therefore, the specified European Maritime Simulator Network has been installed, in order to provide a macro-simulation environment which could facilitate an advanced and IMO regulation conformal FSA. At the example of the outlined baseline runs in the Great Belt and the underlying EMSN test methodology possible metrics

linked to the STM KPOs are proposed. They will provide on the one hand the input towards FSA´s risk assessment as well as cost benefit assessment requirements.

In future common test-principles for concept assessment by EMSN have to be defined, so that the EMSN is applicable for further concept validation, like e.g. MUNIN (Burmeister et al. 2014), or demands for data and system standardization and will last beyond original test purposes for large-scale maritime traffic studies. Moreover, a deeper definition of KOPs and KPIs is necessary so that they can be uncomplicated modelled and assessed.

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