Aalto University

Towards STAMP approach based protection of Underwater Cultural Heritage

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ABSTRACT

According to the UN Law of the Sea Convention (LOSC), states have the duty to protect objects of an archaeological and historical nature found at sea and shall cooperate for this purpose. The 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage stipulates that in-situ preservation of underwater cultural heritage (i.e. on the seabed) must be considered as the first and preferred option before allowing or engaging in any activities directed at this heritage. To prevent incidental damage the State Party shall use the best practicable means at its disposal to prevent or mitigate any adverse effects that might arise from activities under its jurisdiction incidentally affecting underwater cultural heritage. A Systems-Theoretic Accident Modelling and Processes (STAMP) approach to operational safety management considers accident occurrence as the result of a lack of, or inadequate enforcement of, constraints imposed on the system design and operations at various system levels. The objective of this study in progress is to apply the STAMP based Systems-Theoretic Process Analysis (STPA) to identify the system level hazards and potentially unsafe ship anchoring control actions incidentally affecting and damaging underwater cultural heritage objects in the Estonian national Vessel Traffic Service (VTS) Centre sea area in the Gulf of Finland, Baltic Sea. The physical damage to underwater monuments and heritage conservation areas caused by anchoring of ship is identified as an accident (an undesired and unplanned loss event) and the legal protection and preservation restrictions applicable to underwater monuments and the protected zone thereof are considered to be the underwater cultural heritage protection and preservation constraints to be enforced. The critical role of VTS in effective hazard control actions and the enforcement of preventive constraints in real time is identified.

Keywords: Systems-Theoretic Accident Modelling and Processes; Systems-Theoretic Process Analysis; Underwater Cultural Heritage; ship anchoring.

1. INTRODUCTION

According to the UN Law of the Sea Convention (LOSC) states have the duty to protect objects of an archaeological and historical nature found at sea and shall cooperate for this purpose (UN, 1982). The 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage (UNESCO, 2001) stipulates that in-situ preservation of underwater cultural heritage (i.e. on the seabed) must be considered as the first and preferred option before allowing or engaging in any activities directed at this heritage. It is stated also that underwater cultural heritage faces a wide array of threats and negative impacts that endanger its preservation and therefore the protection of underwater cultural heritage is at the heart of this Convention, together with public enjoyment and the fight against commercial exploitation. It is specified further that activities incidentally affecting underwater cultural heritage, despite not having underwater cultural heritage as their primary object or one of their objects, may physically disturb or otherwise damage underwater

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cultural heritage. The State Party shall use the best practicable means at its disposal to prevent or mitigate any adverse effects that might arise from activities under its jurisdiction incidentally affecting underwater cultural heritage.

Referring to Estonian Heritage Conservation Act in force (EHCA, 2019) “A monument is a movable or immovable, a part thereof, a body of things or an integral group of structures under state protection which is of historical, archaeological, ethnographic, urban developmental, architectural, artistic or scientific value or of value in terms of religious history or of other cultural value and due to which it is designated as a monument pursuant to the procedure provided for in this Act”. It is stated further, that the underwater monuments can be things or bodies of things specified by this Act which are located in internal and transboundary water bodies, inland and territorial seas and exclusive economic zones. It is prohibited to destroy or damage monuments and as additional restrictions applicable to underwater monuments and the protected zone thereof it is prohibited to anchor, trawl, dredge and dump solid substances within underwater monuments and the protected zones thereof.

The Systems-Theoretic Accident Model and Processes (STAMP) approach considers safety as emergent property of the system, arising from the interaction of system components within a given environment and the accident occurrence as the result of a lack of, or inadequate enforcement of, constraints imposed on the system design and operations at various system levels (Leveson, 2011). In STAMP the safety is viewed as a control problem, and safety is managed by a control structure embedded in an adaptive socio-technical system while the system itself is viewed as interrelated components that are kept in a state of dynamic equilibrium by feedback loops of information and control (Leveson, 2004). Thus, the basic concepts in STAMP are constraints, control loops, process models and levels of control, and the safety management is defined as a continuous control task to impose the constraints necessary to limit system behavior to safe changes and adaptations.

The STAMP based Systems-Theoretic Process Analysis (STPA) (Leveson, 2011; Thomas, 2012) is a powerful new hazard analysis method designed to go beyond traditional safety techniques has been successfully applied e.g. to space engineering applications (Ishimatsu, Leveson, Thomas, Fleming, Katahira, Miyamoto, Ujiie, Nakao, & Hoshino, (2014) as well as to analysis of maritime traffic safety in the Gulf of Finland (Aps, Fetissov, Goerlandt, Kujala, & Piel, 2017). However, the STAMP approach based protection of Underwater Cultural Heritage has attracted less attention so far.

This study is a part of the INTERREG BSR project “Baltic Sea Region Integrated Maritime Cultural Heritage Management (BalticRIM)". The aim of this study in progress was to apply the STAMP based STPA methodology to the underwater cultural heritage management domain. The objective was to identify the system level hazards and potentially unsafe ship anchoring control actions incidentally affecting and damaging underwater cultural heritage objects in the Estonian part of the BalticRIM Tallinn-Helsinki pilot area covered by national Vessel Traffic Service (VTS) in the Gulf of Finland, Baltic Sea.

2. STUDY AREA

According to IMO (2006) “The mandatory ship reporting system in the Gulf of Finland covers the international waters in the Gulf of Finland. In addition, Estonia and Finland have implemented mandatory ship reporting systems to their national water areas outside VTS areas. These reporting systems provide the same services and make the same requirements to shipping as the system operating in the international waters. The mandatory ship reporting system and the Estonian and Finnish national mandatory ship reporting systems are together referred as the GOFREP and their area of coverage respectively as the GOFREP area” (Figure 1).

Facilitation of exchange of information between the ship station and the shore station aiming at supporting the safe navigation and the protection of the marine environment is seen as the primary objective of the GOFREP system. The GOFREP/VTS Center operator is able to observe the controlled maritime traffic process through the radar and Automatic Identification System (AIS) surveillance of traffic and to actuate the process if the ship under control proceed against ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage requirements.

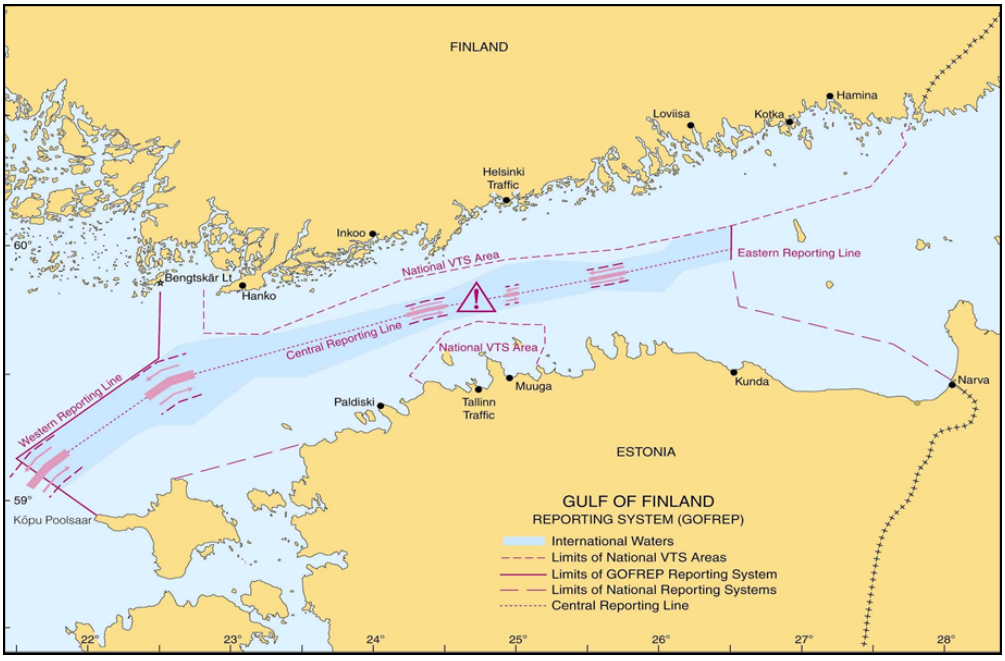

Figure 1. The mandatory ship reporting system in the Gulf of Finland (Baltic Sea) (Source: Estonian Maritime Administration)

The GOFREP maritime traffic control system is jointly managed by the Finnish Transport Agency, Estonian Maritime Administration and the Federal Agency for Maritime and River Transport of Russian Federation and is based on the activities of GOFREP Traffic Centers of Estonia (Tallinn Traffic), Finland (Helsinki Traffic) and the Russian Federation VTMIS Centre in Petrodvorets (Saint Petersburg Traffic).

The BalticRIM Tallinn-Helsinki pilot sea area is situated in the central part of the Gulf of Finland and the Estonian part of this pilot sea area extends from shoreline to the outer border of the Estonian exclusive economic zone (Figure 2).

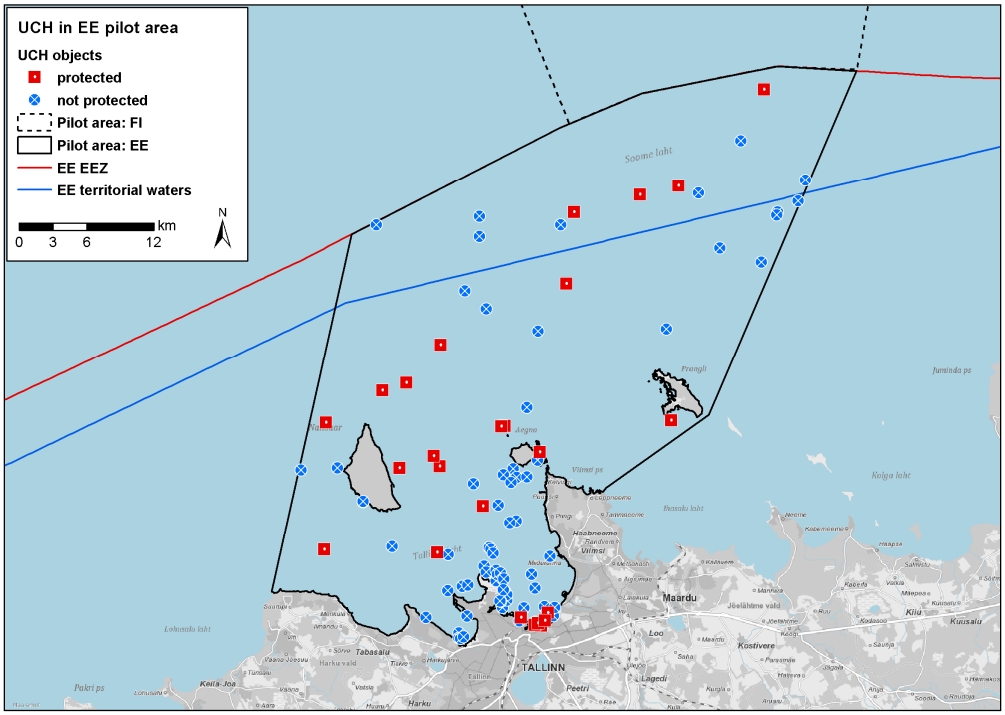

Figure 2. Locations of underwater cultural heritage (UCH) objects in the BalticRIM Tallinn-Helsinki pilot sea area (Source: Estonian National Registry of Cultural Monuments and Estonian Maritime Administration)

Underwater cultural heritage objects in the BalticRIM Tallinn-Helsinki pilot sea area and the high shipping intensity AIS pattern in the background are presented in the Figure 3.

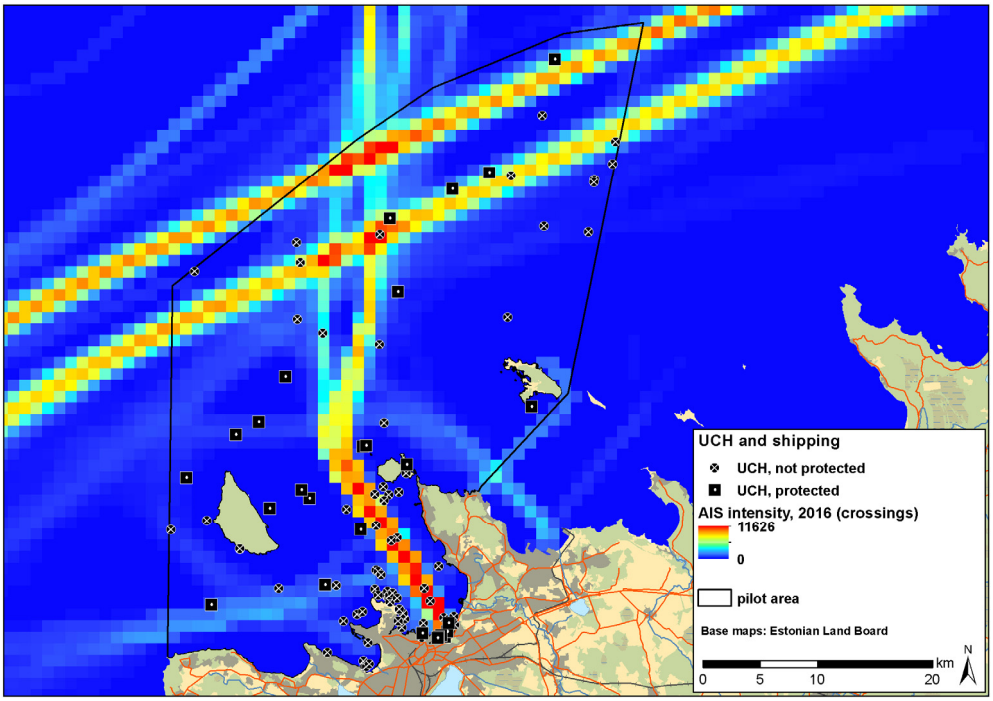

Figure 3. Underwater cultural heritage (UCH) objects in the BalticRIM Tallinn-Helsinki pilot sea area and the high shipping intensity AIS pattern in the background
(Source: Estonian National Registry of Cultural Monuments and Estonian Maritime Administration, HELCOM Map and Data Service)

The BalticRIM Tallinn-Helsinki pilot sea area is characterized by high shipping intensity (Figure 3). The ship anchoring within this shipping intensive area is one of the biggest threats to underwater monuments and heritage conservation areas and therefore the analysis focuses on that threat.

At the same time, to enable effective hazard control and the enforcement of preventive constraints in real time, it is established (IMO, 2003) that on receipt of a position message, the GOFREP/VTS operators are determining the relationship between the ship position and the information supplied by the position-fixing equipment available to them while the information on course and speed is helping operators to identify one ship among a group of ships. This is achieved automatically if the Automatic Identification System (AIS) transponder is used. If necessary, individual information can be provided to a ship, particularly in relation to positioning and navigational assistance or local conditions and if a ship needs to anchor due to breakdown or emergency the operator can recommend suitable anchorage in the area.

2. MARITIME NAVIGATION SAFETY MANAGEMENT IN THE GULF OF FINLAND

The levels of hierarchical structure of maritime navigation safety management in the Gulf of Finland from European to ship on-board level (Figure 4) are connected by communication channels, and referring to Leveson (2011) "… a downward reference channel is providing the information necessary to impose safety constraints on the level below and an upward measuring channel to provide feedback about how effectively the constraints are being satisfied".

The SafeSeaNet is functioning at the European level as the maritime information and exchange system established to facilitate the exchange of information in an electronic format between EU Member States and to provide the Commission with relevant information in accordance with Community legislation.

The GOFREP/VTS Centers represent the onshore level of maritime traffic safety management and communication in the Gulf of Finland. According to IMO (2003), the functions of GOFREP/VTS Centers are performed through a combination of 1) radar and Automatic

Identification System (AIS) surveillance of traffic and navigational marks in the Ship Reporting System (SRS) sea area with particular scrutiny of the development of conflicts in ship traffic, 2) radio communication, and 3) the maintenance of direct and separate communication links between the GOFREP/VTS Centers for the exchange, updating and co-ordination of information. The system is capable of providing an automatic alarm to identify any track that strays into the unauthorized area.

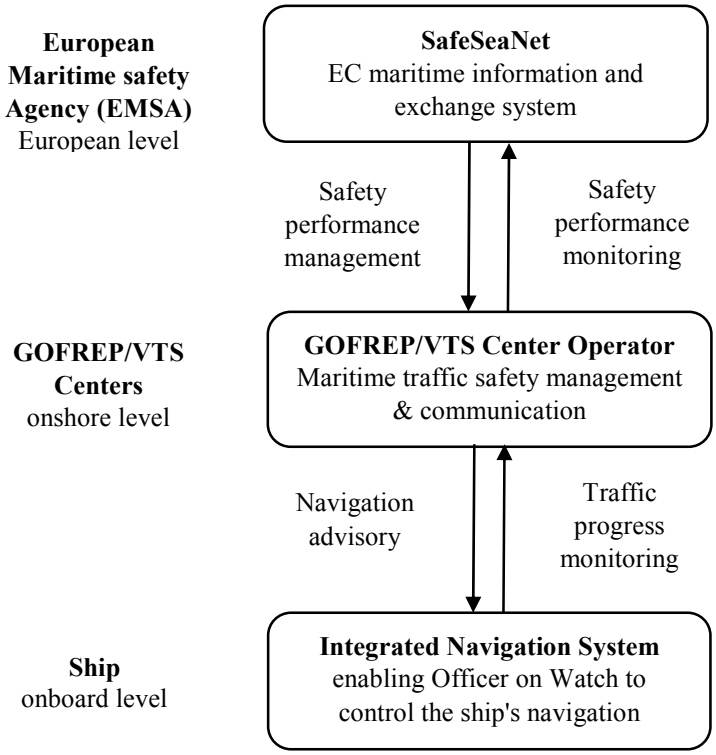

Figure 4. Hierarchical structure of maritime navigation safety management from European to ship onboard level (modified from Leveson, 2011)

The ship onboard level is characterized by the Integrated Navigation System that provides 'added value' to the functions and information needed by the Officer on Watch to plan, monitor or control the progress of the ship. However, as argued by House (2007) “Shipping the world over is notorious for experiencing the unusual and the unexpected. In most cases if and when routine practice goes wrong, the weather is usually a key element which influences the cause and very often the outcome. The other variable is often the human element which can work for, or against, the wellbeing of the ship”. Additionally, ship-related hazards are associated with ship-specific equipment or operations.

3. STPA HAZARD ANALYSIS

Referring to Leveson (2011) “Hazard analysis can be described as ‘investigating an accident before it occurs’. The goal is to identify potential causes of accident, that is, scenarios that can lead to losses, so they can be eliminated or controlled in design or operations before damage occurs”.

As stated by Thomas (2012) “The first step in STPA is to identify the potentially unsafe control actions for the specific system being considered. These unsafe control actions are used to create safety requirements and constraints on the behavior of both the system and its components. Additional analysis can then be performed to identify the detailed scenarios leading to the violation of the safety constraints. As in any hazard analysis, these scenarios are then used to control or mitigate the hazards in the system design”. It is added that before beginning an STPA hazard analysis, potential accidents and related system-level hazards are identified along with the corresponding system safety constraints that must be controlled.

It is further specified (Thomas, 2012) - while potential unsafe control actions are identified in the first step of STPA, the second step examines their control loops to identify causal factors for each unsafe control action, i.e., the scenarios for causing the hazard.

In this study the potential physical damage to underwater monuments and heritage conservation areas caused by ship anchoring is identified as an accident (an undesired and unplanned loss event). The legal protection and preservation restrictions stipulated by Estonian Heritage Conservation Act (EHCA, 2019) applicable to underwater monuments and the protected zone thereof, are considered to be the underwater cultural heritage protection and preservation constraints to be enforced.

3.1. System high level hazards and constraints

According to Leveson (2011), a hazard is a system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to an accident (loss). It is added further that hazards may be defined in terms of conditions or in terms of events as long as one of these choices is used consistently and the only difference is that the events are limited in time while the conditions caused by the event persist over time until another event occurs that changes the prevailing conditions.

Underwater cultural heritage protection and preservation related high level hazard and ship anchoring constraints that are to be enforced are presented in Table 1.

Table 1. Underwater cultural heritage protection and preservation related high level hazard and ship anchoring constraints

Underwater cultural heritage protection and preservation related high level hazard	Underwater cultural heritage protection and preservation related ship anchoring constraints
Controlled ship violate underwater cultural heritage protection and preservation related anchoring requirements	According to Estonian Heritage Conservation Act (2019) it is prohibited to anchor within underwater monuments and the protected zones thereof. Every ship shall at all times use all available means appropriate to the prevailing circumstances and conditions to avoid the potential physical damage to underwater monuments and the protected zone thereof caused by ship anchoring

3.2. Potentially unsafe ship anchoring control actions

Referring to Thomas (2012) “STAMP is based on the observation that there are four types of hazardous control actions that need to be eliminated or controlled to prevent accidents:

1. A control action required for safety is not provided or is not followed
2. An unsafe control action is provided that leads to a hazard
3. A potentially safe control action is provided too late, too early, or out of sequence
4. A safe control action is stopped too soon or applied too long”.

In the context of this study in progress, when situations occur of controlled ship violating underwater cultural heritage protection and preservation related safe anchoring requirements, the control action is required on ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage.

When the required action on ship anchoring adjustment to a safe level appropriate to preservation and protection of underwater cultural heritage is not provided, is provided incorrectly or is provided too late, the system is led to a hazardous state defined as a violation of underwater cultural heritage protection and preservation related safe anchoring requirements.

As the first step of STPA, any potentially unsafe control actions on ship anchoring adjustments to a safe level appropriate to protection and preservation of underwater cultural heritage are identified based on interviews of maritime navigation professionals and their relevant discussions and presented in Table 2.

Table 2. Potentially unsafe control actions on ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage

Control action required	Action required but not provided	Action provided unsafe	Action provided			Stopped too soon
			Too early	Too late	Out of sequence	
Control action on ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage	Hazardous state – ship anchoring is not adjusted to a safe level appropriate to protection and preservation of underwater cultural heritage	Hazardous state – ship anchoring is not adjusted properly to a safe level appropriate to protection and preservation of underwater cultural heritage	N/A	Hazardous state – ship anchoring is not adjusted timely to a safe level appropriate to protection and preservation of underwater cultural heritage	N/A	N/A

3.3. Scenario leading to potentially unsafe ship anchoring control actions

The second step of STPA hazard analysis is performed on a STAMP-Mar standard control loop of the integrated navigation system operated at the ship onboard level (Figure 5). The aim is to identify the causal factors for potentially hazardous control actions on ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage. Analysis is based on interviews of experts - maritime navigation professionals and their topic focused discussions.

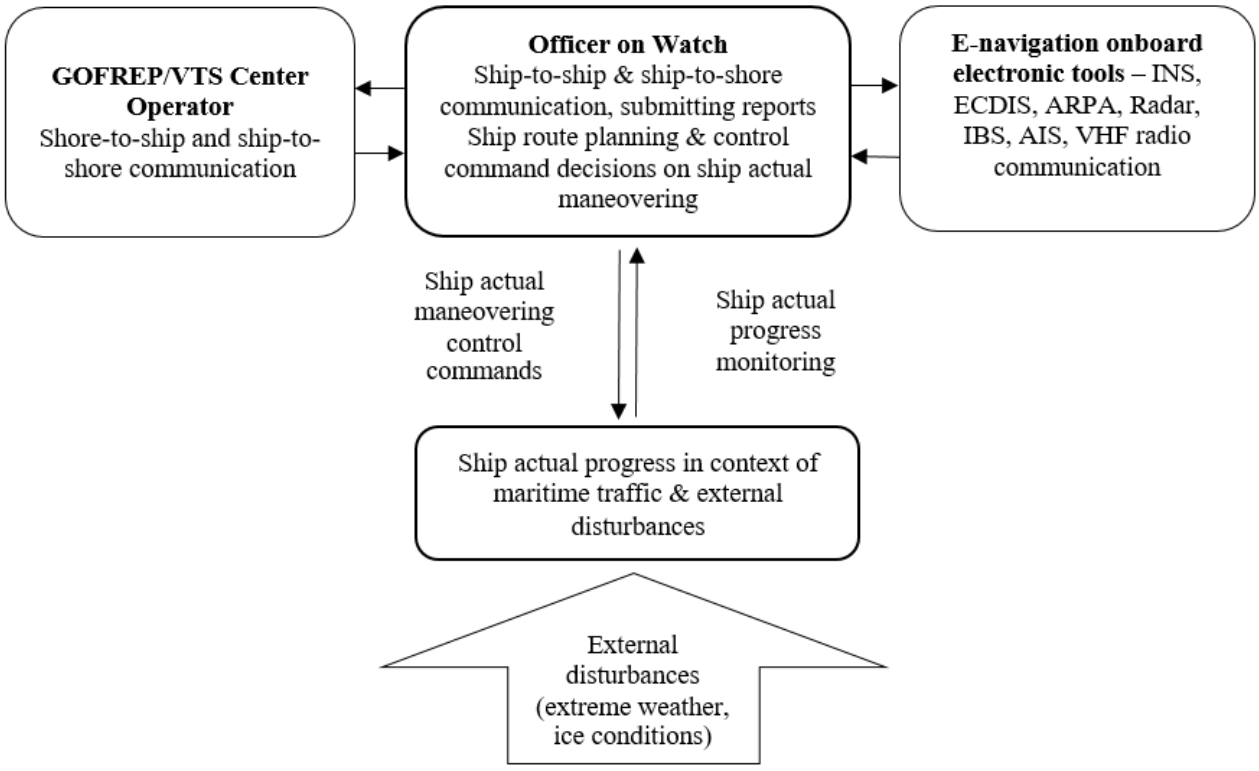

Figure 5. The STAMP-Mar standard control loop of the integrated navigation system operated at the ship onboard level (modified from Leveson, 2011)

As a result, experts have suggested that incomplete awareness of the situation by the Officer on Watch caused by malfunction of one or more e-navigation onboard tools (e.g. satellite navigation system, ARPA, radar equipment, AIS) should be considered an important causal factor leading to potentially hazardous control actions on ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage.

3.4. Enforcement of safety constraints

The STAMP-Mar standard control loop of the integrated navigation system operated at the at the ship onboard level (Figure 5) has been verified and discussed by experts to ensure that the safety constraints for identified scenarios (the incomplete awareness of the situation by the Officer on Watch due to malfunction of one or more e-navigation on-board tools) can truly be enforced in system operations. Efficient ship-to-shore and shore-to-ship communication is recognized as a fundamentally important control factor to update the awareness of the Officer on Watch effectively and in real time.

With respect to enforcement of underwater cultural heritage protection and preservation related anchoring safety constraints, and referring to (IMO, 1997), the WTS is "… a service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area". It is added that VTS should comprise at least an information service to ensure that essential information becomes available in time for on-board navigational decision-making and to monitor its effects. It is specified further that the information service is provided by broadcasting information at fixed times and intervals or when deemed necessary by the VTS or at the request of a vessel, and may include for example reports on the position, identity and intentions of other traffic, waterway conditions, weather, hazards, or any other factors that may influence the vessels' transit. The navigational assistance service is especially important in difficult navigational or meteorological circumstances or in case of defects or deficiencies being normally rendered at the request of a vessel or by the VTS when deemed necessary.

In accordance with the IMO Guidelines and Criteria for Ship Reporting systems (IMO, 1994) the communication between a VTS authority and a participating ship should be conducted and should be limited to information essential to achieve the objectives of the VTS. At that, the IMO Standard Marine Communication Phrases (IMO, 2001) should be used when practicable. In addition, any VTS message directed to a ship or ships should be clear whether the message contains information, advice, a warning, or an instruction. It is suggested (IALA, 2012) that in order to further facilitate shore-to-ship and ship-to-shore communication in a VTS environment, one of the following eight message markers should be used to increase the likelihood that the purpose of the message is properly understood (information, warning, advice, instruction, question, answer, request and intention) leaving it at the discretion of the shore personnel or the ship officer whether to use one of the message markers and, if so, which marker is applicable to the situation.

Furthermore, referring to IALA (2012) the message marker 'Warning' is used to convey potentially dangerous situations or observe developing situations. The contents of a warning message should be assessed immediately in conjunction with any additional information that may not be available to the VTS Center and corrective action taken when necessary.

A fundamental principle of VTS communications (IMO, 1997) is that when the VTS is authorized to issue 'Instructions' to ship, "… these instructions should be result-oriented only, leaving the details of execution, such as course to be steered or engine manoeuvres to be executed, to the master or pilot on board the vessel. Care should be taken that VTS operations do not encroach upon the master's responsibility for safe navigation, or disturb the traditional relationship between master and pilot". The message marker 'Instruction' conveys that the message is a directive given by the VTS Center under the provisions of a statutory regulation and the sender must have delegated authority to send such a message (IALA, 2012). For example, with aim to support an action on ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage, the 'Instruction' messages like 'Anchoring is prohibited as you are in an area of underwater cultural heritage' should be issued to the ship concerned.

4. CONCLUSIONS

The potential physical damage to underwater monuments and heritage conservation areas caused by ship anchoring is identified as an accident (an undesired and unplanned loss event). The legal preservation and protection restrictions stipulated by Estonian Heritage Conservation Act, in force and applicable to underwater monuments and the protected zone thereof, are considered to be the underwater cultural heritage preservation and protection constraints to be enforced.

The STPA hazard analysis is performed in order to identify the causal factors and scenarios for potentially hazardous ship anchoring control actions based on interviews of experts and their relevant discussions. As a result, the incomplete awareness of the situation by the Officer on Watch due to malfunction of one or more e-navigation on-board tools was identified as the potential hazardous scenario leading to anchoring within underwater monuments and the protected zones thereof. The critical role of VTS Centre in effective hazard control actions and the enforcement of preventive constraints in real time is identified.

The GOFREP/VTS Center operator is able to observe the controlled maritime traffic process through the radar and Automatic Identification System (AIS) surveillance of traffic. The operator is also able to actuate the process if the ship under control proceed against ship anchoring adjustment to a safe level appropriate to protection and preservation of underwater cultural heritage requirements, by issuing the 'Instruction' messages like 'Anchoring is prohibited as you are in an area of underwater cultural heritage' to the ship concerned.

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