MERI KOTKA

# DESIGNING EFFECTIVE SIMULATOR-BASED OIL SPILL RESPONSE TRAININGS FOR IMPROVED PERFORMANCE, PREPAREDNESS, AND SOCIETAL RESILIENCE

EDITED BY ANNUKKA LEHIKOINEN

SIMREC

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UNIVERSITY OF HELSINKI

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## ABSTRACT

If a major oil spill materializes on the Baltic Sea, it is of utmost importance that different actors can, both nationally and internationally, join their forces and react fast and effectively to minimize its negative impacts to people and environment. The successful implementation of such complex multi-organizational processes under heavy time pressure is based on skilled and experienced operative teams. The development of such teams requires frequent joint exercises and training. Today's bridge simulators can provide an effective, cost-effective, and safe environment for testing and practising various joint tasks related to oil spill management. Applied complementarily to authentic on-board exercises with real vessels, the simulator-based training programmes bear strong potential for improving the oil spill response readiness of the Baltic Sea countries, thus also developing societal resilience against oil accidents. Based on the work conducted and lessons learned during the project SIMREC (2019 – 2022), this report provides information, tools and recommendations to support the design and construction of effective simulator-based oil spill response trainings for various teams.


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## ACKNOWLEDGEMENTS

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*Annukka Lehikoinen*

# 1 | INTRODUCTION: IMPROVING SOCIETAL RESILIENCE COST-EFFECTIVELY THROUGH SIMULATOR-BASED OIL SPILL MANAGEMENT EXERCISES

Roughly 350 million tons of crude oil and oil products are transported on the Baltic Sea every year. According to Helcom's data, there were more accidents on the Baltic Sea between 2018 and 2020 than in previous years (HELCOM, 2021). In 2020, a total of 251 confirmed ship accidents were recorded on the Baltic Sea, although Russia, which transports the most oil in the region, did not report its accidents.

A break in the fuel tank of an ordinary cargo ship can lead to an oil leak of several tons, as happened, for example, in July 2018 on the coast of southern Sweden. Even a leak of this size can cause considerable damage to the ecosystem. Tankers navigating through the Baltic Sea to the Gulf of Finland and back can transport more than 150,000 tons of oil at a time (Ministry of Environment in Finland, 2018). Maritime traffic in the Baltic Sea, including tankers, cargo, passenger, and fishing vessels, is unlikely to decrease in the future. In addition, private boating in the area is increasing, adding to the number of potential accident candidates. The ongoing green transition and the related regulatory reforms, as well as the prevailing tense world political situation with its side-effects, change the operational environment of the Baltic Sea area in many ways, modifying the risk landscape, too.

Oil entering the sea causes harm to nature and people, leading to both ecological, social, and economic losses (Helle et al., 2015). An oil spill can cause human health risks and remarkably reduce the possibilities of using the ecosystem services provided by the sea. The manifold ecological impacts are species-specific, depending also strongly on the magnitude, characteristics, and spread of the spill, the habitats exposed, as well as the time of year when the emission occurs (Helle et al., 2011; Ihaksi et al. 2011; Lecklin et al. 2011; HELCOM, 2013). The consequences and costs of an oil accident also depend a lot on whether the oil can be collected in the open sea or whether it washes up on the shores and on which shores. In general, the ecological consequences are most significant in shallow coastal waters that provide habitats and shelters for many organisms, and on the beaches (see e.g. Helle et al., 2016). Also, the costs of collecting oil from the beaches can be even ten times more expensive compared to the open sea management of the spill (Montewka et al., 2013).

The low-temperature, low-species brackish water ecosystem of the Baltic Sea is globally unique and classified as a particularly sensitive marine area by the United Nations' International Maritime Organization (IMO). In a community with few species, the loss of even one functionally important species can destabilize the entire ecosystem. The destruction of an endangered species occurrence as a result of an oil spill can lead to the disappearance of the entire species. Nearly 200 coastal species classified as endangered in Finland live on the coasts of the Baltic Sea (Hyvärinen et al., 2019). There are nesting, wintering and resting places for millions of individual birds in the area.

In the Baltic Sea, a major oil spill can contaminate tens to even hundreds of kilometers of coastline if the oil is not collected in the open sea (Helle et al., 2011). Continuous work to prevent oil spills is significantly cheaper than combating a major one, thus the most essential thing in oil spill risk management is to prevent the accidents from happening (Haapasaari et al., 2014; Helle et al., 2015). Despite all the prevention efforts, as long as oil is transported in the Baltic Sea, spills can occur, thus continuous maintenance and development of response readiness is essential.

Training for oil spill response operations is about building performance, readiness to react and therefore also a part of building societal resilience for a situation where the worst happens. The national preparedness levels, strategic plans, and joint rehearsals are typically built on accident scenarios that are considered probable: on the likely spill sizes, accident locations, and environmental conditions. However, the success and efficiency of offshore oil control depends on several situational random factors, such as the weather and the time of day and season, being thus highly uncertain (Lehikoinen et al. 2013).

Oil spill response field training exercises are typically relatively costly large-scale projects. Although highly important for practicing in the authentic environment and with the real infrastructure, they are limited in terms of repeatability and testing of alternative strategies and ways of operation under controlled conditions. The COVID-19 pandemic also led to a situation where – due to the assembly restrictions – the organization of authentic field rehearsals was not possible, revealing one vulnerability of the system.

Oil spill operations require collaboration among people with various skills and backgrounds, representing different organizations and having differing roles during the operation. In the Baltic Sea, a large-scale oil accident would also immediately become an international issue, requiring transboundary collaboration as well. This creates a need for tools and solutions that can cost-effectively support collaborative training by relevant actors across both organizational and national borders.

Project SIMREC - Simulators for improving Cross-Border Oil Spill Response in Extreme Conditions (2019 – 2022) aimed to meet these needs and tackle the challenges by developing tools and solutions to support cost-effective and safe inter-organizational training of oil spill management operations, including extreme weather conditions. The focus of the project was on the utilization of a simulator environment for training and in developing risk analytic models and novel protocols for planning effective simulator training events.

This report summarizes the key results of the project SIMREC, providing a roadmap for the effective utilization of simulator environments in the context of oil spill management rehearsals. The project gathered knowledge and developed tools for simulator-based operative response trainings, paying special attention to extreme weather conditions and multi-organizational and cultural contexts. The Gulf of Finland served as the case study area.

Chapter 2 of the roadmap document provides a general situational picture of oil spill prevention and preparedness in the Gulf of Finland. Chapter 3 presents a step-by-step approach to planning effective and spot-on simulator-based training programs for various teams and purposes. Chapter 4 shows the estimated accident-prone locations and plausible oil spill scenarios in the Gulf of Finland area, demonstrating how data analysis and modelling tools can be used to create plausible scenarios for training. Chapter 5 presents a protocol for the formation of shared situational awareness and shows how, by observing and analyzing the simulation exercises, even more effective training programs can be designed. Finally, in Chapter 6, the authors summarize their key take-home messages, providing a roadmap and recommendations for the design of future simulator-based oil spill response trainings.

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GYRO
HDG
STW
COG
SOG
POSN
122.0°
ROT
0.0 °/min
WIND
True
0.0 m/s
DEPTH
2.4 m
DELL

*Ossi Tonteri*

# 2 | OIL SPILL PREVENTION AND PREPAREDNESS IN THE GULF OF FINLAND

## 2.1. Introduction

Maritime traffic has increased rapidly on the Baltic Sea and on the Gulf of Finland during the last years. The main increase has been from increased oil transport from Russia (Jolma et al. 2018). The Baltic Sea has several oil terminals and 6 of them are on the Gulf of Finland. About 8,000 tankers cross the Gulf of Finland every year, carrying up to 150,000 tonnes of oil. Increased traffic has increased possibility for larger oil spill, but also smaller oil spills occur regularly from discharges. In 2021, the HELCOM countries reported 166 spill observations and 31% of these were confirmed as mineral oil spills (Helcom 2022). Some oil spills also occur from old wrecks.

The Baltic Sea has been classified as a sensitive marine environment because of its brackish water, climate conditions, enclosed characteristics, broken coastal line and unique biodiversity. Therefore, possible oil pollution could have negative effects on the sensitive ecosystem. (Rousi & Kankaanpää et al. 2012).

## 2.2. Mechanical recovery

The main method for oil recovery for all countries in the Baltic Sea and Gulf of Finland is mechanical recovery. Use of dispersants in the Gulf of Finland is not recommended by The Baltic Marine Environment Protection Convention (HELCOM), and the use of sinking agents and absorbents is minimised. In situ-burning should also be used only when other means are not available and when using it means avoiding greater damages.

Mechanical recovery has been understood as a method to contain and collect oil from the water's surface for disposal. This approach requires storage of recovered fluids until they can be properly managed. There are various operational methods to conduct mechanical recovery, for example: mechanical recovery with two vessels with a boom or mechanical recovery with a single vessel with an outrigger (sweeping arms and inbuilt oil lifting system to the recovery tank) (Figure 1) (Häkkinen & Rytkönen 2019). The three-vessel system is also used in the Baltic Sea, where two smaller boats or tugboats may tow a U-shaped boom with an opening at the top of the U shape. The third vessel, having the inbuilt recovery system with sweeping arms, is positioned in the opening and collects all the oil forced to spill out when towing the boom with a velocity of 1–2 knots (Häkkinen & Rytkönen 2019).

Skimmers are typically used to recover oil from the boomed area, or an opening is left to the top of the U-shaped boom from where the recovery ship will take the oil into her storage tanks. The effectiveness of mechanical containment and recovery at sea largely depends on the sea and wind conditions at the spill site. Containment and recovery are likely not possible, and are probably unsafe to attempt, in wave heights exceeding 2 m or in wind speeds faster than 10 m/s (Häkkinen & Rytkönen 2019).

Booms are typically used anchored to the site for shoreline protection (stopping spreading or re-diverting the slick) or trapping the oil for skimming purposes. Booms can also be used when towed by two vessels, where the U-shaped boom will trap the oil for recovery purposes. In open water, booms can be used in U, V or J configurations. Interception of free-floating, thin slicks is not as effective as containment and removal of oil at source (Häkkinen & Rytkönen 2019).


**Figure 1. Finnish oil recovery ship HALLI with the inbuilt oil recovery system, inbuilt storage chamber for recovered oil and sweeping arms on both sides of the hull (reprinted from Häkkinen & Rytkönen 2019).**

## 2.3. Oil spill response capacity and exercises in GoF

In 2012 it was estimated that different nations have set different goals for their oil spill responses, for example Finland is prepared for an oil spill of 30,000 tonnes, Germany for 15,000 tonnes, Sweden for 10,000 tonnes and the Russian Federation for 5,000 tonnes (Pålsson 2012).

Countries around the Baltic Sea regularly organise joint cross border oil spill response exercises under various bilateral agreements, e.g. the Helsinki Convention, Copenhagen agreement, Nordic agreement, Baltic Agreement or the European Maritime Safety Agency. Annual exercises are held by the respective countries' Navy and Coast Guard on combatting oil spills at sea. In addition, municipalities and ports of most countries have their own oil spill contingency plans and organise their own smaller exercises.

The main international oil spill exercise in the Baltic Sea region is Balex Delta HELCOM organised under the HELCOM agreement. Balex Delta exercises have been organised annually since the late 1980s to test response capability to a major accident and an international response operation and to ensure that every HELCOM Contracting Party is able to lead a major response operation. According to the HELCOM RESPONSE Manual, the overarching aims of Balex Delta are to test the alarm procedure, the response capability, and the response time of the agreement parties, partly to test and train the staff functions and the co-operation between the units from different Contracting Parties. Although these overarching aims are reflected in most exercises, it is seldom specified which desired levels of proficiency the exercises should train or test. (Helcom 2018)

## 2.4. Retos tool assessment of OSR preparedness in the Baltic Sea

Retos tool is a Microsoft Excel based tool that is based on the work of the Regional Association of Oil and Gas Companies - Latin America and the Caribbean (ARPEL) and developed originally for the 2008 International Oil Spill Conference and later refined in workshops and practical applications (Taylor et al. 2014, Taylor & Lamarche 2014). The tool can be used to assess the level of oil spill response planning and readiness management of governments and industry in relation to pre-established criteria.

A Retos tool assessment consists of seven scopes or general OSR program areas for governments or industry, for example for facilities, ports or regions depending on the type or scale of assessment. For each scope there are 3 different levels for assessment (A, B or C) indicating the maturity of the program. Level A indicates basic level preparedness with all basic components in place. Level B indicates that a program is more developed and for example earlier feedback is used to improve and evaluate management capabilities. Level C is the highest level that requires consistently implemented feedback and maintained readiness through the application of best international practices. Each level contains 10 different categories, for example Training and Exercises, Logistics and Operational Response (Taylor & Lamarche 2014).

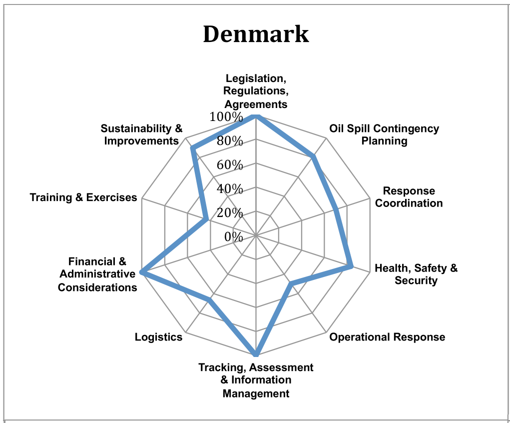
The Retos tool has been used to assess oil spill preparedness of Sweden (Pålsson 2016) and Baltic Sea countries (Pålsson 2016). Overall results (Figure 2) indicated that there was large variation between the countries. United States was included as comparison and it achieved higher scores than any of the Baltic Sea countries, however it should be noted that the tool is modelled after the preparedness system in the United States and all issues listed in the Level A evaluation have been addressed in the United States. Scores from all Baltic Sea countries were more or less on the same level between 56% and 74%.

Radar charts showing the results in different Retos categories for individual countries are shown in Figure 3. Based on the results, all countries achieved collectively the highest scores in Legislation, Regulations, Agreements; Response Coordination; and Tracking, Assessment & Information Management. Lowest scores collectively were achieved in Training and Exercises, Logistics and Sustainability & Improvements. Finland achieved a score of 83% with highest scores in Legislation, Regulations, Agreements (100%), Tracking, Assessment & Information Management (100%) and Financial & Administrative Considerations (100%) and lowest scores in Training and Exercises (56%), Health, Safety & Security (75%), and Logistics (83%). Russia obtained a score of 74% with highest values in Response coordination (100%), Tracking, Assessment & Information Management (100%) and Oil spill Contingency Planning (80%) and lowest values in Sustainability & Improvements (42%), Financial & Administrative Considerations (50%) and Health, Safety & Security (75%) (Pålsson 2016).

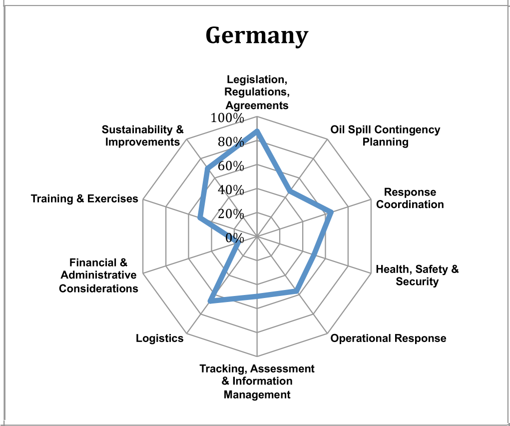
It should be noted that these evaluations were not approved as “official evaluations” by all countries but were based on questionnaire data obtained from individuals responsible for the national contingency planning. The assessment also focuses more on the response actions at sea and onshore preparedness and response is not fully reflected (Pålsson 2016).

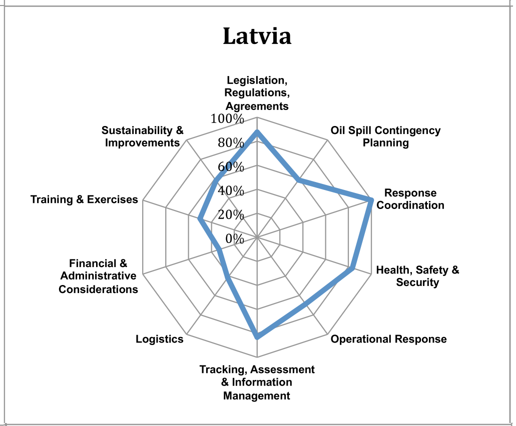
| Country | RETOS™ Score |
|---|---|
| Denmark | 73 |
| Finland | 83 |
| Germany | 56 |
| Latvia | 66 |
| Lithuania | 65 |
| Norway | 98 |
| Poland | 74 |
| Russia | 74 |
| Sweden | 69 |
| U.S. | 99 |
| Average | **73.1** |
| ***STD*** | ***12.0*** |

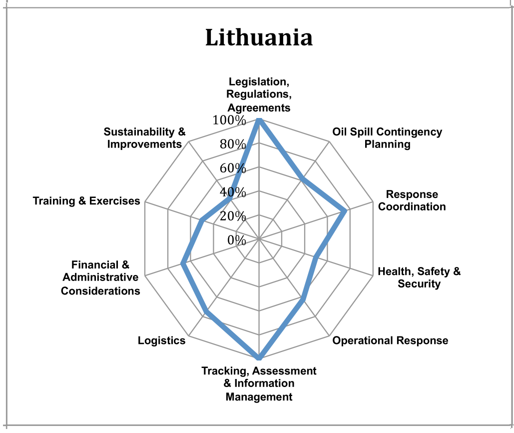
**Figure 2. Total RETOS Level A overall scores (scale 0-100%) for Baltic Sea countries (not including Estonia) and United States (Pålsson 2016).**


Denmark
Legislation, Regulations, Agreements
100%
80%
60%
40%
20%
0%
Oil Spill Contingency Planning
Response Coordination
Health, Safety & Security
Operational Response
Tracking, Assessment & Information Management
Logistics
Financial & Administrative Considerations
Training & Exercises
Sustainability & Improvements


Finland
Legislation, Regulations, Agreements
100%
80%
60%
40%
20%
0%
Oil Spill Contingency Planning
Response Coordination
Health, Safety & Security
Operational Response
Tracking, Assessment & Information Management
Logistics
Financial & Administrative Considerations
Training & Exercises
Sustainability & Improvements


Germany
Legislation, Regulations, Agreements
100%
80%
60%
40%
20%
0%
Oil Spill Contingency Planning
Response Coordination
Health, Safety & Security
Operational Response
Tracking, Assessment & Information Management
Logistics
Financial & Administrative Considerations
Training & Exercises
Sustainability & Improvements


Latvia
Legislation, Regulations, Agreements
100%
80%
60%
40%
20%
0%
Oil Spill Contingency Planning
Response Coordination
Health, Safety & Security
Operational Response
Tracking, Assessment & Information Management
Logistics
Financial & Administrative Considerations
Training & Exercises
Sustainability & Improvements


Lithuania
Legislation, Regulations, Agreements
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80%
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40%
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0%
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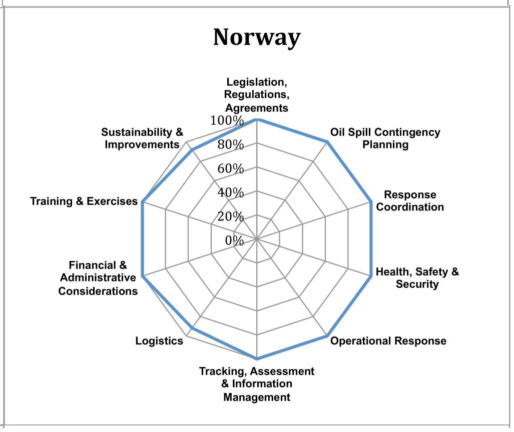
Sustainability & Improvements


Norway
Legislation, Regulations, Agreements
100%
80%
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Oil Spill Contingency Planning
Response Coordination
Health, Safety & Security
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Tracking, Assessment & Information Management
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Training & Exercises
Sustainability & Improvements

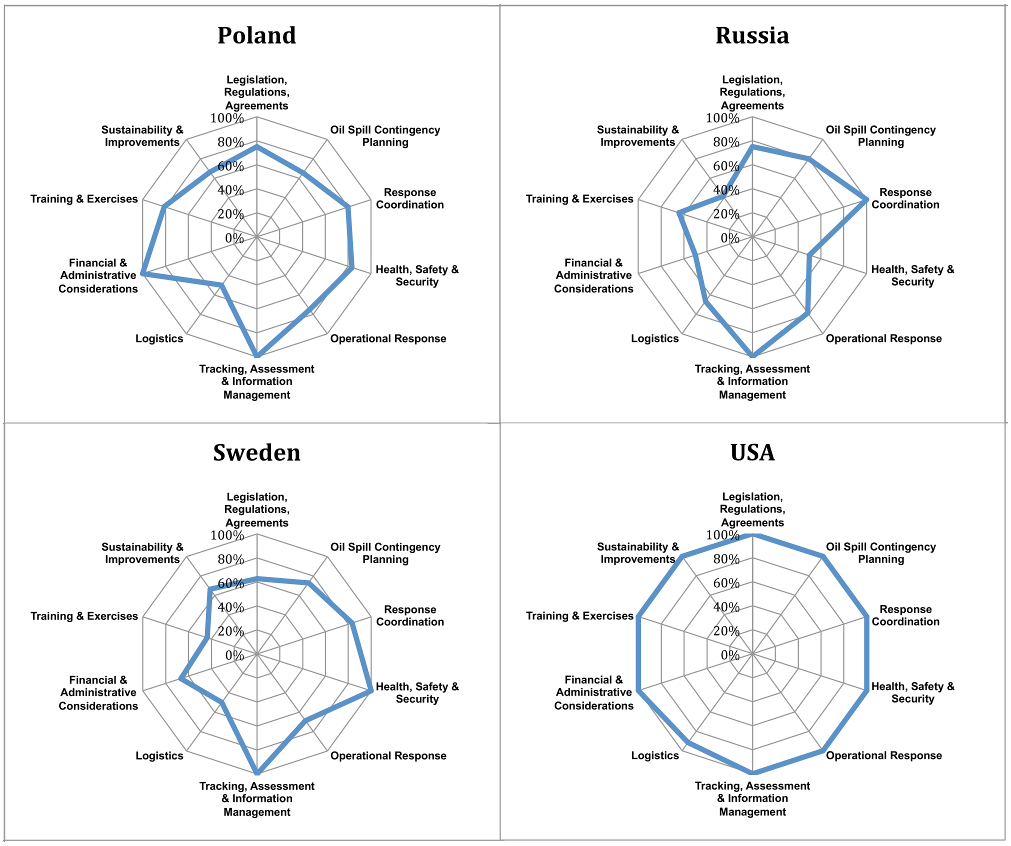


**Figure 3. RETOS tool assessment results as radar charts for the Baltic Sea countries (not including Estonia) (reprinted from Pålsson 2016). Percentages indicate the score (scale 0-100) for different categories.**

## 2.5. Discussion

Previous RETOS assessments have shown that training and exercises have been the relative weakness in the overall oil spill response preparedness of Baltic Sea countries. Organising regular exercises is needed to maintain a good level of preparedness, and they are especially important in maintaining cross border co-operation capabilities in case of larger scale oil spills. Organising simulator exercises could be a cost-effective way to increase oil spill exercises. Simulator training utilises mechanical removal which is the primary oil spill cleaning method used by the Baltic Sea countries.

Compared to traditional exercises, simulator exercises could be easier to organise and can also simulate oil spill removal in more extreme weather conditions. They could also be used to practise oil removal in the winter and under icy conditions, which is more difficult to conduct in traditional exercises.

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YES TO THE SHIT YOU HATE.

*Antti Lanki and Annukka Lehikoinen*

# 3 | A PROTOCOL FOR BUILDING SIMULATOR-BASED TRAINING PROGRAMS FOR OIL SPILL RESPONDERS

## 3.1. Introduction

In terms of technology, maritime (bridge) simulators have become more and more akin to flight simulators with authentic visualization, motion platforms, and control systems (Helovuo et al., 2021). When it comes to oil response simulators, the behavior of oil in the water, as well as its interaction with booms and other collection devices under various weather conditions are represented in a highly realistic manner. The communication technology on the bridges is authentic and the teams on different vessels (bridge rooms) can operate together. Even connections between simulation centers in different locations can be established, allowing cost-effective international collaboration.

Simulators make it possible to break down scenarios into smaller parts and focus on training a certain part of an operation and the specific skills needed in it, including both “soft” skills (e.g. leadership, teamwork and decision-making) and more technical ones (e.g. software skills and the use of hardware and equipment) (Lanki & Tuomala, 2020). The simulators provide a laboratory-like environment, where the weather parameters and other conditions can be manipulated and various operational strategies tested through repetitions. Maritime simulators allow safe and controlled familiarization with potentially safety-critical operations (Helovuo et al., 2021), such as oil spill management in extreme weather conditions.

As oil spill simulators offer a huge number of possible scenarios, it is highly important to carefully plan each training session to meet the objectives and needs of the teams. Based on the experiences during the SIMREC project, we propose a four-step protocol to support the planning of targeted and effective simulator training programs for various operative tasks and multi-organizational teams participating in real-life oil spill management operations.

## 3.2. A four-step approach to planning an effective simulator training

### *Step 1: Identifying the target groups*

When organizing a simulator-based training program to develop the preparedness for oil spill management, an important starting point is to define the target groups for the scenarios to be practiced. This means identifying the real-life operators that would be involved in the corresponding spill management scenario, and who should thus be the learners of the intended training. Step 1 of the developed protocol thus answers to the question: *"Who should be involved in the training?"*

To ensure that all (and only) the relevant actors are included, the existing IMO organizational definitions (*Tiers I - III* and *Levels 1 - 3*) can be employed for categorizing and structuring the different levels of oil spill preparedness and response (figure 2). The tiers refer to the national responsibilities and roles of different response organizations, Tier I representing the local oil spill response operators, Tier II the regional rescue services, and Tier III the international governmental agencies. Under each tier, the actors representing the three operational levels – operational staff (Level 1), supervisors (Level 2), and managers (Level 3) – should be named and their applicability for participation in the simulator training evaluated. Based on the IMO principles, it is important to develop training activities that develop the preparedness on all the levels.

| Identification of Finnish oil spill responders as target groups | | Candidate for joint training |
|---|---|---|
| **Responders** | **FIN (according to Xamk)** | **FIN** |
| **IMO Tier I<br>- Local responders** | **Geographically closest fire-department<br>** Hamina*** | |
| T.I -Level 1 - Operational staff | Rescue units (operators) | YES |
| T.I -Level 2 - Supervisors | Executive fire officer (P41) | YES |
| T.I -Level 3 - Management | Chief executive officer (P20) | POSSIBLE |
| **IMO Tier II<br>- Regional/national responders** | **Regional rescue service<br>** Kympe (Kymenlaakso Rescue Department)*** | |
| T.II -Level 1 - Operational staff | Rescue units (operators) | YES |
| T.II -Level 2 - Supervisors | Executive fire officer (P31) | YES |
| T.II -Level 3 - Management | Chief executive officer (P1) | POSSIBLE |
| **IMO Tier III<br>- International responders** | **Governmental agency<br>** Finnish border guard*** | |
| T.III -Level 1 - Operational staff | FBG Ship and crew (OSC) | POSSIBLE |
| T.III -Level 2 - Supervisors | FBG Fleet command (SMC) | POSSIBLE |
| T.III -Level 3 - Management | Commander of the Coast Guard District | NO |

**Figure 1. An example matrix for identifying and classifying the potential (Finnish) oil spill response operators of different IMO tiers and levels and their applicability (or availability) for involvement in oil spill management trainings (*oil spill scenarios for the Eastern Gulf of Finland).**

### *Step 2: Agreeing and defining the educational objectives*

All training should be goal-oriented and meaningful for the target groups. Only clear, concrete learning objectives are reachable and measurable. As described in Chapter 5 of this report, training needs can be recognized by empirically observing the teams' work during rehearsals (see also Laurila-Pant et al., submitted manuscript). However, when starting with a new group of actors, we recommend starting with a survey on what the actors themselves think about their training needs and priorities (figure 3) and designing the training program based on the answers.

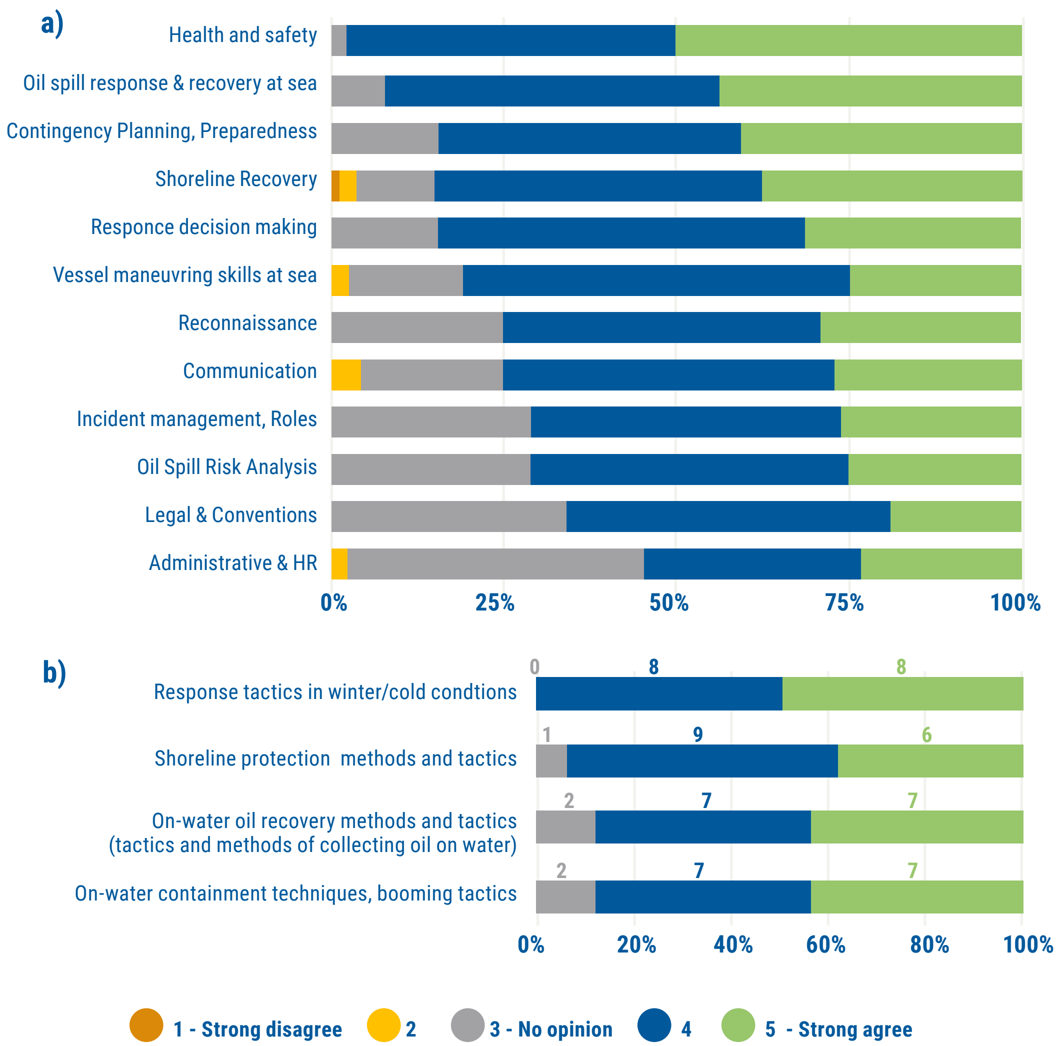


**Figure 3. Example results from a Likert-scale (1-5) questionnaire to a group of oil spill response actors (n = 16) concerning their needs for additional training under different (a) main themes and (b) sub-themes under the main theme Oil spill response and recovery (Statements: "I would benefit from additional training in…").**

Once the key training functions have been identified, list the related tasks of each responsibility level, i.e. the supervisors and executive officers, as well as the operational staff (see figure 1), in different phases of an oil response operation (see figure 4). The main phases (timeline) of the operation are: 1. *Reconnaissance and Planning*, 2. *Immediate Response Operation*, and 3. *Continued Operation*. Create a matrix to specify and make notes on the more detailed learning objectives of the actors on different response levels in the distinct phases of the response operation following the framework developed in figure 4.

| Stages of Oil-spill response: | 1.Reconnaissance and Planning | 2.Immediate Response Operation | 3.Continued Operation |
|---|---|---|---|
| **Educational Functions:** | **Supervisors** | **Operators** | |
| **F1.Controlling the vessel** | Fleet level control, Strategic understanding:<br>Manage reasonable convoy speeds | Single vessel control, Navigation, Practical skills:<br>Maintain reasonable unit speed | |
| **F2.Communication & Coordination** | Strategic cross-border and internal communication (leadership):<br>Transmitting effectively | Operational communication with units in vicinity (understanding):<br>Receiving/ relaying correctly | |
| **F3.Response Tactics** | Fleet level awareness and management:<br>Coordinate multi-vessel operations and formations | Single vessel operation:<br>Understand own position and actions in relation to other units | |

**Figure 4. Framework for specifying the training needs of supervisors and operational personnel per each of the identified key learning functions (F) in each stage of an oil spill response operation.**

In figure 4, the training function *Controlling the vessel* (F1) contains all the objectives for learning the skills and competences related to navigation, maneuvering and the correct use of navigational aids and equipment onboard. For the supervisors (IMO Level 2 actors, see figure 1) the topic is relevant on a more strategic level as they are not operating the vessels themselves, whereas for the operational staff (IMO Level 1 actors) it is more about practical hands-on skills. The function *Communication and Coordination* (F2) contains all the skills and competences related to the management and control of the joint operation as well as (radio)communication. For the supervisors it means (e.g.) effectively receiving and transmitting correct and precise information, whereas for the operators it is about correct interpretation and relaying of information and data. The function *Response Operations* (F3) in turn contains all the skills and competences required to execute coordinated response measures. For the supervisors it means (e.g.) the skills for managing fleet-level operations, whereas for the operators this function is about the skills of operating the vessel's response material and understanding their positions as "a link in the chain".

### *Step 3: Drafting the training framework and schedule*

In Step 3 – based on the results of the previous steps – the training program can be outlined and a 'curriculum' created (figure 5). The important practical issues to be considered here are:

- **Locations of the participants**. Are all the participants going to be in the same simulator or in different geographical locations with remotely connected simulators? In the latter case, it is important to make sure the connection between the simulators works, and the participating simulator centers have the same and compatible (map)areas, ship models and other relevant objects.
- **Duration of the training**. This is typically a compromise between the training needs and the time resources of the participants. It is also important to reserve time for familiarizing the learners with the simulator interface. Many of the operators are competent in the operation of their actual vessels and equipment. However, as a simulation is always an approximation of reality, it is important to get to know and use the simulated interface before conducting a real objective-oriented exercise – especially if the system is in the online mode (via the European Maritime Simulator Network). With a new team, if possible, investing time in a separate day or session only for technical checks and testing and demonstration purposes is highly recommendable.
- **Schedule of the training**. Given the possible duration of the training program, and the locations of the participants, schedule the simulator training day(s) in terms of the learning objectives (from Step 2), thinking which stages and tasks (F1-3) are to be practiced and what are the responsibilities of the participating learners. Consider how you can optimally divide the day(s) into the tasks and how to pace the briefings and debriefings in relation to the actual simulations.

| Time | Day 1<br>*Local Familiarization* | Day 2<br>*Joint EMSN Training* |
|---|---|---|
| 08:00 – 09:00 | Technical set-up and preparations | Technical set-up and preparations |
| 09:00 – 10:00 | Introduction and tour of the simulation centre | Common briefing |
| 10:00 – 11:30 | Basic facilities and equipment demonstration | **Exercise 1**: Locating and reporting the oil-spill |
| 11:30 – 12:30 | Lunch | Lunch |
| 12:30 – 14:00 | Task specific familiarization. Operators learn the use of nav. equipment and controls. Supervisors learn the communications and operations control center | **Exercise 2:** |
| 14:00 – 15:30 | Test scenario demonstration and internal communications check | **Exercise 3:** |
| 15:30 – 16:00 | (Optional: Second scenario demonstration) | Common debriefing and feedback |

**Figure 5. An example of a two-day simulator training program (schedule), where the second day is organized as a distance joint training between two simulator centers via the European Maritime Simulator Network (EMSN).**

### *Step 4: Designing the individual scenarios and exercises*

In the last phase of the training program design process, each individual exercise and the related scenario are scripted and the necessary simulator files programmed. The following to-do list for creating simulator training scenarios (a process description) includes the elements of any simulator scenario scripting instance and can be used to guide the work:

0. Define the THEME and OBJECTIVE of the scenario.
1. Select the SCOPE of the exercise.
2. Select the scenario AREA.
3. Select the SHIP(S) operated.
4. Select the OBJECTS (e.g. Dynamic spill, booms, anchors, target ships etc.)
5. Create the exercise file using the Simulation software (e.g. NTPro).
6. Perform the first test on the file.
7. Modify and adjust Ships / Objects in the file.
8. Select and modify the environmental conditions and the time of day.
9. Perform the next test(s) on the file.
10. Make the final adjustments and save the file.
11. Make a backup of the file for sharing.
12. Document the scenario.
13. Conduct the potential additional (EMSN connectivity) tests and validations.

The above process is repeated for each exercise scenario. The checklist can also serve as an 'agenda' in the scenario planning workshops and meetings. Item 12 (*documentation*) refers to a written script document used when running the joint exercise, describing all the details and specifications needed for the actual execution of the simulator training. This document is the simulator instructor's guidebook and reference for all the details related to the whole training program (and all the exercises it contains). The main parts of the document are:

- Project information and objectives
- Educational framework (pedagogy)
- Connected centers and the contact persons

- Instructor(s) and participants (learners)
- Communication channels and methods
- Schedule
- Exercise details and specifications

Plausibility of the simulated scenarios is important, both in terms of the mental orientation of the learners and the likely usefulness of the exercise in the real life (Schank et al. 1994). To script plausible scenarios, it may be reasonable to think about the potential accident locations in the sea area in focus (e.g. Kujala et al., 2009; see also Chapter 4 of this report on how modelling can help in creating plausible scenarios), specifically sensitive areas – e.g. in terms of ecological vulnerability to oil (Kokkonen et al., 2010; Helle et al., 2016), or otherwise in terms of presenting challenging operating environments. In addition, it is important to acknowledge the type of existing oil-spill response vessels in the focus area and to involve corresponding vessel types in the scenario.

The main environmental variables that define the conditions at sea (and that can be simulated) are: wind, waves, ice and visibility. Importantly, wind and waves are to some extent interdependent, which should be considered in a realistic scenario. Roughly speaking, the increasing wind force affects the waves by increasing their amplitude, frequency, and period (Suursaar & Kullas, 2009; Egidijus & Petras, 2013; see also [1]). Wind and waves affect the maneuvering of the response vessels (Lehikoinen et al., 2013) and the occupational safety on the deck. Eastern and Northern Baltic Sea is subject to seasonal ice in the winter. Ice and freezing temperatures mostly affect the maneuvering of the vessels, vessel integrity and stability, and the operational conditions of the equipment (Xu et al., 2021). In addition, the behavior and collectability of oil in ice is very different from open sea conditions (Lu et al., 2019) and something that cannot, to our knowledge, be represented realistically by the simulators yet. Visibility as a variable consists of darkness (during night), fog and precipitation (rain, snow etc.). Visibility mostly affects the navigation of the vessel and emphasizes the correct use of different kinds of navigational aids and equipment.

To create plausible (even in terms of extreme cases) and most relevant weather scenarios, it is recommendable to analyze the weather and ice (maybe also accident) statistics of the sea area in focus and to utilize the tacit knowledge of experts who operate in the area as part of their daily work.

[1] www.weather.gov/media/akq/marine/Wind_Wave_Relationship_Reference.pdf

## 3.3. Discussion and conclusions

Bridge simulators provide a safe and cost-effective but close to realistic environment for various response teams to test and practice oil spill management operations. The simulators provide a flexible educational environment with an endless variety of scenarios to run, thus it is highly important to carefully plan the trainings, considering (1) who should be involved; (2) what are the learning objectives; (3) what are the available time resources and how to effectively structure and schedule the training; and (4) how to create relevant and plausible scenarios to attain the learning objectives of the team in question. In this chapter, based on the lessons learned during the project SIMREC, we have provided a simple four-step protocol with tools and ideas for building functional bridge simulator training programs.

Learning in a simulator environment implements the principle of Goal-Based Scenarios (GBS) (Schank et al., 1994). Following the principle, the designers of the simulator training should aim for creating realistic cover stories that provide opportunities to acquire and practice skills that are necessary to reach a certain (clear and concrete) goal. The simulators provide an authentic task environment where the learners can recognize the conditions in which the desired skills are applicable and useful. In other words, the learners rather acquire knowledge to be used to reach the goal than facts to remember. In GBS, the learners are active participants of the scenarios in which they move forward by completing various tasks.

The plausibility of the cover story of a simulator exercise ensures the learning of truly relevant skills (Schank et al., 1994). In a realistic and coherent story, the target skills to be learned are naturally called for when the learners are pursuing the defined objective. Thus, a plausible cover story also increases the motivation and commitment of the learners. The realistic individual *roles* (tasks and responsibilities of each learner), as well as the authentic *setup* (e.g. the group of actors involved and collaborating in the exercise, and the tools used by them) ensure that the learners will face realistic situations and thus learn skills that are most likely useful in the real-life operations. The accident scenario represents the *scene* of the cover story that is acted in the simulation: the physical setting (e.g. the location, oil type and volume, and weather conditions) that provide opportunities for the learners to engage in the operation. The presented four-stepped SIMREC protocol for designing effective simulator-based training programs for oil spill responders guides its user in the consideration and practical inclusion of all these important aspects.

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TUG

*Liangliang Lu*

# 4 | SIMULATING ACCIDENT PRONE LOCATIONS AND POTENTIAL OIL SPILLS

## 4.1. Introduction

About 80% of Finnish imports and exports are transported through the Northern Baltic Sea (Asplund and Malmberg, 2011). The Gulf of Finland (GOF), part of the Northern Baltic Sea, is recognized as one of the most transited maritime areas in the world (Kuronen et al., 2009). Oil tankers are usually among the busy traffic vessels in this area, which exposes the area to more risk of oil spills. Considering the relatively shallow water and near coastline conditions in GoF, oil spills can cause significant damages to the ecosystem and cause socioeconomic loss as mentioned in Chapter 1. Therefore, to understand oil spills better, this chapter focuses on simulating plausible scenarios for oil spill simulators and relevant training for response and recovery.

The main structure can be illustrated as above in Figure 1. First, the Automatic Identification System (AIS) data will be analyzed to find the characteristics of the spatial maritime traffic and corresponding ships in Section 2. Then, accident locations and frequency are estimated based

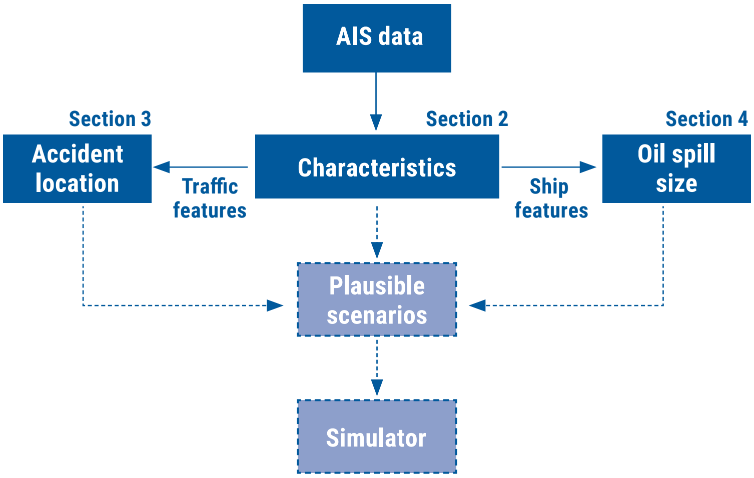


**Figure 1. Procedure to generate plausible oil spill scenarios**

on the traffic data in Section 3. Meanwhile, ship related features are applied to simulate the potential oil spill sizes in Section 4. By combining the information, plausible oil spill scenarios can be generated for the simulator and training. Following sections will illustrate each part in detail.

### 4.2. Spatial maritime traffic and characteristics

Automatic Identification System (AIS) data covering GoF for the year 2018 are analyzed as a base in this report. Two months (February and March) are excluded from this study as they involve ice navigation which has different features.

The maritime traffic density distribution in the Gulf of Finland is depicted in Figure 2, where there exist several dominating traffic flows. One consists of the major shipping lines cutting the Gulf in east-west directions, which are the shipping lanes most oil tankers navigate. The other consists of the north-south flows in western part of the Gulf, which mainly concern the passenger traffic linking Helsinki and Tallinn. Additionally, the traffic flows are directed to the north, to the harbors along the coast of Finland as well as to the south, to Estonian and Russian harbors.

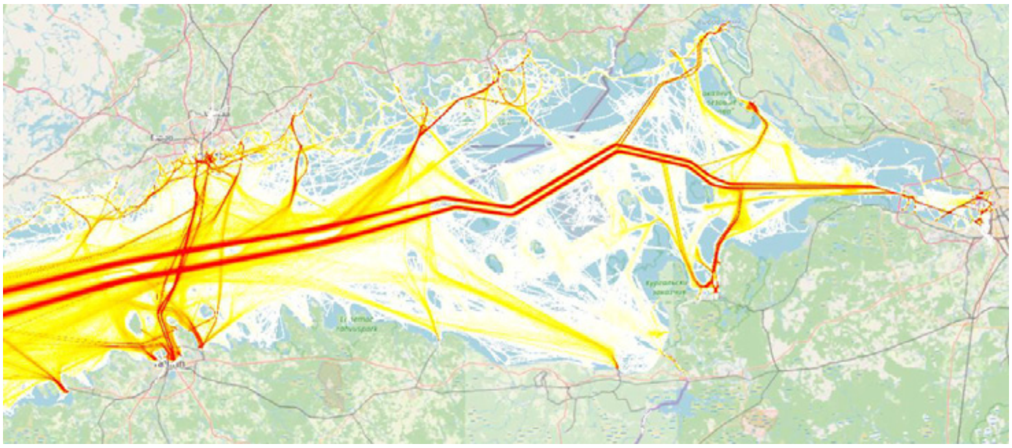

**Figure 2. Maritime traffic density distribution map in GoF (reprinted from Mazurek et al., 2022)**

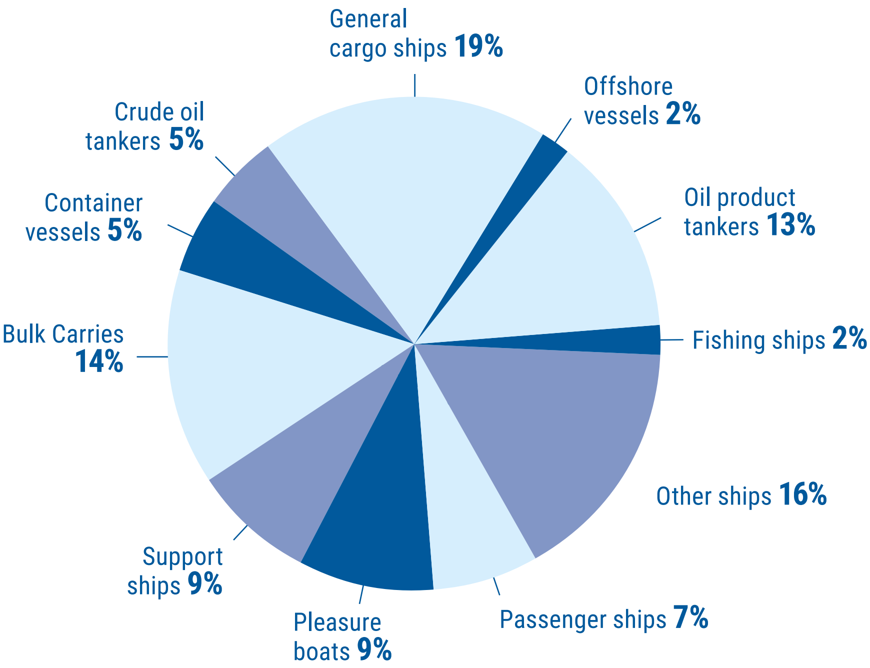


**Figure 3. Distribution of ship types navigating in the Gulf of Finland in 2018 (redrawn from Mazurek et al., 2022)**

In general, the AIS data include static, dynamic, and voyage-related information. By looking into the data, the distribution of relevant ships is presented as in Figure 3. Our main concern is oil tankers, including crude oil tankers and oil product tankers, accounting for around 18% of the total maritime traffic in the area. The other frequently observed ship types are general cargo (19%), bulk carriers (14%), and others (16%), including small auxiliary vessels, such as bunkers, harbor tugs, pilot boats, and the like.

The distribution of ship speeds and courses over ground for oil tankers are shown in Figure 4. The main speed range is around 8-13 knots, with a maximum around 15-17 knots. The main courses are east-west directions as expected and the rest are relatively evenly distributed which indicates that there are quite often changes of directions.

The distribution of the main dimensions of the oil tankers are presented in Figure 5. For oil product tankers there are two identifiable dimension groups, one with a length of around 200 m and the other spanning roughly from 70 m to 180 m. The corresponding DWT starts from around 1E3 to 8E4 tons. For the crude oil tankers there is one dominating group with a ship length of around 250 m and DWT of 10E4 to 14E4 tons.

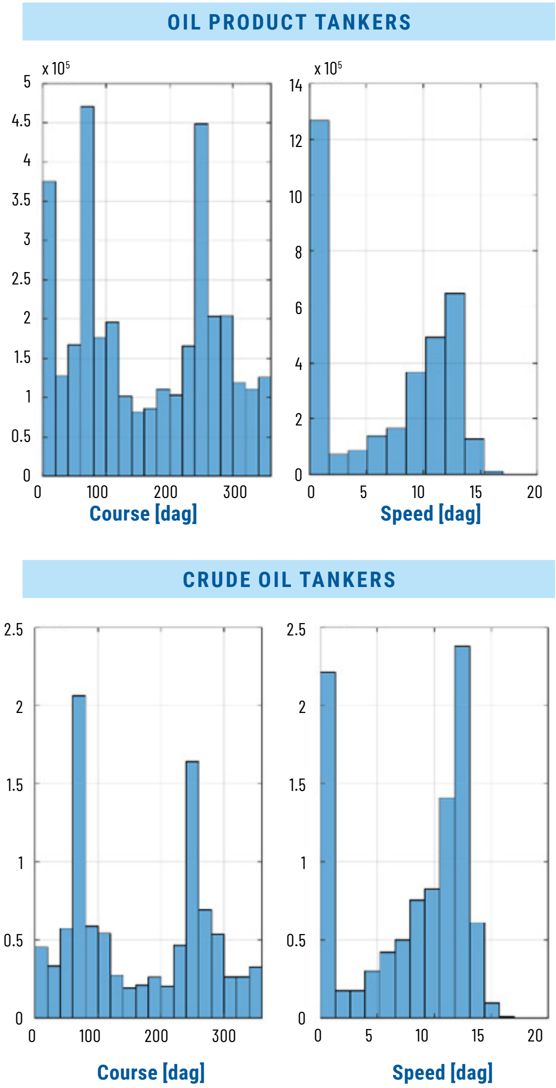


**Figure 4. The distribution of speeds and courses over ground for oil product tankers (above) and crude oil tankers (below) navigating in GoF in 2018 (diagrams reprinted from Mazurek et al., 2022)**

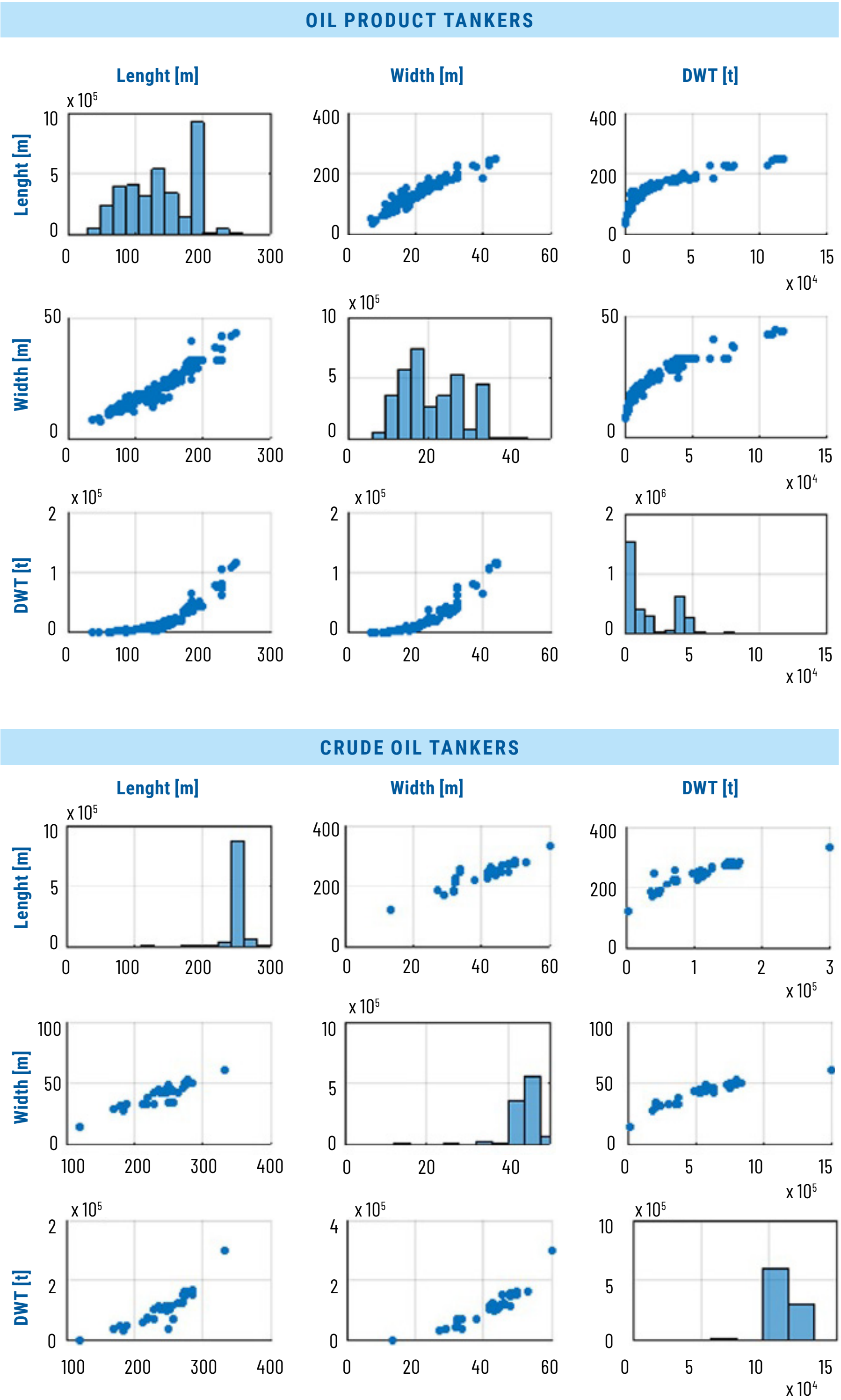


**Figure 5. The distribution of main dimensions for oil product tankers (left) and crude oil tankers (right) navigating in GoF in 2018 (diagrams reprinted from Mazurek et al., 2022)**

## 4.3. Ship-oil tanker collision frequency and hot spots

Ship-oil tanker collision is considered as the main accident type in w study. Therefore, the focus moves to the estimation of the potential collision probability and collision hot spots in GoF for oil spill considerations. Five collision types are considered in the modelling, which can be grouped into two types: parallel type and crossing type. The parallel type of collision includes head-on and overtaking collision along a leg. The crossing type of collision includes collision in waypoints where two routes intersect or merge or where a single route bends. Figure 6 shows an illustration of a collision along the route (parallel type) and a collision on crossing waterways (crossing type) respectively. With the relevant parameters obtained from AIS data, ship related parameters, e.g., ship length, breadth, velocity, and numbers of ships passing through one area and the distribution of the ship positions are known. The number of collision candidates can then be calculated accordingly by following established principles (Friis-Hensen et al., 2008). By multiplying the reported causation probability, the ship-ship collision frequency can be determined.

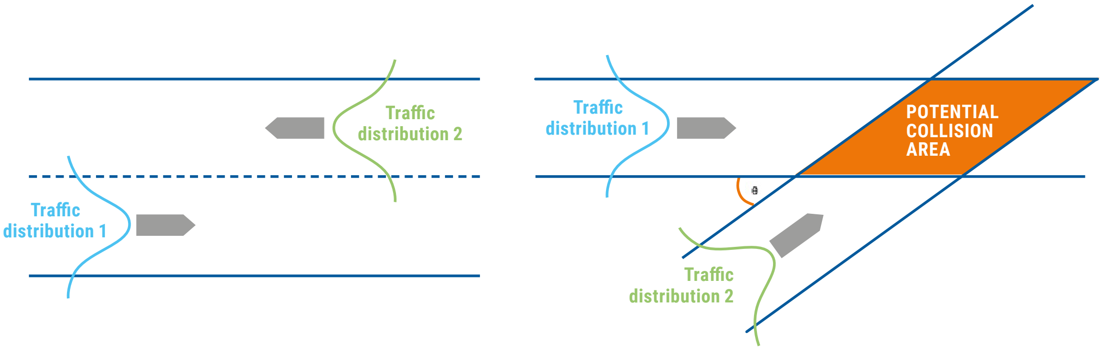


**Figure 6. Collision along the route (left) and collision on crossing waterways (right) (redrawn from Mazurek et al., 2022)**

In order to identify the collision prone legs for parallel type collisions in the main shipping routes, a normalized ship collision frequency is adopted, i.e., the calculated collision frequencies are divided by the legs which results in a collision frequency per nautical mile. By comparing that normalized collision frequency, the accident-prone legs can then be identified. The collision-prone nodes for crossing type collisions are calculated based on the defined waypoints which are defined as an area of a constant size, and there is no reference to its size in the equations estimating frequency of collision, therefore the obtained values can be directly compared across all the nodes without normalization.

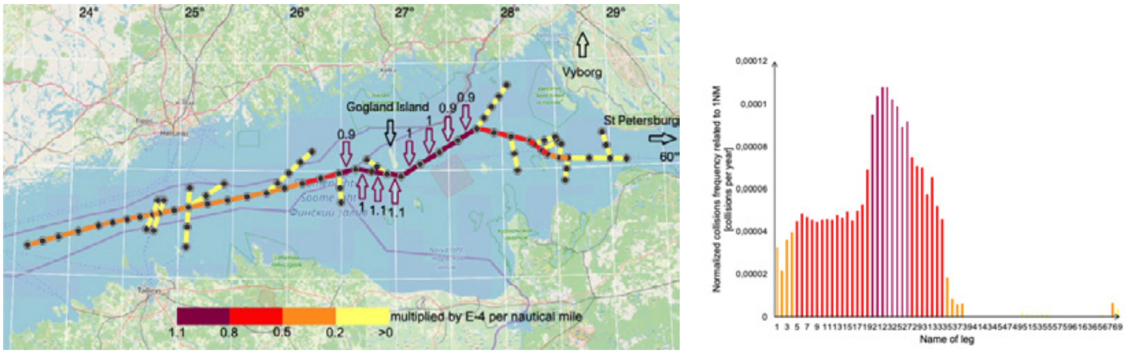


**Figure 7. Map of annual normalized collision frequency for tankers – the most collision-prone legs (reprinted from Mazurek et al., 2022)**

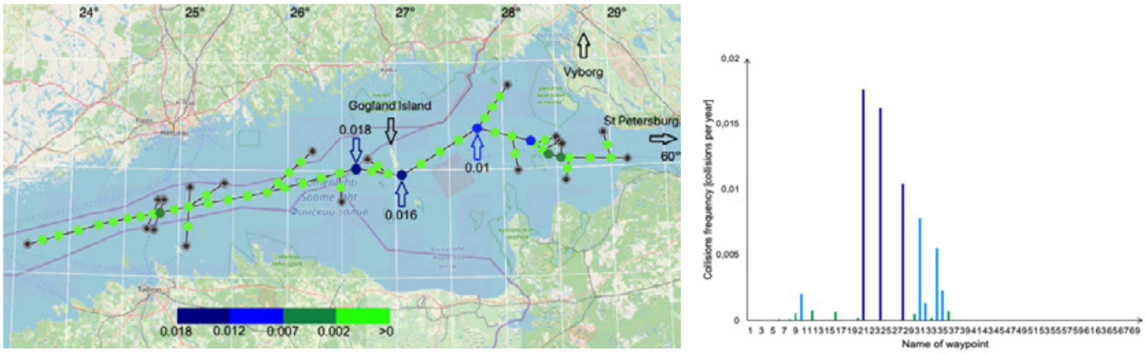


**Figure 8. Map of annual collision frequency for tankers – the most collision-prone waypoints (reprinted from Mazurek et al., 2022)**

The main shipping routes are modelled by 69 legs and 70 waypoints in total as depicted in Figure 7 and 8. The normalized annual frequency of collisions involving at least one tanker is calculated and presented, expressed as the annual number of collisions per 1 nautical mile of a leg.

The most collision-prone legs are determined based on the map, as depicted in Figure 7 (left). The dark red represents the highest values of the normalized annual collision frequency while the yellow color denotes the opposite. The most collision-prone legs (marked with dark red) are labelled with arrows showing the associated value of the normalized annual collision frequency. The right figure shows the normalized annual collision frequency per 1 NM in each leg with the same color code applied.

Similarly, the most collision-prone waypoints are determined as shown in Figure 8, marked with dark blue color, and additionally labeled with the arrow and associated numerical value. The dark blue represents the highest values of the frequency and green refers to the lowest values. The right figure shows the annual collision frequency in each waypoint with the same color code applied.

In general, the estimated annual collision frequency for the whole Gulf of Finland for all ship types yields 0.19, which means one collision per 5.3 years. While the annual frequency of collisions involving at least one tanker yields 0.078, meaning an occurrence interval of around 13 years.

With respect to head-on and overtaking collision types, the most collision-prone locations for tankers steaming through the Gulf of Finland during ice-free seasons are as follows. They constitute over 63% of the collision frequency in GoF:

- On the main route around the Gogland Island, where the normalized annual collision frequency reaches up to 1.1E-4 per NM;
- The routes adjacent to those legs, heading east and west, where the normalized annual collision frequency is in the range of (0.5–0.8)E-4 per NM;
- In the eastern part of the GoF, at the split of waterways towards Vyborg and St Petersburg, where the normalized annual frequency is around 0.4E-4 per NM.

With respect to crossing types of collision, the results obtained reveal a similar pattern as in the case of the parallel types of collision. The areas with the highest frequency of crossing-type collisions are located on the main route, as follows:

- South of Gogland Island, annual collision frequency of 1.8E-2;
- West of Gogland Island, close to the junction of a route to the Estonian oil terminal of Sillamäe, annual collision frequency of 1.6E-2;
- In the eastern part of the GoF, at the split of the waterways towards Vyborg and St Petersburg, annual collision frequency of 1.0E-2.

## 4.4. Ship-oil tanker collision induced oil spills

Based on the estimation in Section 3, the accident hot spot areas in the main shipping routes are determined. These areas are also the potential oil spill regions. With that location information available, it is very useful to also know how much oil may be spilled out from the oil tankers in these regions so that relevant preparations and oil spill response trainings can be planned on the basis of some plausible scenarios.

In order to estimate how much oil may be spilled out during collision accidents with oil tankers, collision scenarios are generated based on the characteristics of the oil tankers and traffic. Different sizes of representative oil tankers are selected as struck ships, which include four tanker sizes (DWT 3,232, 15,000, 37,000 and 136,000 tons). Two vessels are selected as striking ships (DWT 6,430 and 28,429 tons). The collision scenarios are assumed to happen among the striking and struck ships with three striking speeds, two impact locations, and two collision angles. The striking speeds are considered as 3, 6 and 9 knots, roughly half of the normal operation speeds, as ships usually try to reduce their speed to avoid the collision before the accident really happens. The impact locations are random points in two ranges, 15%-50% of ship from stern and 50%-85% of the ship from stern. The two collision angles are assumed at 90 and 150 deg. These collision scenarios are then simulated based on the double hull breaching energy model (Heinvee and Tabri, 2017; Lu et al., 2020), which identifies whether the inner hull of the oil tanker is breached in a certain scenario. The inner hull and tanker arrangements are based on the relevant information in Goerlandt et al., 2017. The double hull breaching model is suitable for application contexts where very limited structural data is available for the ships participating in the accident, thus making it suitable for the cases here. In the collision, it is assumed that the dimensions of the opening follow the dimensions of the intruding structure at its intersection with the hull plating and that oil then outflows from the opening.

The oil outflow depends on different variables, such as tanker structure, hydrostatic pressure difference and locations of the damage opening. An oil outflow from a tanker occurs when the inside pressure in a cargo-oil tank exceeds the outside pressure at the level of a submerged or semi-submerged damage opening. Excess hydrostatic pressures can result from a relatively high oil level in a tank. One simplest possible outflow scenario is that a unidirectional flow would occur under excess hydrostatic pressure until the pressure inside and outside the tank equalizes. However, especially for double hull tankers, the process is likely to be more complex as the excess hydrostatic pressure is not necessarily dominating the flow. In this situation a bidirectional flow would occur, where oil flows out from a leaking tank and seawater flows in the opposite direction and their mixing inside the double hull may even further complicate the situation. The oil spill hydraulic model (Kollo et al., 2017) is used to simulate the oil outflow process and estimate the spilled oil amount based on hydraulic modelling for bidirectional exchange flow through a damage opening, as shown in Figure 9.

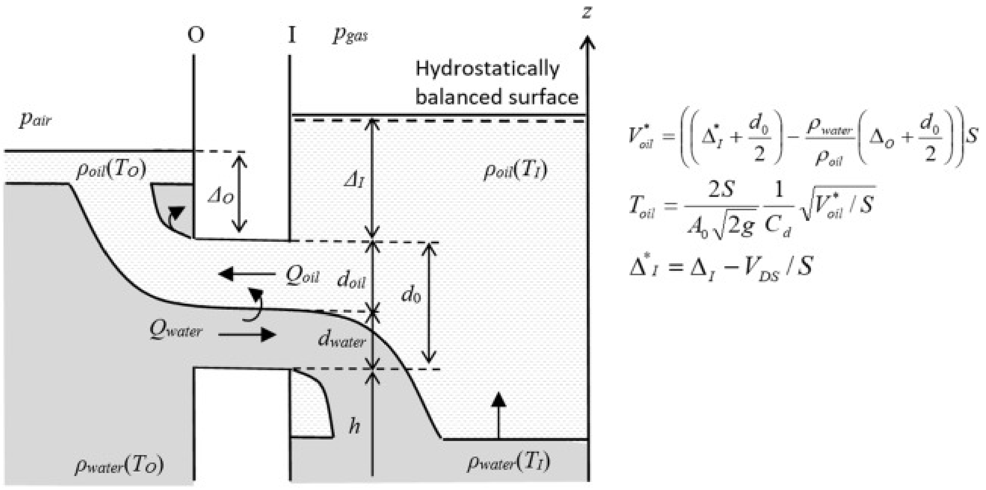


**Figure 9. Oil-spill through a side opening in double hull tanker, where $V^*_{oil}$ is the spill volume (reprinted from Lu et al., 2020).**

The oil spill amounts are calculated accordingly for different defined scenarios. The distribution of the plausible oil spills is summarized as in Figure 10. In general, the amount of oil spilled can be in the range of 0 to 1.8E4 tons. Zero spills or small spills account for the majority, while large spills (over 1E4 tons) are likely to happen in extreme cases.

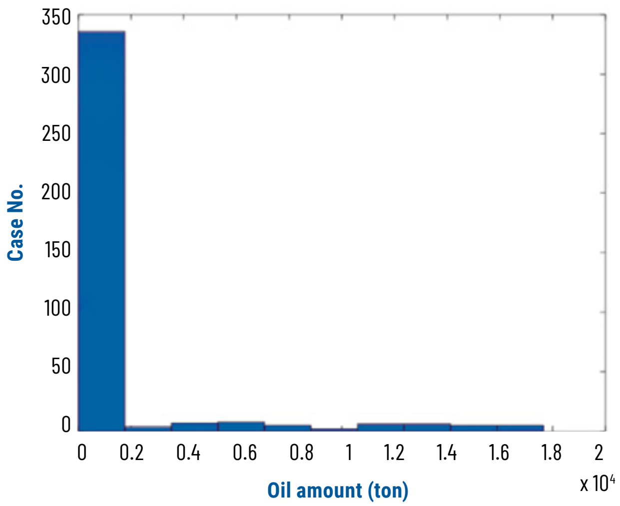


**Figure 10. Plausible oil spill distribution based on the defined collision scenarios**

### 4.5. Summary and discussion

This chapter focuses on the estimations of accident-prone locations in GoF and plausible oil spill amounts so that this information can support a better understanding of oil spill risk in GoF and the relevant preparation of training for such accidents, especially in simulator environments that allow generation and demonstration of different scenarios.

As there are different models and simplifications involved, uncertainties are unavoidable in this study. Further refined models and approaches are always suggested for further improvement. This study however provides a good foundation for generating exercises for training purposes as it accounts for as close characteristics of GoF traffic as possible.

In the future, it is suggested that the simulator may need to include more regions with sea state features to cover more exercise and training areas and purposes. In addition, as GoF is an ice-infested region, an oil spill in ice-infested GoF is likely to happen, which is also a relatively difficult and extreme situation as pointed out by Lu et al. (2019). Further oil spill features in ice-infested waters in the simulator may also help in the overall preparation for oil spills in GoF.

### ACKNOWLEDGEMENTS

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*Mirka Laurila-Pant*

# 5. | ANALYSIS OF OBSERVATIONS MADE DURING AN OIL SPILL RESPONSE SIMULATOR EXERCISE – FOCUSING ON THE SIGNIFICANCE OF SITUATIONAL AWARENESS AND OPERATIONAL DECISION-MAKING

## 5.1. Introduction

In case of a large-scale oil spill, individual organizations or even countries rarely have the resources and capacity to overcome the response measures alone. This type of incident would require effective and well-organized multi-agent cooperation between various response agencies, organizations and even the neighbouring countries to limit the oil spill and minimize the potential damage. In multi-agent cooperation, management strategies or the plans for optimal courses of actions and response measures are not always the same between cooperating agencies. Different operational systems, cultures and legislations may define what works and is feasible in each agency (Ödlund, 2010; Ley et al., 2014). Especially, the formation of situational awareness is often hampered in multi-agent crisis cooperation. Joint training can provide a practical environment to test and improve teamwork within and between operational and tactical response agencies and thus develop common understanding of how to deal with the crisis response (Tena-Chollet et al., 2017).

The project SIMREC aims to reduce the risk of an oil spill to the environment of the Gulf of Finland by developing a joint oil spill response training program with virtual simulators that aims to optimise multi-agent oil spill preparedness and response. One of the aims of the project was also to improve the understanding of the formation of individual and shared situational awareness and the following operational decision-making during an oil spill response operation through the crisis simulation trainings. To attain this aim, we have developed a protocol that can be used as toolkit for instructors and analysts of the oil spill simulation exercises to develop efficient preparedness trainings.

Trainings in virtual simulator environments provide an accessible, cost-effective, and commonly used alternative for preparedness exercises as field trainings for oil spill response simulations are costly and laborious to organise. Simulator-based trainings are found to be practical and useful to practice tactics, skills and techniques (Halonen and Lanki, 2019), to enhance information sharing between agencies (Sweeney et al., 2014; Dohaney et al., 2015), and to study the strategic and tactical decision-making (Alison et al., 2013) of the response agencies. A virtual simulator as a learning environment provides a platform for repetitions and testing under controlled conditions allowing systematic observation of the effects of various factors (e.g. adjusting weather conditions and the amount of light, controlling what information is provided). It also allows repeating the same scenario run and to test the improved practice. Advances in digitalization, programming and processing capability of computer systems have allowed for the construction of more sophisticated and high-quality simulators (Mallam et al., 2019). These advancements have also provided platforms to connect simulators from different locations to allow agencies to participate remotely in the joint exercises (Rizvanolli et al., 2015; Burmeister et al., 2020).

This Chapter presents the developed protocol for analyzing the significance of individual and shared situational awareness and the following operational decision-making in a cooperative oil spill simulator exercise. We show the applicability of the developed protocol in an oil spill response exercise organized as part of a training event in the project SIMREC. The training event was carried out with the oil spill virtual simulators at the Kotka Maritime Centre (KMC) in May 2022. The protocol was used to monitor and capture the operational practices of actors, the formation of the situational awareness among agents as well as the key elements of a decision-making process as part of the crisis management training. To provide the above analysis, the data collection during the training event included observations during the simulation exercise and the debriefing discussion, individual interviews and audio recordings. We provide an analysis of the participants' performance and learning experience during the organized oil spill simulator exercise. As a result, we identify potential future oil spill response training needs and provide some recommendations for best practices for simulator training.

## 5.2. Case study: The SIMREC simulation training event

The training event was carried out with the oil spill simulators at the KMC in May 2022. KMC is a training and simulator centre co-ordinated by the South Kymenlaakso Vocational College (Ekami) and the South-Eastern Finland University of Applied Sciences (XAMK). The event comprised of three exercises: Exercise 1: Reconnaissance (searching and locating a spill) mission near island Sommers, Demo exercise 2: Oil spill response vessel in spring ice and Demo exercise 3: Seining with two vessels and the boom-oil interaction. In the observations and analysis of this work, we mainly focused on Exercise 1, unless otherwise noted. The exercises were implemented using the oil spill simulator training model developed by the XAMK's specialists together with the other project partners (see Chapter 3 introducing a protocol for building simulator-based training programs). Aalto University researchers modelled a probable oil spill scenario for the eastern Gulf of Finland, on the basis of which a new additional modelling of the accident area had been created for the oil spill simulators (see Chapter 4 on how modelling can help in creating plausible scenarios).

During the training event, four representatives of the Kymenlaakso Rescue Department carried out the exercises. The task in exercise 1 was performed as a cooperative effort between three teams, with two strike teams located at sea (separate simulator rooms with a realistic bridge and a simulated view) and the operational control including two supervisors of the rescue operation in a Command Centre (CC; a separate classroom). Figure 1 shows the exercise setup.  The aim of the exercise was for the operational control to determine an accurate situational awareness of the oil spill (the location, shape and size) based on the information provided by the agents of the strike teams.

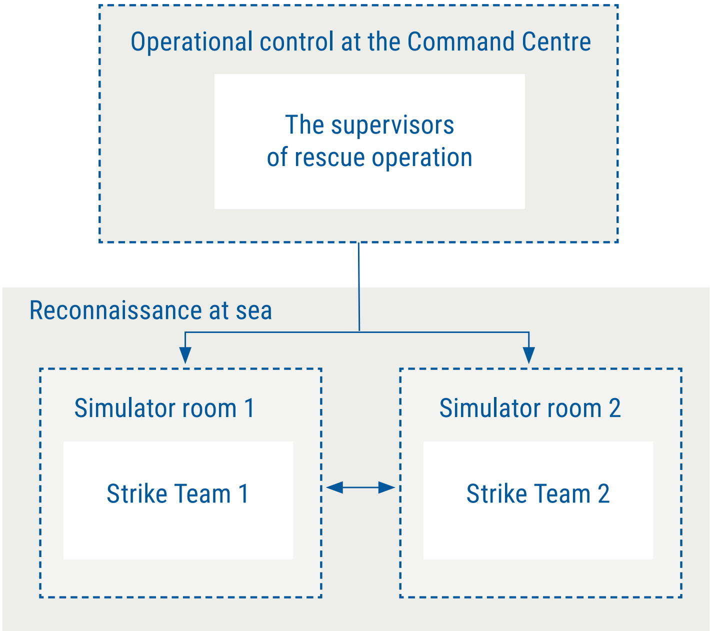


**Figure 1. The setup of exercise 1.**

## 5.3. The formation of situational awareness during a crisis response operation

A novel systemic framework for the operational decision-making in a crisis captures the iterative situational awareness creation – sensemaking – decision-making – Execution (action) cycle (Fig. 2). It is seen as a continuous cycle of elements and processes that begin with a stimulus, for instance an emergency call of an incident, in the physical domain. To be able to react on the emergency call (e.g. to request response agencies or response measures), the first phase is to gather more data about the situation, i.e. to start creating awareness. To update the situational picture, data have to be used and integrated to form an updated picture of the situation. Situational awareness is defined by involving the perceived data about the incident and the prevailing circumstances around it, interpreting and understanding the acquired data and then using these to predict possible future states (Endsley, 1995). Thus, situational awareness is part of the information and cognitive domains.

To form a shared situational awareness, data and information need to be communicated within and between the agencies. The shared situational awareness and understanding of the overall oil spill response implementation are important to assure effective cooperative crisis management. However, the formation of situational awareness is often hampered in multi-agent crisis cooperation due to different norms and practices, roles of the rescue agents and educational and cultural backgrounds (e.g. Mendonça et al., 2007; Eide et al., 2012; Seppänen et al., 2013). It must be noted though that not all information is supposed to be shared among every agent (Endsley and Robertson, 2000). For instance, the operational leaders should have a full picture of the situation such that they are able to lead the response operation effectively. Therefore, the information that is shared must be relevant to the tasks and roles of the agents.

In the next step, the received information is sorted out in the light of the agents' prior knowledge and mental models in order to interpret the information and think about what could be done next (in the phases of sensemaking and decision-making). However, it is often the case that additional information is needed in order to evaluate the options and make the final decisions. In this case, it might be necessary to return back to the creation of situational awareness. Then, after the decision-making, the action is taking place in the physical domain and the observations of its effects on the situation provide a stimulus that starts a new situational awareness creation – sensemaking – decision-making – Execution (action) cycle.

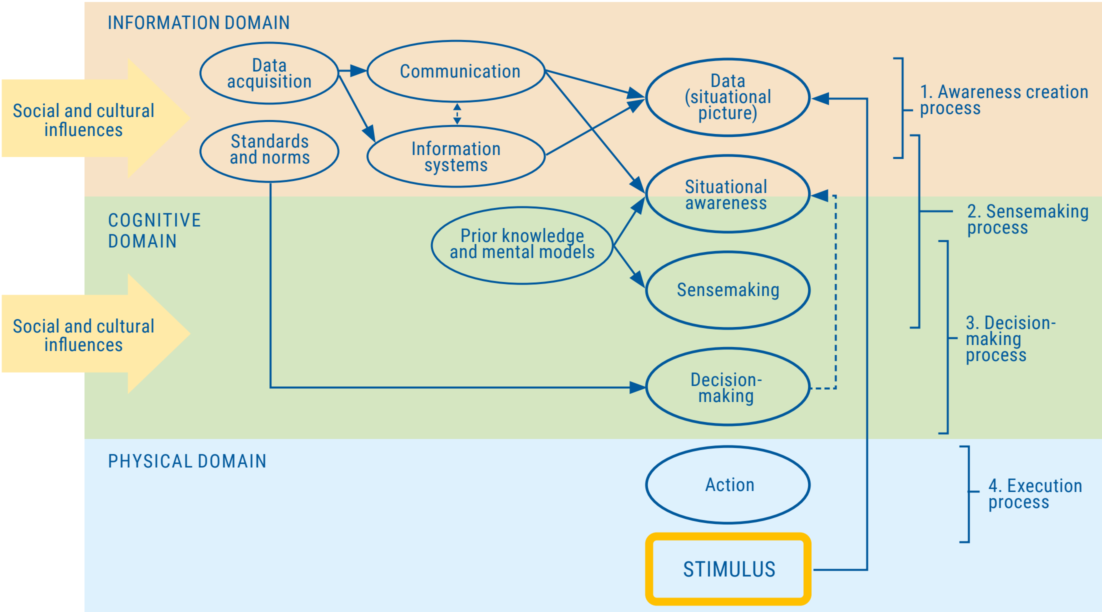


**Figure 2. Framework for a decision-making process during oil spill response management. The main phases are awareness creation, sensemaking, decision-making and execution. The elements in the physical domain = Blue nodes; The elements in the information domain = Orange nodes; The elements in the cognitive domain = The green nodes.**

More detailed information of the formation of situational awareness and the literature analysis of the iterative situational awareness creation – sensemaking – decision-making – action cycle phases can be found in Laurila-Pant et al. (a submitted scientific manuscript).

## 5.4. A protocol to monitor and analyse multi-agent cooperation during crisis simulations

Based on the framework (Fig. 2) and the knowledge gained through the iterative research process, we constructed a protocol comprising questions and aspects to be considered when aiming to analyse and improve a multi-agent crisis simulation exercise. The protocol with questions and relevant aspects to be monitored is presented comprehensively in Laurila-Pant et al. (a submitted scientific manuscript).

In this study, we used the protocol and the selected predefined questions while planning what we should specifically look for during the training event. The protocol contains four different themes (Table 1; Awareness creation, Sensemaking and decision-making, Execution of the actions and Background information on social and cultural factors). Each of these themes comprises three parts: A) the general analytical questions of interest, B) the defined questions to support the analysis of the participants' behaviour during the exercise, and C) aspects to be discussed further with the participants in debriefing sessions. The background information on social and cultural factors refers to the social and cultural influences (e.g. culture, traditions, experiences, educational background) in Figure 2. The questions related to these aspects can be asked using various questionnaires and/or interviews.

**Table 1. Illustration of the protocol with the four themes and the questions and aspects concerning each theme.**

| | General analytical questions | Monitoring during the simulation scenario | Debriefing after the simulation scenario |
|---|---|---|---|
| Theme 1: Awareness creation in the information domain | *Example: What data are acquired and how are the data integrated to create the situational picture?* | *Example: What data are acquired and how?; What sources, platforms and tools are used to acquire data and by whom?* | *Example: How well the participants think they performed with the data acquisition (1) as individuals and (2) as a team?; What challenges did they experience and how the challenges could be addressed?* |
| Theme 2: Sensemaking and decision-making phases in the cognitive domain | | | |
| Theme 3: Execution of the actions in the physical domain | | | |
| Theme 4: Background information on social and cultural factors | | | |

## 5.5. Data collection and analysis

In the training event, we had a total of five analysts (one to two analyst in each of the simulator rooms and at the CC) who monitored and took notes from the observations during the exercise and the debriefing session based on the questions selected from the protocol. After the exercise day, we organized a follow-up interview where one of the analysts (M.L-P) interviewed two of the rescue agents who participated in the training event. The topic of the interview was to find out participants' earlier experience in simulators and oil spill training, thoughts about the exercise, opinion about how the training day/event went (e.g. data acquisition, communication, situational awareness) and ideas to developed and improve future simulator training. In addition to these, the entire exercise, the debriefing session and the follow-up interview were recorded.

The observation and the transcribed interview notes were analysed using the content analysis method (e.g., Bengtsson, 2016) and coded using the element and processes introduced in the framework for operational decision-making process (Fig. 2). As the theme of the exercise 1 was the reconnaissance and information sharing to locate the oil spill, we especially focused on the communication between the participants and the creation of the shared SA. In the beginning of the analysis process, the transcriptions of the interviews and observation notes were read multiple times in order to attain a complete picture of the content and the exercise. Secondly, to capture the key elements and processes of the events and activities of the participants, the transcriptions were read again, and important sentences or phrases from the text were coded with respect to the research questions and the colour coding using the element and processes introduced in the framework (Fig. 2). In the following sections, we provide the results and analysis of the oil spill simulation exercise.

## 5.6. Analysing the oil spill simulation exercise - The formation of situational awareness during the exercise

The overall aim was to monitor and analyse how the operational control forms an accurate situational awareness of the oil spill (the location, shape and size) based on the information provided by the strike teams. In this section, we explain the key steps of the exercise to create situational awareness in the CC (Fig. 3). In the text, the key elements of the framework (nodes in the Figure 2) are marked in bold.

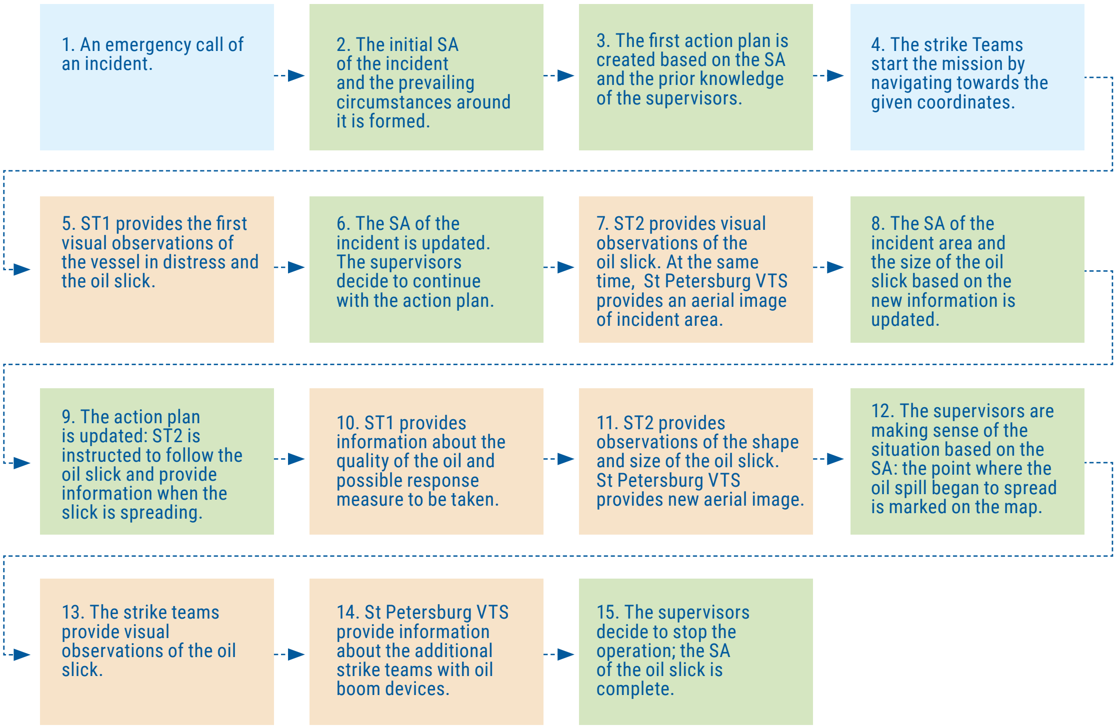


**Figure 3. Illustrating the main steps of creating the complete situational awareness at the Command Centre during the exercise. The colours indicate the elements of the framework for the decision-making process in figure 2. The elements in the physical domain = Blue nodes; The elements in the information domain = Orange nodes; The elements in the cognitive domain = The green nodes. SA = situational awareness, ST = strike team, VTS = vessel traffic services.**

At the beginning of exercise 1, participants were informed of a ship in distress that was leaking oil. First, the operational control of the exercise began to form a **situational awareness** of the overall situation based on the initial **data (situational picture)** about the incident, the resource availability (the number of rescue vessels), and the weather information (step 1 in Fig. 3). The operational control started the **sensemaking** process by using his own **prior knowledge and mental models** and thus, created the first action plan, i.e. how to proceed. At this point, the operational control examined the electronic and printed maps. As there were two strike teams, the operational control decided to send them in two different directions to attain a good overall **situational awareness** of the oil spill.

The creation of awareness is a continuous process during the operation. During the exercise, the **data acquisition** of the strike teams included examining the electronic maps and reading coordinates, using maritime monitoring and tracking with satellite data, communication channels (radio), and making visual observations (e.g. the incident, oil slick and the other rescue vessel). Whereas the operational control used for data acquisition both electronic and printed maps, weather forecast and additionally maritime monitoring and tracking with satellite data and communication channels (radio). For the exercise, it was also simulated that the St Petersburg VTS contacted the operational control and provided two aerial images and, at the end of the exercise, also information of the additional rescue vessels. Thus, all the participants, and especially the operational control, constantly updated their **situational awareness** and the following action plan when new **data (situational picture)** were received. To integrate and process the **acquired data**, both the operational control and the strike teams were using paper and pen to write down notes, coordinates and observations. To update the overall **situational awareness**, the operational control drew the coordinates (observations by the strike teams) on the map. Therefore, the printed map represented the **information systems** that were the platform to integrate and process information. However, this was only visible to those participants who were at the CC.

**Communication** had an important role in the whole exercise as it included requesting and providing information and knowledge as well as sharing the cognitive processes of the participants. **Communication** from the operational control to the strike teams included instructions and commands (e.g. decisions on which direction they should go, what observations they should provide, and what response measures should be done). The operational control also requested additional information and observations from the agents to update the **situational picture**. When the strike teams contacted and communicated directly with the operational control, they either provided observations and data or requested their next task. **Communication** also occurred directly between the two the strike seams when the teams were close to each other and one of the teams announced that they were passing close to the other vessel. With this **communication**, they aimed to increase safety and reduce any possibility of a collision. The primary **communication** took place over VHF radio connection that was used between the strike teams and the operational control. As only one radio channel was used during the exercise, all the participants heard each other's conversations and were thus aware of the events. The participants were using a certain protocol for **communication** (i.e. how to respond and discuss in the radio) which helped to get the message across. If the **communication** was not clear, the person was asked to repeat the message. The long coordinates were especially difficult to record at once and some mistakes were noticed during the exercise. The operational control discussed the acquired **data (situational picture)**, the **situational awareness**, and the **sensemaking** process with the facilitator of the exercise and other colleagues who were at the CC.

As the operational control was constantly receiving new information, the **situational awareness** and the action plan also had to be updated based on these. He was using the electronic and paper maps to locate where the accident occurred and where the strike teams were. In the **sensemaking** and **decision-making** phases, the relevance of the acquired data and information were evaluated in the light of the experience and **prior knowledge** of the operational control. When the strike teams were observing the oil slick, they were simultaneously **making sense** of what they saw, as they tried to reflect their observations to their past experiences and **prior knowledge**, e.g. trying to find out whether the detected oil slick is the main slick or a thin film. However, the visual representation of the virtual simulator is not accurate, as one cannot go out to take a closer look at the spill. They cannot smell the oil spill either, and, thus, odour detection cannot be made. During **sensemaking** and **decision-making**, the leader often requested additional information from the strike teams to assess the selection between options and the optimal decision. The discussions of alternative options for acting, i.e. joint **sensemaking,** occurred at the CC. The operational control discussed the updated action plan (e.g. where to send the vessel after the oil slick has been reached) with the agents at the CC. The strike teams were not involved in the discussions about the alternative options. However, the operational control asked one of the strike teams to decide the possible response measures to prevent the spread of the oil. The operational control monitored how the executed **actions** were implemented by following the strike teams on the electronic map and asking for interim information and observations from them. For example, during an exercise, the operational control noticed that one of the strike team was going in the wrong direction and asked for clarification on the matter. At this point, it was noticed that the coordinates had been entered incorrectly. At the end of the exercise, the operational control made a decision on when the **situational awareness** of the oil spill was accurate enough and the exercise could be successfully completed.

## 5.7. Discussion

In this study, we used the developed analysis protocol to recognize the role and importance of individual and shared situational awareness to implement successful decisions and actions during an oil spill simulator exercise. The protocol offered a guide to focus on the main processes in emergency and crisis decision-making and provided steps to monitor the performance of the participants who were attending the oil spill response exercise. We observed and captured how the participants operate and communicate to form individual and joint situational awareness, and what challenges can be encountered especially when training in a simulator environment. During the observation, it became clear that communication and coordination of information exchange played an important part in the successful implementation of this exercise. The participants were using a specific protocol for communication that helped to get the message across and to form an accurate situational awareness of the incident. At the end of the exercise, the participants also felt that they had a consensus and a shared understanding of the situation.

The pre-briefing phase of the simulation training is important as it provides the participants with information about the particular scenario that they are about to join and about their roles and the roles of the other participants. When these are clear, everyone can orient themselves to their own roles and focus on the tasks related to them. When planning the training and the division of roles, it is also important to think about the optimal number of participants for each exercise scenario so that the division of tasks is as realistic as possible and that each participant can focus on their own responsibilities.  At the beginning of the exercise, it is also important to reserve enough time to learn how to use the simulators, get to know the functions they offer and the visual presentation. During the exercise scenario, it was noted that the visual representation of the oil in the simulator was to some extent different than in the real situation. Thus, the participants' own prior knowledge or expertise to detect oil failed as the virtual simulator view (i.e., how the oil looked in the simulator) did not match this. Thus, these type of challenges or errors should also be taken into account when analysing the performance of the participants and the overall result of the exercise. In a real oil spill response situation, agents could smell the oil and feel the wind and other factors that have an effect on making observations together with the visual observations. As said, in the presented reconnaissance exercise, communication between the three units had a key role. It was discussed that in a larger scale multi-vessel operation, there would probably be an intermediate level group leader who would have 1-3 response vessels to manage. This group leader would communicate directly to the command centre. The vessel units would also communicate with each other. The response vessels behind one group leader perform some specific task together, in which case these ships may also communicate directly with each other. Therefore, in this type of large-scale exercise, there would be more communication levels, and, in this case, it should be monitored how communication takes place on all these levels and between them.

During the debriefing discussion, virtual simulators were found to be very useful and a cost- and time-effective alternative for the field trainings by the participants (learners). When organizing a field exercise at sea, starting up the exercise takes a lot of time (e.g. moving the boats to the exercise area), and it is also possible for boats and other equipment to break down or get damaged during the operation. Thus, the virtual simulator as a training environment was found to be very useful and flexible as the theme and length of an exercise can range from a small-scale task exercise (e.g., use of oil booms, vessel manoeuvring, communication) to complete operational oil spill response exercises following the response manuals, such as the SÖKÖ (Halonen, 2021) and HELCOM Response Manual (HELCOM, 2021). It was also discussed that Internet-based information system (i.e. situational awareness system) tools could be part of the trainings, as they would allow for instance the management of the operation to practice how to forecast the spreading of the oil and thus help in making sense of the situation. These information systems that provide real-time, spatiotemporal information are especially important in multi-agent oil spill response cooperation efforts to support the formation of shared situational awareness and the following decision-making (Seppänen and Virrantaus, 2010; Seppänen et al., 2013). An example of this is the Marine Environment Response Tool (MERT) of the Finnish Border Guard that was put into operational use in June 2022. It was discussed that the new tools (e.g. information systems) are useful and the cornerstones of effective communication, but there are some risks associated with using them as well. For example, these tools may be relied on too much or their use has not been learned well enough.

The feedback also revealed that the simulator environment together with the debriefing discussion provided the participants in the exercise with a good overall picture of the exercise, the events during it and what the other participants were doing. In the field exercises, participants can be very strongly focused only on their own tasks. When training with simulators, participants also get to try different functions and techniques more freely and make deliberate mistakes and see how it would turn out. As simulators from different locations can be connected, agencies can participate remotely in the joint exercises. Thus, the training organised in a simulator environment connecting the different simulator centres together opens up new opportunities for joint remote exercises. In situations when face-to-face field training activities are not possible, as for instance during the COVID-19 pandemic, this could help to meet statutory training obligations.

### The user guide for the protocol - How to use the protocol

**Step 1: Becoming familiar with the concept.** The first step in using the protocol during an acute oil response exercise is for exercisae facilitators and analysts to familiarize themselves with the decision-making processes of the emergency and crisis framework (see Section 3 and Fig. 2). This provides a useful and similar knowledge base for exercise facilitators and analysts when planning observation and analysis.

**Step 2: Defining the key questions and aspects to be monitored and analysed.** Based on the concrete learning objectives and the scope of the exercise (see Chapter 3), the next step is to acknowledge the key aspects to be monitored and analysed and to select the questions from the protocol that should be considered in this exercise. At this point it is useful to review challenges or notes that have emerged from the previous exercises. These can help to structure and plan the next exercise, as well as plan its monitoring and analysis.

**Step 3: Planning the data collection.** Once the objectives and aspects to be analysed are determined, a strategy plan for collecting the appropriate data is created. A key part of the data collection plan is to determine which type of data is needed (e.g. a descriptive understanding of people's behaviour or actions during a specific situation, specific observations related to the predefined questions). The data collection plan should cover each stage of the training: introduction and pre-exercise briefing, simulated exercise scenarios and debriefing. A mixture of qualitative data collection methods such as notes from observations (e.g. a timeline of events, list of key decisions or actions, marking down the communication between the participants), documents, self-report questionnaires and interviews are effective. This type of qualitative data is in forms of text, images and audio or video recordings.

**Step 4: Collecting the data.** During each stage of the training, a minimum one analyst and/or exercise facilitator in each room and/or location is needed to mark down the observations. Knowing in advance the script for the simulation scenario makes it easier to take notes. Video or audio recordings are useful to track down the discussions during the pre-exercise briefing, simulated exercise scenarios and debriefing exercise. During the debriefing, analysts or exercise facilitators lead the discussions by identifying important events and decisions. To cover the predefined research objective, they can have a list of predefined questions to be discussed with the active participants. Open discussion between all the participants is important at this stage. Some virtual simulators allow to replay events from the exercise. This can be used to illustrate to the participants how the exercise went. Follow-up interviews can be held to clarify issues that came up during the exercises or to provide. In case the socio-cultural background aspects (e.g. educational background, the level of experience, organizational culture) are important for the analysis, pre- and / or post-training surveys are recommendable to conduct.

**Step 5: The results of the analysis.** The type of the data analysis largely depends on what type of data have been collected and what the goal of the analysis is. The analysis should refer to the defined objectives and aspects to be analysed. It is important to document the participants' reasoning and practices, as well as the challenges they face. The result of the analysis can then support the development of the preparedness exercises and further on to improve the future real oil spill response competence.

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# 6 | SYNTHESIS: A ROADMAP FOR DESIGNING EFFECTIVE SIMULATOR-BASED OIL SPILL RESPONSE TRAININGS FOR IMPROVED PERFORMANCE, PREPAREDNESS, AND SOCIETAL RESILIENCE

Maritime traffic and the related oil accident risk landscape in the Baltic Sea are currently (in late 2022) undergoing numerous changes. Due to the war in Ukraine, environmental cooperation with Russia has ceased. The tense atmosphere increases the activity of military vessels, and harassment and disturbance of different forms has become the new normal. This undermines both the safety and security at sea. The trade sanctions against Russia affect the maritime traffic flows and the shipping routes used and, consequently, the ship distribution in different parts of the sea, changing the oil accident proneness of different areas. In addition, the continuing COVID-19 pandemic has corresponding impacts. National and EU-level climate goals and the subsequent regulation to reduce carbon dioxide and other greenhouse gas emissions are already affecting cargo flows, increasing automation, and bringing new types of fuels and vessels. Under the circumstances, there is a clear need to update the situational picture concerning potential oil accidents – their probabilities and likely consequences in different parts of the Baltic Sea – and re-evaluate the adequate joint preparedness level of the coastal countries in light of that picture.

If a major oil spill materializes on the Baltic Sea, it is of utmost importance that different actors can, both nationally and internationally, join their forces and react fast and effectively to minimize its negative impacts to people and environment. Successful implementation of such complex multi-organizational processes under heavy time pressure requires frequent joint exercises and training. As demonstrated in Chapter 2, based on the Retos assessment concerning the level of oil spill response planning and readiness management, exercising and training seem to be among the weakest aspects in almost all the Baltic countries.

Today's bridge simulators can provide relatively realistic experiences of operating on divergent vessels under varying circumstances. The in-water behaviour of oil and oil booms, given the prevailing environmental conditions, are logically represented by the simulators as well, and the vessels can operate together, interacting with each other. Combined with the use of the communication technology and operational tools applied in real oil spill operations, the bridge simulators seem to provide an effective, cost-effective, and safe environment for testing and practising various tasks related to oil spill management. The fully controllable laboratory-like environment enables repeated tries and experimentation, as well as the profound examination of the learners' behaviour and choices (Chapter 5). All this creates an excellent basis for the creation and long-term development of tailor-made spot-on training programmes for various teams (see Chapter 3).

Applied complementarily to authentic on-board exercises with real vessels, we see the simulator-based rehearsals bearing strong potential for improving the preparedness level of the Baltic Sea countries, improving societal resilience against oil accidents. Based on the lessons learned during the project SIMREC, we here list our *key recommendations for future bridge simulator-based oil spill response trainings*, especially in the Baltic Sea area, crossing both organizational and national borders. Figure 1 summarizes the recommendations to a *visual framework for designing effective simulator-based oil spill response exercises*.

## Recommendations

1. Careful analysis of *training needs* enables the design of efficient and impactful simulator exercises, as it creates a basis for the task of defining the *learning objectives*. Surveys, such as the Retos assessment on different aspects of preparedness (Chapter 2), and Likert-scaled assessments of the key training needs (Chapter 3) provide useful insights in how the operators of different levels see the areas of improvement and educational needs. Notes on progress and challenges from previous exercises also serve as a good basis for setting training needs for future exercises (Chapter 5).

2. All aspects of the simulator exercises should be realistic and carefully designed. A realistic and coherent *cover story* behind the exercise enables the learning of truly relevant skills. In a realistic and coherent story, the skills to be learned are naturally called for when the learners are pursuing the defined objective. A plausible cover story also increases the motivation and commitment of the learners. The key elements of a plausible cover story are (a) a realistic physical *scenario*, including the parameters of the oil spill and environmental conditions, (b) realistic or real *tools* used during the operation, (c) realistic *roles* of the individual learners, and (d) a realistic operative *team*. (Chapter 3) The elements (a – d) are interdependent. For example, the relevant team depends on the location of the spill, as well as the learn-

ing objectives. On the other hand, if a spill scenario creates the starting point for a training to be designed, it defines the relevant team, roles, and tools (see figure 1).

3. *Modelling* and *data analytics* can support the construction of plausible and realistic scenarios to be simulated. A physical oil accident scenario consists of such settings of the spill as the spill location and drifting, spilled oil type and volume, and the prevailing weather conditions. Additional simulation elements to enrich the simulator capability, such as new geographical areas, vessels etc. require investments, and accident modelling can also help with choosing the objects to be prioritized. (Chapter 4)

4. The use of *real-life tools* for the acquisition and interpretation of data and for communication during the simulated oil spill operation ensure the learners will face realistic situations and thus learn skills that are most likely useful in potential real operations. (Chapters 3 and 5)

5. Realistic individual *roles*, corresponding to the real-life tasks and responsibilities of each learner in an actual oil spill operation, increase the motivation and commitment of the learners and ensure they will learn relevant skills. (Chapter 3)

6. An authentic simulation setup when it comes to the organizations and teams involved and collaborating in corresponding real-life operations is recommendable, to allow the operators to learn about each other's tasks and viewpoints, and ways of thinking, operating, and communicating. The joint exercises in a safe and fully controllable simulator environment provide circumstances where the groups can pay attention to developing their joint communication and other joint practices. This will remarkably advance the effective creation of shared situational awareness in a real situation. Debriefing sessions provide the key forum for the exchange of experiences, questions, and ideas. (Chapters 3 and 5)

7. The oil spill scenarios to be simulated in a training, as well as the geographical location of the learners, create various technical requirements for the simulator centres. Fluent connectivity, compatible software with the added functionalities (e.g. oil spills and ice) required by specific scenarios, and shared object models and environments should be ensured in the early stages when designing inter-centre joint trainings over the European Maritime Simulator Network (EMSN) (Chapter 3). If these aspects were to be actively developed and invested in, the bridge simu-

lator stock of the Baltic Sea region could in the future be utilized more comprehensively to organize regular international large scale oil spill response rehearsals, for example to complement the yearly Balex Delta exercises. This would also create a back-up system for situations such as the COVID-19 pandemic, where live field training activities are not possible, ensuring that preparedness can be maintained and developed in emergency conditions as well.

8. An important part of training programs and their continuum is monitoring and iterative learning – not only by oil spill operators, but also by training organizers. Carefully planned monitoring protocols help to identify the future training needs, identifying weak points through observation and follow-up (Chapter 5). In addition, observing and analysing the exercises can provide valuable information on what other things (besides training) should be invested in and prioritised to optimally develop oil spill response readiness. For example, the results can support such investment decisions as whether to develop new tools for communication or data acquisition, or whether to invest in new booms or other oil recovery equipment.

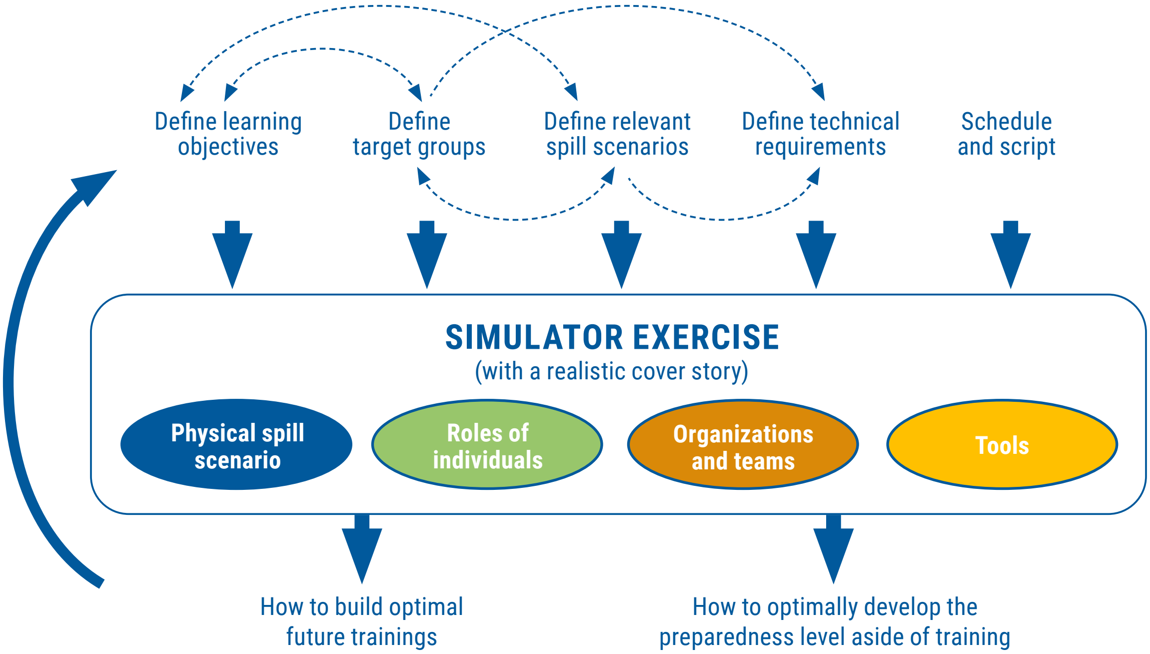


**Figure 1. The visualized SIMREC framework for designing effective simulator-based oil spill response exercises for improved performance, preparedness, and societal resilience. For explanation, see the text.**


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