European Maritime Safety Agency

EMSATOIL
Part 1

Feasibility study for the development of a software tool to support Member States on oil pollution response operations at sea

Final Report

Date of publication: 28 July 2023

Report prepared for the European Maritime Safety Agency under contract number 2021/EMSA/NEG/5/2021 by the Environmental Hydraulics Institute of Cantabria (IHCantabria)

EMSA

Document History

Version	Date	Changes	Prepared	Approved
3.0	15/06/2022	■ Integration of minor comments provided by EMSA to the 2.0 version of the interim report.	IHCantabria	
3.1	18/10/2022	■ Integration of minor comments provided by EMSA.	IHCantabria	
Final Report	17/11/2022	■ Integration of minor comments, division of chapter 4 into two parts, renaming of chapter 4, creation of a new chapter 5, renumbering of existing chapters 5, 6 and 7.	IHCantabria	

In December 2021, the Environmental Hydraulics Institute of Cantabria (IHCantabria) was awarded the European Maritime Safety Agency (EMSA) contract 2021/EMSA/NEG/5/2021, call for *"A feasibility study for the development of a software tool to Support Member States on oil pollution response operations at sea".* In the framework of this contract, IHCantabria will evaluate the feasibility of the development of an enhanced IT tool and will define its functional and technical requirements. To achieve this objective, the scope of the work is divided into two parts:

- Part 1: gathering of information to fully understand the functional aspects of the tool and its limitations.
- Part 2: proposal for options for the definition of the functional, non-functional and technical requirements of the tool.

This document presents the work carried out to fully understand the functional aspects of the tool and its limitations (Part 1).

Document Summary

EMSA is currently exploring the feasibility to develop an IT tool, hereinafter referred to as system, to support Member States in their preparedness and operational decision-making process of mobilizing and deploying oil pollution response resources at sea. The main goal of this project is to gather information on existing tools to evaluate the feasibility of the development of an enhanced IT system and to define its functional and technical requirements. As mentioned above, the work is divided into two parts (Part 1 and Part 2). This document is the final report referring to Part 1 of the deliverables: gathering information to fully understand the functional aspects of the system and its limitations.

To achieve these objectives, this document is focused on the following analysis:

- review and assessment on oil spill models (Section 3);
- review and assessment on the response simulator to calculate the efficiency of oil response operations at sea (Sections 4 and 5);
- review and assessment on the met ocean and observational data to be used in the new system (Section 6) and
- review and assessment on the databases of the new system (resources/equipment and oil database) presented in Section 7.

Section 1 englobes the objectives, scope, and structure of the document whilst Section 2 provides the general overview of the new system.

Regarding oil spill modelling, Section 3 presents an extensive review of the most relevant state-of-the-art oil spill models (see Sections 3.1and 3.2). The model's comparison has been carried out in terms of, inter alia, their capacity to simulate the physical processes affecting the oil spill, their scientific and technological quality, and their applicability in the EU Member States. The models selected and analysed in this section are 3D state-of-the-art models that compute the most important transport and weathering processes affecting the oil spill at sea. They have all been published in scientific journals, assuring the scientific quality of the model, and have also been validated and applied in real cases. Therefore, the analysed models are suitable to be integrated into the new system. However, since there is unknown information regarding non-public models, the feasibility for the integration has to be confirmed with the software proprietary. Following this review, the minimal requirements of the oil spill model to be suitable for the development of the new system are summarized. Subsequently, this section also identifies and assesses options to provide data from different sources to the system, such as data from third-party oil spill models, the location of the oil spill based on observations from aerial, satellite, or RPAS images, and the possibility of integrating different GIS layers (see Sections 3.3, 3.4 and 3.6). Finally, this section analyses and provides options to calibrate the model using real data from observations (see Section 3.5).

Once the oil spill models were analysed, Section 4 focused on the assessment of the simulator to calculate the efficiency of oil spill response operations at sea. Firstly, an overview of the relevant aspects that influence the oil spill operations is carried out (see Section 4.1), taking into account the basic response techniques, the phases of the response, the factors that influence the operability of the operations, and the agents affecting the efficiency of the recovery. Subsequently, a review of the most important and well-documented response calculators has been carried out, mainly focused on the comparison between Response Operations Calculator (ROC) used by NOAA and Response Calculator (RC), developed by RPS for EMSA. This analysis allowed us to identify the following potential improvements for the future new system:

- modelling the oil spill in a more realistic approach, considering for example, the dynamic evolution of the slicks and the simulation of multiple independent slicks.
- implementation of the encounter rate for the estimation of the recovery performance;
- applying recovery rate reductions due to adverse weather conditions based on hourly weather forecasts provided by the European met ocean forecasting systems
- implementation of a daily operability assessment and estimation of the window of opportunity based on the aforementioned weather forecast systems and the oil weathering provided by oil spill numerical models.

Based on this analysis and on the exchanges of information provided by EMSA, Section 5 presents the new methodology proposed for the new Response Simulator (RS), which is based on the following steps:

- <u>Step 0</u> – Assignation of resources to support the user on the selection of the most adequate assets to be used.

- Step 1 – Operability assessment to check if response operations are feasible and estimation of the window of opportunity, based on the weather conditions and the oil properties (weathering).
- Step 2 – Calculate hourly recovery rates for that specific working day. Total Fluid Recovery Rate (TFRR) and the Oil/Emulsion Recovery Rate (ORR) will be calculated based on a new methodology proposed for mechanical recovery response. This new estimation, described in Section 5.3, is one of the main contributions of this analysis to improve the accuracy of the future Response Simulator.
- Step 3 – Schedule recovery operations for that specific working day. Once hourly recovery estimation is calculated, it is possible to define the schedule of the recovery operations, usually defined in blocks of transit – recovery – transit – unload.
- Step 4 – Summarize results for the simulation time horizon. The results provided by the RS will be: the amount of oil removed/dispersed/burned, the Gantt chart for the schedule of the operations, and the total cost for a set response strategy.

Once proposed the general overview of the methodology for the Response Simulator, the following sections analyse the different elements of the methodology. First, the options for pairing stand-alone equipment with adequate vessels are analysed in Section 5.1. Secondly, the aspects that influence the operability assessment and the window of opportunity are discussed in Section 5.2. Next, the aspects that influence the efficiency of the mechanical recovery and the options for capturing the encounter rate of the response asset with the oil slick are presented in Section 5.3 and Section 5.4.Subsequently, the technical and logistic aspects associated with the deployment of response assets at sea are analysed in Section 5.5. Finally, the options of the integration in the simulator's calculations the changes in time to the surface oil, as well as the feasibility of having the simulator GIS based are discussed in Sections 5.6 and 5.7, respectively.

Once the oil spill models and the response simulator were reviewed, Section 6 analyses external sources to provide the geospatial (e.g. bathymetry, coastline), met ocean (e.g. wind, waves, currents), in-situ instrumental measurements, and the satellite providers that will be required by the new system. On one hand, this section provides the relevant environmental data parameters needed for the oil spill model and the simulator as well as a prioritization according to their relevance to the models (see Section 6.1). On the other hand, the potential sources and the potential exchange mechanism from the source to the future system are assessed in Section 6.2. Furthermore, the possibility of integrating in the system the impact of coastal environmental data and real time met ocean data is analyzed in Sections 6.4 and 6.5. Finally, Section 7 focuses on the integration of the databases of the future system, specifically, the resources and equipment database and the oil properties database.

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List of Abbreviations

ADIOS	Automated Data Inquiry for Oil Spills
API	Application Programming Interface
BE	Belgium
BG	Bulgaria
CF-conventions	Climate and Forecast Metadata Conventions
CMEMS	Copernicus Marine Environment Monitoring Service
DAS	Dispersant Application System
DE	Germany
Dir	Wave mean direction
DK	Denmark
DWD	Deutscher Wetterdienst (Germany's National Meteorological Service)
ECMWF	European Centre for Medium-Range Weather Forecasts
EMODnet	European Marine Observation and Data Network
EMSA	European Maritime Safety Agency
EnR	Encounter Rate
ER	Encounter Rate
ERPS	Estimated Recovery System Potencial Calculator
ETL	Extract, Transform & Load
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
FIN	Finland
FR	France
GEBCO	General Bathymetric Chart of the Oceans
GFS	Global Forecast System
GIS	Geographic Information System
GNOME	General NOAA Operational Modelling Environment
GSHHG	Global Self-consistent, Hierarchical, High-resolution Geography Database
GTSM	Global Tide Surge Model
HF Radar	High Frequency Radar
Hs	Significant wave height
INSPIRE	Infrastructure for Spatial Information in the European Community
IRL	Ireland
IT	Italy
LAT	Lowest Astronomical Tide
MFS	Mediterranean Forecasting System
MHW	Mean-High-Water

MOR	Mechanical Oil Recovery
MS	Member State
MSI	Multispectral Instrument
MSL	Mean-Sea-Level
NetCDF	Network Common Data Form
NL	Netherlands
NOAA	National Oceanic and Atmospheric Administration
NOAA NOMADS	NOAA Operational Model Archive and Distribution System
NP	Nominal Plate Capacity
NP	Nominal Plate Capacity
ORR	Oil/Emulsion Recovery Rate
OSM	Oil Spill Model
OSRV	Oil Spill Recovery Vessel
RC	Response Calculator
RE	Recovery Efficiency
RO	Romania
ROC	Response Options Calculator
RS	Response Simulator
SAR	Synthetic Aperture Radar
TFRR	Total Fluid Recovery Rate
Tp	Wave peak period
VOO	Vessel of Opportunity
WP	Work Package

1. INTRODUCTION

1.1. Objectives

EMSA is currently exploring the feasibility to develop an IT system to support Member States in their preparedness and operational decision-making process of mobilising and deploying oil pollution response resources at sea.

The main goal of the project "*Feasibility study for the development of a software tool to Support Member States on oil pollution response operations at sea*", is to gather information on existing tools, to evaluate the feasibility of the development of an enhanced system and to define its functional and technical requirements.

This feasibility study discusses to which extent EMSA's vision and desired functionalities of the tool are technically feasible. It also proposes technical solutions that EMSA may take into account in the preparation of the requirements for the procurement of services for the development of the future IT tool.

The information to be gathered and the assessment to be made within this project will enable the concrete definition of the functional, non-functional and technical requirements of the future IT tool. To achieve these objectives the work is divided into two parts:

- Part 1: gathering of information to fully understand the functional aspects of the tool and its limitations.
- Part 2: proposal for options for the definition of the functional, non-functional and technical requirements of the tool.

This document is focused on the analysis and assessment of the functional aspects of the tool and its limitations (Part 1).

1.2. Scope of the document

This document is the final report on Part 1 of the deliverables. This work has been carried out in the framework of Work Package 1, with the objective to gather information in order to fully understand the functional aspects of the tool and its limitations. To achieve this objective, the following tasks have been undertaken:

- Task 1.1. Oil spill models to estimate the trajectory, dispersion and weathering of oil spills at sea.
- Task 1.2. Simulator to calculate the efficiency of oil response operations at sea.
- Task 1.3. Met ocean data sources.
- Task 1.4. Databases of European oil pollution resources and equipment and oils transiting European waters.

1.3. Report structure

The document is organized as follows:

- Section 1 provides an introduction to the project.
- Section 2 provides a general overview of the new system.
- Section 3 presents the analysis carried out in Task 1.1.
- Sections 4 and 5 presents the analysis carried out in Task 1.2.
- Section 6 presents the analysis carried out in Task 1.3.
- Section 7 presents the analysis carried out in Task 1.4.
- Section 8 presents the reference list.

2. GENERAL OVERVIEW OF THE SYSTEM

2.1. Objective

The objective of the system required by EMSA is to support Member States in their preparedness and in the logistical and operational decision-making process of mobilizing and deploying oil pollution response equipment and resources in response to an oil spill at sea. As an added value the system is expected to provide information on the operational efficiency and the optimal use of oil pollution response resources.

To suit the needs of all EU member states, it should be flexible, allowing the integration of national sources of data (national and regional oil spill models and local environmental data sources) and allowing the modification and addition of new elements to the databases used by the future system.

The final output from the system will be presented to the user in charts and lists that the user may customize. The data should be exportable in excel format. The output of the oil spill model should be exportable, e.g. shape files and excel format.

The aim is to provide Member States with a user-friendly system allowing for quick calculation and visualization.

2.2. Functional specifications of the system

To fulfil the EMSA's requirements, it will be necessary to design and develop an IT system with the following functional specifications (see Figure 1):

- To run the Oil Spill Model (OSM) and the Response Simulator (RS). The system should be able:
  - To run oil spill simulations to predict the trajectory, dispersion, and weathering of oil spills at sea considering the met ocean conditions at the spill site. The initial oil spill location will be provided from a specific location or polygons obtained, e.g., from aerial observations, satellite images, or RPAS images.
  - To run several independent spills to take into account the division of the oil spill into several slicks.
  - To run the response simulator to estimate the amount of oil removed, dispersed, or burned from the sea surface by the deployment of oil pollution response equipment and resources. The output of the 3D oil spill model will serve as the basis for the simulator.
  - It should be flexible to import data from third-party oil spill models and to run the response simulator with this information.
- Management and visualization of external databases: earth observation, met ocean forecasting, and geospatial information.
- Management and visualization of the system databases:
  - It shall integrate a database of oils that are frequently transiting European waters. The database shall gather the physical and chemical properties of the oils required for the oil spill model.
  - It shall integrate a database of European oil pollution resources. In addition, it should be possible the integration of other regional or local sources of environmental data from EU Member States.
- Management, export, and visualization of the simulation results:
  - OSM: transport and dispersion of the oil spill, as well as, the temporal evolution of the weathering processes.
  - RS: the amount of oil removed/dispersed/burned, the Gantt chart for the schedule of the operations and the total cost for a set response strategy.

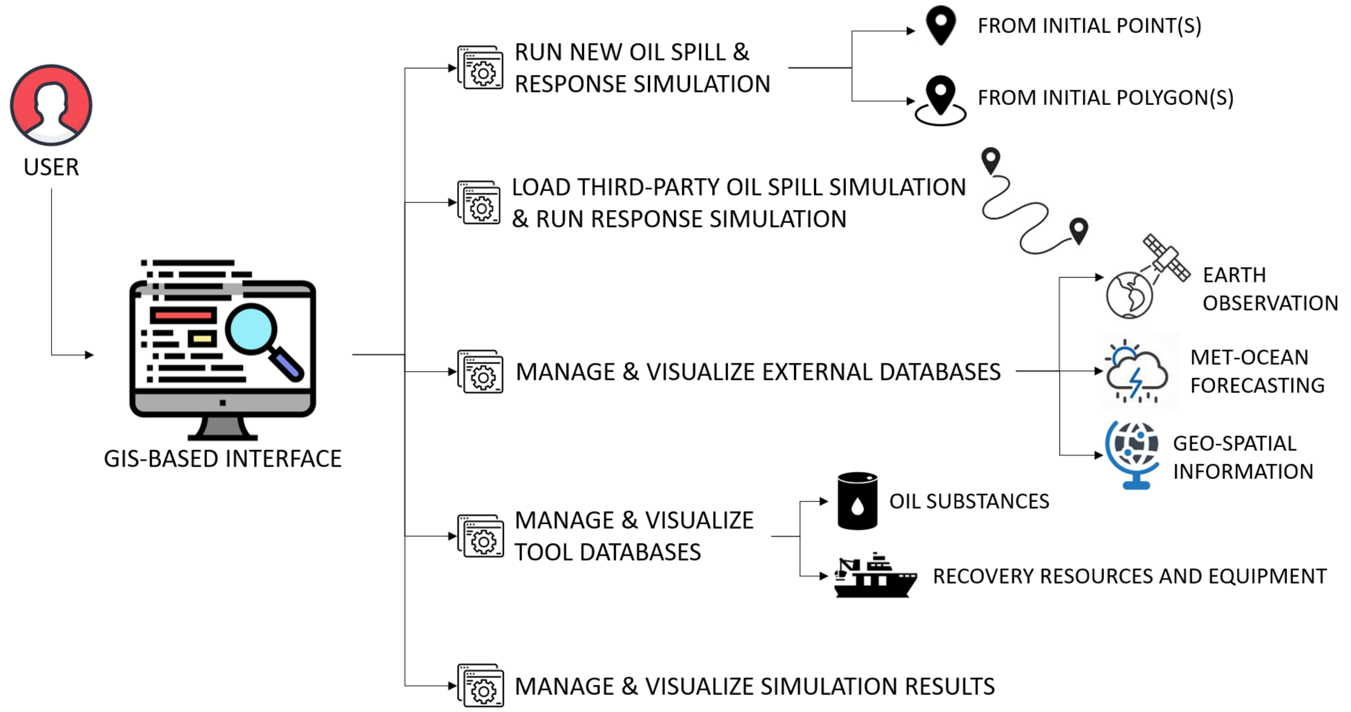

Figure 1 – General overview of the system.

3. OIL SPILL MODELS TO ESTIMATE THE TRAJECTORY, DISPERSION, AND WEATHERING OF OIL SPILLS AT SEA

3.1. General overview of oil spill models

The oil spilled into the sea is transported by a combination of winds, currents, and waves. Once the oil is spilled, it is also affected by several physicochemical processes that depend on the oil's properties and environmental conditions. Figure 2 shows the most important mechanisms affecting an oil slick in the marine environment (SINTEF, 2010). These processes are described in detail in several state-of-the-art reviews (e.g. ASCE, 1996, Spaulding, 2017; Keramea et al., 2021or https://www.itopf.org/knowledge-resources/documents-guides/fate-of-oil-spills/weathering/). According to ITOPF, there are eight main weathering processes: spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation and sinking, and biodegradation.

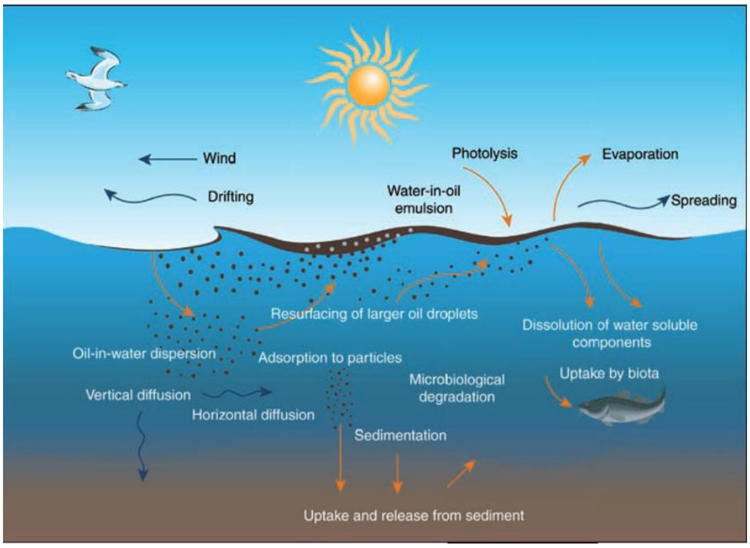

Figure 2 - Processes affecting the oil slick (SINTEF, 2010).

Most of the state-of-the-art oil spill models use Lagrangian formulation to compute oil transport (advection and dispersion) and utilise individual formulations to compute crude oil weathering processes. The Lagrangian approach involves representing oil slicks by several constituents (particles) that are transported by advection and dispersion. In a lagrangian model, the oil spill motion is computed by means of the transport induced by surface currents, wind, wave fields, and turbulent diffusion. Accordingly, to simulate the movement of an oil slick, it is assumed the transport to be composed of an advective and a diffusive velocity. The advective velocity depends on the currents and wind velocity, and the sea state. Thus, the advective velocity, $\boldsymbol{U}_a$, is calculated as the linear combination of currents, wind velocity and/or wave-induced Stokes drift, expressed as:

$$\boldsymbol{U}_a = \boldsymbol{U}_C + C_D \boldsymbol{U}_W + \boldsymbol{U}_s \quad (1)$$

where $\boldsymbol{U}_C$ is the surface current velocity; $\boldsymbol{U}_W$ is the wind velocity at a height of 10 m over the sea surface; C_D is the wind drag coefficient, usually defined as 3% of the wind speed (ASCE, 1996), and $\boldsymbol{U}_s$ is the wave-induced Stokes, expressed as (Dean and Dalrymple, 1991; Daniel, 2004):

$$U_s = \frac{gH}{8C} \quad (2)$$

or

$$U_s = \frac{2\pi^3}{g}\frac{\mathrm{H}^2}{\mathrm{T}^3}\exp(2kz) \quad (3)$$

where g is the gravitational acceleration, H is the wave height, C is the wave celerity, T is the period and k is the wave number.

The diffusive velocity ($\boldsymbol{U_d}$) depends on the sea turbulence characteristics. Usually, the latter is simulated as a Brownian motion of particles by means of a random walk procedure (e.g. Hunter, 1993), calculated for each time step (Δt) as:

$$|\boldsymbol{U}_d| = \sqrt{\frac{6D}{\Delta t}} \quad (4)$$

where D is the diffusion coefficient.

Regarding weathering, the most common processes usually included in the oil spill models are spreading, evaporation, dispersion, entrainment, evaporation, and emulsification and beaching. Other processes such as dissolution, photo-oxidation, biodegradation, and vertical mixing are less common and supported by a limited number of models (see Section 3.2 for more details).

The environmental variables required by the oil spill models will depend on the characteristics of the oil spill (e.g. surface or subsurface oil spill) and the weathering processes included in the model:

- In a surface oil spill, the slick is mainly transported by a combination of wind, waves, surface currents, and the effect of turbulence dispersion. Moreover, natural dispersion occurs when fine droplets of oil are transferred into the water column by wind and wave action, and turbulence. Weathering processes such as evaporation, emulsification, or dissolution are also influenced by met ocean conditions, e.g. wind and temperature.
- For a subsea oil spill, sea water temperature, salinity and/or density are required to take into account the oil buoyancy. Moreover, to simulate the transport of the subsea oil current velocities in the water column are also required.

Figure 3 shows a summary of the main inputs required for oil spill modelling and the main outputs provided by the models.

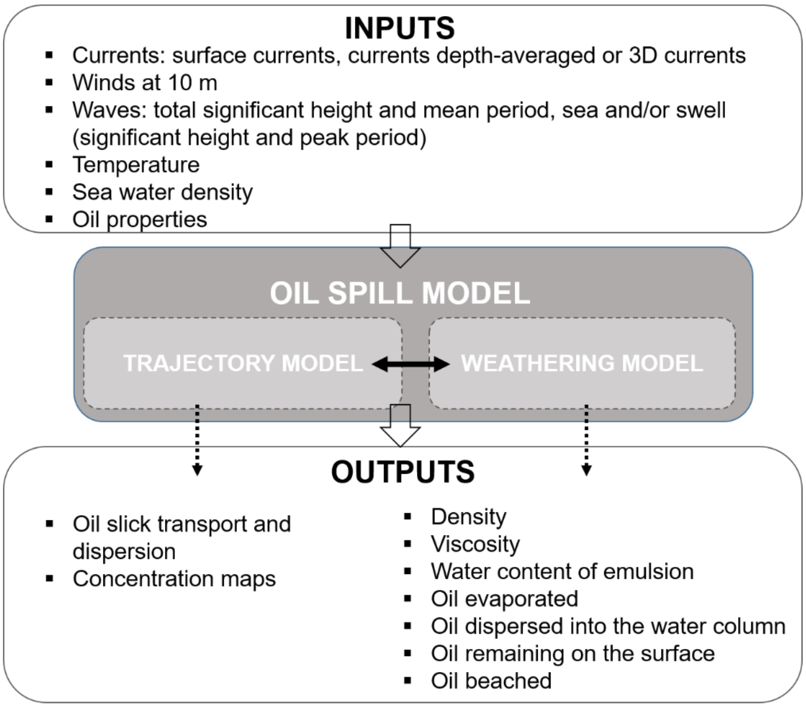

Figure 3 - Main inputs and outputs for oil spill modelling.

Although the results provided by an oil spill model will also depend on the characteristics of the oil spill and the model itself, the most common model's outputs are the following: temporal evolution of the trajectory and dispersion of the oil slick, temporal variation of density, viscosity, water content, amount of evaporated oil, oil dispersed into the water column, oil remaining on the surface and oil beached. Some models also provide the amount of total product, i.e. the amount of oil and water. As an example, Figure 4 shows the temporal variation of the emulsification of a 100 m^3 oil spill (Alvheim Blend, 2009) provided by the ADIOS model. It is worth mentioning that thickness is calculated by the majority of models, however it is not a common output provided by the models.

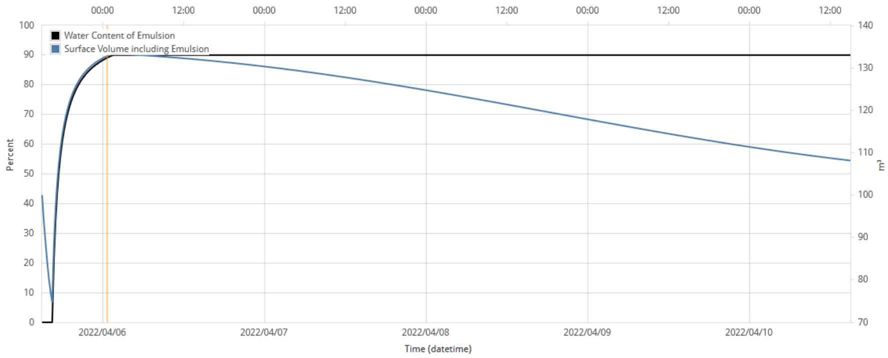

Figure 4 - Example of emulsification provided by the ADIOS model.

3.2. Review of available oil spill models

3.2.1. Selection of oil spill models

The frequency of accidental oil spills in marine environments has triggered the development of a large number of mathematical models that simulate the transport and fate of oil slicks. The characteristics of these models range from simple trajectory tracking models to three-dimensional models that simulate the oil spill trajectory taking into consideration the characteristics of oil during the weathering process.

Over the years, many EU projects have focused on the development of these models and their dissemination to end-users and the scientific community. As a result of this noticeable effort, many oil spill models used by EU Member States are well established and well documented, through scientific literature and public dissemination.

The objective of this section is to gather information on available oil spill models used in Europe and to select the most relevant for the comparative analysis carried out in Section 3.2.2. The model's selection has been based, inter alia, on their capacity to simulate the physical processes affecting the oil spill, their scientific-technological background, and their applicability in the EU Member States. The list of models provided by EMSA (see Appendix A) has also been included in the analysis.

Taking into account these criteria, the following models have been selected (see Table 1):

Table 1 - Oil spill models selection.

Name	Organization	Website	Scientific Publications	Technical manuals and project reports
TESEO	IHCantabria	https://ihcantabria.com/en/specialized-software/english-teseo/	Abascal et al., 2007; Sotillo et al., 2008; Abascal et al., 2008; 2009; 2012; Castanedo et al., 2014; Abascal et 2017a; 2017b; Chiri et al., 2020	
MOHID	MARETEC	http://www.mohid.com/	Fernandes, 2001; Fernandes et al., 2013; Janerio et al.,	http://arcopol.maretec.org/Tools/SpillSimulator/SpillSimulator_Manual.pdf

Name	Organization	Website	Scientific Publications	Technical manuals and project reports
			2014; Fernandes, 2018	
MEDSLICK-II	Several institutions (see website)	http://www.medslik-ii.org/ http://www.oceanography.ucy.ac.cy/medslik/	De Dominicis et al., 2013a,2013b; Coppini et al., 2011	
OpenDrift-OpenOil	Norwegian Meteorological Institute	https://opendrift.github.io/index.html	Jones et al., 2016; Dagestad et al., 2018; Röhrs et al., 2018.	
GNOME	NOAA	https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/gnome-suite-oil-spill-modeling.html https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/gnome-references.html	Beegle-Krause, 2001; Beegle-Krause et al.; 2007	Zelenke et al., 2012 https://gnome.orr.noaa.gov/doc/
DELFT3D-PART	Deltares	https://oss.deltares.nl/web/delft3d	Deltares, 2021; Bi and Si, 2012; Wang et al., 2017	https://content.oss.deltares.nl/delft3d/manuals/Delft3D-PART_User_Manual.pdf
MOTHY	Météo-France	http://www.meteorologie.eu.org/mothy/	Daniel, 1996; Daniel et al., 2003; 2005; Cucco and Daniel, 2016; Daniel et al, 2021	
OSERIT	The Royal Belgian Institute of Natural Sciences	https://oserit.naturalsciences.be/about.php	Legrand and Dulière, 2012;2013	Dulière et al., 2013
SEATRACK WEB	Swedish Meteorological and Hydrological Institute	https://stw.smhi.se/	Ambjörn, 2007; Verjovkina et al., 2010; Ambjörn et al., 2014;	https://helcom.fi/action-areas/response-to-spills/manuals-and-guidelines/ https://stw.smhi.se/player/help/classic/?domain=helcom https://www.smhi.se/polopoly_fs/1.15599!/Seatrac

Name	Organization	Website	Scientific Publications	Technical manuals and project reports
				k%20Web%20manual.pdf
POSEIDOM-OSM	Hellenic Centre for Marine Research	https://poseidon.hcmr.gr/components/forecasting-components/oil-spill-model	Perivoliotis et al., 2005; 2011; Zodiatis et al.; 2016.	
OILMAP	RPS	https://www.rpsgroup.com/services/oceans-and-coastal/modelling/products/oilmap/)	Spaulding et al., 1992; 1994;1996; Howlett et al., 2008; French-McCay et al., 2021	
OSCAR	SINTEF	https://www.sintef.no/en/software/oscar/ https://www.oilspillresponse.com/es/services/preparedness-services/consultancy/oil-spill-modelling/	Aamo et al., 1996; Reed et al., 1995;1996;2000; Nordam et al., 2019	
OSIS	Warren Spring Laboratory and BMT Ceemaid Ltd		Leech et al., 1993; Leech et al:, 2012; Rezvandoost et al., 2012	
MIKE21	DHI	https://www.mikepoweredbydhi.com/products/mike-21/sediments/oil-spill	Verma et al., 2008; Perrie and Goharnejad, 2021	https://manuals.mikepoweredbydhi.help/2017/Coast_and_Sea/MIKE_213_OS.pdf https://www.mikepoweredbydhi.com/-/media/shared%20content/mike%20by%20dhi/flyers%20and%20pdf/product-documentation/short%20descriptions/mike213_os_fm_short_description.pdf

- **TESEO** is a three-dimensional lagrangian oil spill model developed by IHCantabria (Chiri et al., 2020). The model computes oil slick transport, diffusion, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation. TESEO has been used during major real oil spill incidents, such as the Prestige (Spanish coast, 2002) and the Grande America oil spill (Bay of Biscay, 2002) and it is currently implemented in operational oil risk management systems for oil and gas companies. The model has been validated with drifting buoys (Abascal et al., 2007; Sotillo et al., 2008; Abascal et al., 2008; 2009; 2012; 2017a; 2017b) and laboratory experiments (Castanedo et al., 2014).

- **MOHID**: the MOHID lagrangian oil spill model is a sub-model of the MOHID water modelling system, developed by the Technical University of Lisbon (Fernandes, 2001; Fernandes 2018). It is a 3D model that computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, dissolution, sedimentation. It has been operationally applied during oil spill accidents, such as the Prestige (Spanish coast, 2002) and Costa Concordina (Tyrrhenian Sea, 2012) (Carracedo et al., 2006; Janeiro et al., 2014) and validated with drifting buoys (Fernandes, 2013).

- **MEDSLIK-II** is a three-dimensional lagrangian oil spill model developed by several institutions (see http://www.medslik-ii.org/team.html) around the Mediterranean Sea. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation. MEDSLIK has been used operationally for real oil spill accidents, such as the Lebanon oil spill pollution crisis (2006), and validated with drifting buoys (Coppini et al; 2011; De Dominicis et al., 2013a,2013b). It is operational in the Mediterranean Sea region (Karamea et al., 2021).

- **OpenOil**: the oil drift module OpenOil is based on the open-source, python-based, trajectory framework of OpenDrift, and it is a newly-integrated oil spill transport and fate model. OpenDrift is a software package for modelling the trajectories and fate of objects or substances drifting in the ocean under development at the Norwegian Meteorological Institute, and OpenOil is a full-fledged oil drift model, bundled within the OpenDrift framework. OpenOil computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation. The model has been validated with field exercises (Jones et al., 2016; Dagestad et al., 2018; Röhrs et al., 2018).

- **GNOME**: the GNOME (General NOAA Operational Modeling Environment) Suite is a set of modelling tools for predicting the fate and transport of pollutants (such as oil) spilled in water. These modelling tools are used for NOAA's spill response support and are also publicly available for use by the broader academic, response, and oil spill planning communities. GNOME is a 3D Lagrangian model that computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, dissolution, and biodegradation. It has been used to support spill response for oil spills in USA for almost twenty years (Beegle-Krause, 2001; Beegle-Krause et al.; 2007; Zelenke et al., 2012);

- **Delft3D-PART**, developed by Deltares, is a module of the Delft3D modelling suite that estimates the transport and simple water quality processes via a particle tracking method, implementing the 2D or 3D flow data by the Delft3D-FLOW (hydrodynamic module). Delft3D-PART provides an oil spill module that computes oil slick transport, diffusion, entrainment into the water column, and the weathering processes evaporation, emulsification, and sedimentation (Deltares, 2021; Bi and Si, 2012; Wang et al., 2017). Delft3D-part, directly coupled to Delft3D modelling suite, is used by Spill Response Group Holland (SRGH) (http://www.srgh.nl/deltares.html)

- **MOTHY** is a 3D lagrangian pollutant drift model developed by Météo-France. The model is operated since 1994 on demands of the French authorities for support of the oil spill fighting operations and demands of the Maritime Rescue Co-ordination Centres for support of the search and rescue operations. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation. The model uses current fields from different models, such as MERCATOR and wind forecasts from ECMWF (the European Centre for Medium-Range Weather Forecasts). It has been applied in major oil spills, such as the Prestige (Spanish coast, 2002) and the Grande America oil spill (Bay of Biscay, 2002) (Daniel, 1996; Daniel et al., 2003; 2005; Cucco and Daniel, 2016; Daniel et al, 2021) and validated with field observations.

- **OSERIT** is a three-dimensional lagrangian oil spill model developed by the Royal Belgian Institute of Natural Sciences. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification. The OSERIT used to be linked to EMSA's CleanSeaNet Service. It could use the oil spills detected in EMSA CSN service and estimate the trajectories in the North Sea area. It is also used by Coast Guard Centres and other governmental authorities. OSERIT model uses Copernicus Marine Service European North West Shelves model as forcing at its boundary conditions (https://marine.copernicus.eu/it/node/1886). The OSERIT model has been validated in various academic and real case studies, including the "Gannet" platform accident (Legrand and Dulière, 2012;2013; Dulière et al., 2013).

- **SEATRACK WEB** is an operational oil drift forecasting system developed by the Swedish Meteorological and Hydrological Institute. It covers the Baltic Sea and part of the North Sea. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation and emulsification. The model uses current fields from the High-Resolution Operational Model for the Baltic and wind forecasts from ECMWF. It has been validated using surface drifters in the Gulf of Finland and Baltic Proper (Verjovkina et al., 2010). SEATRACK Web is the HELCOM system for forecasting oil drift, and the primary users are oil combating authorities in the countries surrounding the Baltic Sea. It has been in operation since the early 1990s (Ambjörn, 2007; Verjovkina et al., 2010; Ambjörn et al., 2014).

- **POSEIDON OSM** is a three-dimensional Lagrangian oil spill model generated by the Hellenic Centre for Marine Research, implemented and operational in the Aegean and Ionian Seas since 2000. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation. It has been validated in one drifter exercise (Pollani et al., 2001; Perivoliotis et al., 2005; 2011; Zodiatis et al.; 2016). It is operational in the Mediterranean Sea region (Karamea et al., 2021).

- **OILMAP** is a three-dimensional oil spill response and contingency planning model developed by Applied Science Associates. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation, and oil-ice interaction. OILMAP is operational by Oil Spill Response Limited (OSRL) in United Kingdom and by the Spanish Maritime Safety Agency (SASEMAR) in Spain. Among other applications, OILMAP has been used by SASEMAR to predict the oil spill during the Prestige (Spanish coast, 2002) and the Grande America (Gulf of Biscay, 2019) oil spills. It has been validated with drifting buoys and observations from spill incidents.

- **OSCAR** is a three-dimensional model for planning and response to oil spills developed by SINTEF. The model computes oil slick transport, diffusion, spreading, entrainment into the water column, beaching, and the weathering processes evaporation, emulsification, sedimentation. Overall, OSCAR has been used in oil spill risk assessment, as well as in response planning and operations. The model has been applied for hindcast and forecast of accidental releases in locations such as the North Sea, the Baltic Sea, the Gulf of Mexico, and the Mediterranean basin. OSCAR is, among other regions, operational in the UK by Oil Spill Response Limited (Aamo et al., 1996; Reed et al., 1995;1996;2000; Nordam et al., 2019).

- **OSIS** (Oil Spill information System) is an oil spill model to predict the three-dimensional spreading and transport of an oil slick under the influence of wind, waves, tide, turbulence, and shear diffusion. Oil weathering and fate processes of spreading, emulsification, evaporation, and dispersion are also simulated. It has been developed by Warren Spring Laboratory and BMT Ceemaid Ltd. The physical models have been tested against data obtained from sea trials and spill incidents.

- **MIKE 21/3 Oil Spill** is an add-on module to MIKE 21 & MIKE 3 Flow Model FM hydrodynamic model. The weathering processes include spreading, entrainment into the water column, buoyancy, biodegradation, photo oxidation, evaporation, emulsification, and dissolution. The hydrodynamic basis is obtained with the MIKE 21 hydrodynamic module and current data come from a coupled or de-coupled MIKE 21 hydrodynamic simulation (Verma et al., 2008; DHI, 2017; Perrie and Goharnejad, 2021).

It is worth mentioning that besides the models presented in Table 1, PISCES II and NOOS-DRIFT were identified as interesting models by Member States (see Appendix A). PISCES II has been discarded because it is a 2D oil spill model (Toz and Koseoglu, 2018). NOOS-DRIFT is a distributed transnational multi-models ensemble system to assess and improve drift forecast accuracy in the European North West Continental Shelf (Legrand et al., 2020). NOOS-DRIFT has not been included in the analysis because more than an oil spill model, it is a distributed multi-models service.

3.2.2. Comparative analysis of models

The comparison of the oil spill models has been carried out taking into account:

1. <u>The scientific and technological quality of the model:</u> the scientific publications, the validation of the model, and its application to real incidents are important criteria to ensure the robustness of the models.

2. Transport and oil weathering processes: most of the state-of-the-art models include advection, diffusion, spreading, beaching, entrainment, evaporation, and emulsification, which are the main processes affecting the oil at the time scale of the response. Other processes such as dissolution, photo-oxidation, or biodegradation are less common and supported by a limited number of models (see Table 2).
3. Definition of the oil spill discharge: capacity to consider surface and sub-surfaces releases of oil and instantaneous or continuous releases, which is of relevance to address the oil spill scenario of a sunken vessel releasing oil.
4. Definition of the initial slick shape: capacity to provide the location of the oil spill in different ways (e.g. providing geographical coordinates or polygons), which is important to update the information of the oil location with observations (e.g. aerial observations, satellite images, images from RPAS, marine pollution surveillance reports).
5. Setting met ocean forcings: oil spill models require met ocean fields to simulate the fate and transport of oil. However, some of them are closely coupled to met ocean forecasting systems in their application area or to hydrodynamic models. The capability of the model to run with standard met ocean data and de-coupled from any forecasting system or hydrodynamic model is important to ensure the integration with different data providers.
6. Model parameters available for calibration: model parameters to adjust the model outputs with real data. The most important parameters in a lagrangian transport model are the wind drag coefficient (C_D) and the diffusion coefficient (D) (see Ec. 1 and Ec. 4). The model calibration aims to find the optimal values of these coefficients to minimize the difference between actual data and numerical trajectories. The application of calibration techniques in real time is not a common practice and it is usually carried out offline (e.g. Abascal et al. 2009a,b; 2015; De Dominicis et al., 2013b). The manual calibration is more feasible than the automatic calibration and will allow the user to modify C_D and D to adjust, as far as possible, the advection and diffusion of the oil slicks.
7. Model outputs: results provided by the oil spill model and required for the response simulator.
8. Model interoperability and standardized outputs: capacity of the model to provide standardized outputs (e.g. netCDF, json) and interoperability for exchanging the results.
9. License: oil spill models range from open-source code to commercial. Open-source code will facilitate the integration of the model in the new system and the maintenance and sustainability of the system. Moreover, source codes hosted in a public source code management system, such as GitHub, facilitate to follow the life of the model: new features, improvements, bug fixes, deployment rhythm, team involvement in development, among many other aspects.

The models have been analysed based on the available and public references and documents shown in Table 1 which includes: scientific publications, technical manuals, project reports, and websites. As previously mentioned, the list of models of interest for MS provided by EMSA (see Appendix A) has been also considered in the analysis. It is worth mentioning that the available information depends on the model, being higher for open-source models and more limited for private models. Based on this analysis, Table 2 shows the comparison of the different models (unknown fields refer to information not found in the review of the documentation), and Table 3 shows the pros and cons of each model.

The models included in Table 3 are 3D state-of-the-art models that compute the most important transport and weathering processes affecting the oil spill at sea. All of them have been published in scientific journals, which ensures the scientific quality of the model, and have been validated to a greater or lesser extent using drifting buoys and applied in real cases.

In general terms, all models provide the most important variables required by the future response simulator, such as the temporal evolution of the transport and dispersion of the oil spill or the temporal evolution of the water content and viscosity. However, other variables such as thickness, are calculated by the models, but sometimes not provided as an output. In this case, an specific implementation in the selected model for the new system would be required to provide this variable as an output of the numerical modelling. It is worth mentioning that the numerical modelling of the oil slick thickness is complex and it is is usually represented by models as an average value for the slick.

Thus, the oil spill model to be implemented in the new system shall be able to be updated. Likely, it could be needed (or not) specific developments to incorporate the requirements of the system and potential issues that may arise during the system development.

Table 3 presents the pros and cons of the models, highlighting some specific aspects beyond these general features.

Table 2 - Comparison of models.

MODEL NAME		TESEO	MOHID	MEDSLIK-II	OpenOil	GNOME	DELFT3-PART	MOTHY	OSERIT	SEATRACK WEB	POSEIDON-OSM	OILMAP	OSCAR	OSIS	MIKE 21/ OIL SPILL
License		Public	Open-source	Open-source	Open-source	Open-source	Open-source	unknown	unknown	unknown	unknown	Proprietary software	Proprietary software	unknown	Proprietary software
First release		2007	2001	2013	2019	late 1990's	unknown	1994	2013	1995	2003	1992	early 1990's	early 1990's	unknown
Download and access		on-demand	github-site	on-demand	github-site	github-site	on-demand	info	on-demand	on-demand	on-demand	on-demand	info	unknown	info
Scientific-technological publications		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Third-party model of interest for EU members (based on Appendix A)		NA-Not applicable	NA	NA	NA	BG	NA	NA	BE	DE, DK, FIN	NA	IRL, NL, SP, RO	NA	IT	NA
Feasible to be implemented in the future system		Yes	Yes	Yes	Yes	Yes	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
3D model		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Discharge methods	Single	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Continuous	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	unknown	Yes
Initial slick definition	Point	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	unknown	Yes
	Polygon	No	Yes	Yes	Yes	Yes	Yes	unknown	unknown	Yes	unknown	unknown	unknown	unknown	Yes
Able to use met ocean fields from different sources		Yes	Yes	Yes	Yes	Yes	unknown	unknown	unknown	unknown	unknown	Yes	Yes	unknown	unknown
Transport and weathering processes	Advection	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Wind drift	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
	Stokes's drift	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No
	Spreading	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Diffusion	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Beaching	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

MODEL NAME		TESEO	MOHID	MEDSLIK-II	OpenOil	GNOME	DELFT3-PART	MOTHY	OSERIT	SEATRACK WEB	POSEIDON-OSM	OILMAP	OSCAR	OSIS	MIKE 21/ OIL SPILL
	Entrainment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Evaporation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Emulsification	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Dissolution	No	Yes	No	No	Yes	Yes	No	No	No	No	No	Yes	No	Yes
	Sedimentation	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No
	Biodegradation	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes
	Photo-oxidation	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes
Calibration variables	Wind drag coefficient	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
	Diffusion coefficient	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Output variables	Oil slick transport and dispersion (particles evolution)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Thickness	No	unknown	unknown	unknown	unknown	unknown	No	unknown	unknown	unknown	unknown	unknown	unknown	Yes
	Viscosity evolution	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	unknown	Yes	Yes	Yes	Yes
	Oil Budget	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	unknown	Yes	Yes	Yes	Yes
	Mass of oil and water	Yes	Yes	Yes	Yes	Yes	unknown	No	unknown	Yes	unknown	Yes	unknown	unknown	Yes
Interoperability	Interoperability (csv, json, netcdf...)	Yes	Yes	Yes	Yes	Yes	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown

Table 3 - Pros and cons of the models.

NAME	PROS	CONS	REMARKS
TESEO	■ Well documented from the scientific point of view. ■ It has been highly validated with drifting buoys (supported by a high number of scientific publications) and applied in real accidents (e.g. Prestige).	■ It is not an open-source model. The model is public and available on-demand. ■ Technical documentation (manuals) is not publicly available.	■ Feasible to be implemented into the new system. ■ The implementation will require support from the model's team.
MOHID	■ Open-source code (hosted in a public source code management system) ■ Well documented from the scientific and technological point of view. ■ It has been applied, inter alia, during the Prestige accident and in many EU projects (e.g. ARCOPOL project)	■ It is a module from a complete hydrodynamic model, less flexible than a stand-alone oil spill model. However, it can be run uncoupled.	■ Feasible to be implemented into the new system. ■ Open-source code facilitates the integration of the model into the new system.
MEDSLICK-II	■ Open-source code (on-demand). ■ Well documented from the scientific and technological point of view. ■ It has been validated with drifting buoys and applied during the oil pollution crisis in Lebanon (2006). ■ It is operational in the Mediterranean Sea Region.	■ It is not hosted in a public source code management system.	■ Feasible to be implemented into the new system. ■ Open-source code facilitates the integration of the model into the new system.
OPENOIL	■ Open-source code (hosted in a public source code management system) ■ Well documented from the scientific and especially from the technological point of view.	■ It is a new development.	■ Feasible to be implemented into the new system. ■ Open-source code facilitates the integration of the model into the new system. ■ It is mainly written in Python which may affect the model performance in high-demanding simulations (e.g. for long periods and when a high number of particles is required). For short-term simulations, this is not a handicap since lagrangian models are very fast.

NAME	PROS	CONS	REMARKS
GNOME	■ Open-source code (hosted in a public source code management system) ■ It is a model that has been widely used around the world for more than 20 years. It is the modelling tool for the Office of Response and Restoration's Emergency Response Division (USA). ■ Well documented from the scientific and especially from the technological point of view. ■ It has been identified as an interesting third-party model by BG (see Appendix A)		■ Feasible to be implemented into the new system. ■ Open-source code facilitates the integration of the model into the new system.
DELFT3D-PART	■ Open-source code (on-demand). ■ Well documented from the technological point of view. ■ It is used by Spill Response Group Holland	■ It is not hosted in a public source code management system ■ It is a module from a complete hydrodynamic model, less flexible than a stand-alone oil spill model. ■ Current data usually come from DELFT3D hydrodynamic model	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).
MOTHY	■ Well documented from the scientific point of view. ■ It has been highly applied in major oil spills (e.g. Erika, Prestige, Grande America) ■ It is the model of the National Forecasting Centre of Météo-France (France).	■ It is not an open-source model. ■ Technical documentation (manuals) is not publicly available.	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).
OSERIT	■ The OSERIT used to be linked to EMSA's CleanSeaNet Service. It could use the oil spills detected in EMSA CSN service and estimate the trajectories in the North Sea area. ■ It has been identified as an interesting third-party model by BE (see Appendix A)	■ It is not an open-source model. ■ Technical documentation (manuals) is not publicly available.	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).

NAME	PROS	CONS	REMARKS
	■ It is operational for the North Sea.		
SEATRACKWEB	■ It has been identified as an interesting third-party model by DE, DK, and FIN (see Appendix A) ■ It is the HELCOM system for forecasting oil drift. ■ Well documented (user guide and scientific documentation are publicly available)	■ It is not an open-source model.	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).
POSEIDON-OSM	■ It is operational in the Mediterranean Sea Region.	■ It is not an open-source model. ■ Technical documentation (manuals) is not publicly available. ■ Unclear documentation about the scientific aspects of the model.	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).
OILMAP	■ It is a model that has been widely used around the world for more than 20 years. ■ It is a well-known and established software ■ It has been highly validated and applied in real spill incidents. ■ It has been identified as an interesting third-party model by IRL, NL, SP, and RO (see Appendix A)	■ Proprietary software – the software is licensed	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).
OSCAR	■ It is a model highly used worldwide. ■ It is operated in UK by Oil Spill Response Limited.	■ Proprietary software – the software is licensed.	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).
OSIS		■ It is not an open-source model. ■ It is not well documented (technical documentation is not publicly available)	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).

NAME	PROS	CONS	REMARKS
MIKE21	■ It is a well-known and established software.	■ Proprietary software – the software is licensed ■ It is a module from a complete hydrodynamic model, less flexible than a stand-alone oil spill model. ■ Current data usually come from a coupled or de-coupled MIKE 21 hydrodynamic simulation.	■ The feasibility of the model to be integrated into the new system has to be confirmed with the software proprietary(*).

(*) The feasibility for the integration will depend on several factors, such as the license of the model, the availability to modify the code (if required by the new system) and the support of the proprietary and the development team for the implementation of the model in the system. These issues would have to be verified with the proprietary software after the definition of the architecture of the system (Work Packge 2) and the definition of functional, non-functional and technical requirements defined in Work Package 3.

3.2.3. Proposal of minimum requirements for the oil spill model

As mentioned, the models included in Table 3 are 3D state-of-the-art models suitable to be integrated into the new system. Since there is unknown information regarding non-public models, the feasibility of these models to be integrated into the system has to be confirmed with the software proprietary. Note that open-source code will facilitate the integration of the model in the new system and its maintenance and sustainability.

Following the review of the state-of-the-art, this section summarizes the minimal requirements of the oil spill model to be suitable for the development of the new system:

- It has to be a state-of-the-art model, which may be supported by scientific publications, validation, and/or application in real accidents.
- It has to be a 3D lagrangian model to simulate the transport and weathering of oil spills. At least, the model should compute the most important processes affecting the oil spill: advection, diffusion, spreading, entrainment, beaching, evaporation, emulsification, and the changes in the physical and chemical properties of the oil. Sedimentation and additional processes are desired. Advection should include currents and wind drag. Stoke's drift is desired.
- It should run surface and sub-surfaces releases of oil, as well as, instantaneous or continuous releases.
- It should be read the initial location of the oil from specific points (coordinates) or polygons.
- It should be forced, at least, with ocean and wind fields such as those provided by met ocean forecast systems. Other variables such as waves, temperature, and salinity (or density) are also desired as spatio-temporal fields.
- The wind drag coefficient (C_D) and the diffusion coefficient (D) should be modified by the user.
- Outputs should include, at least: oil slick transport and dispersion, the temporal evolution of the oil viscosity, water content in oil emulsification, oil evaporation, oil dispersed into the water column, oil remaining on the surface, oil thickness, and oil beached.
- It should provide standardized outputs (e.g. netcdf, json).
- It should run with standard met ocean data.
- It should be invoked from the system. It is required that both the methods that can be invoked and the data to be exchanged be known.
- A "log mechanism" to facilitate monitoring the functioning of the model and other services and at the same time to be able to dynamically discover the status of the service is desired.

3.2.4. Conclusions

The main conclusions of the state-of-the-art review in oil spill modelling are the following:

- A review of the state-of-the-art models used in Europe has been carried out in terms, inter alia, of their capacity to simulate the physical processes affecting the oil spill, their scientific and technological quality, and their applicability in the EU Member States.
- All the reviewed models are 3D state-of-the-art models that compute the most important transport and weathering processes affecting the oil spill at sea. All of them have been published in scientific journals, which ensures the scientific quality of the model, and have been validated to a greater or lesser extent using drifting buoys and applied in real cases.
- In general terms, the models provide most of the variables required by the future response simulator. However, specific implementations can be needed to fulfil all the requirements of the new system.
- The integration of the OSM into the new system and its modification (if required) is a complex task that could require collaboration with the model development team or the proprietary model.
- Open-source, especially hosting in a public source code management system, and well-documented models will facilitate the integration of the model into the new system and the maintenance and sustainability of the system.
- The minimal requirements of the oil spill model to be suitable for the development of the new system have been established based on the analysis carried out.

3.3. Options for importing oil spill model data from different models in the system

The objective of this section is to assess and compare the different options for importing oil spill model data from different models in the system. The new system must have one model integrated to generate the data needed for the simulator, however, it should be flexible to allow users to input data from their own oil spill models.

Oil spill model integrations could be undertaken under two different approaches, according to their level of integration (see Figure 5 - Approaches for model integration.). The “fully integrated" approach will execute and run the model into the system, whereas the “not fully integrated *approach*” will integrate model outputs into the system through Extract Transform and Load (ETL) processes.

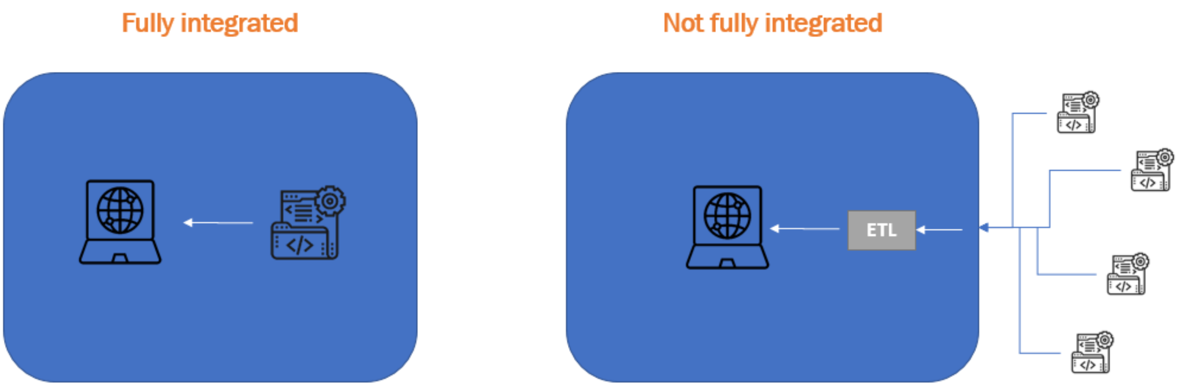

Figure 5 - Approaches for model integration.

Although interoperability standards are mature and well-defined (see INSPIRE Directive or the Open Geospatial Consortium standards), the available oil spill models require data and provide outputs in different formats and structures. In the case of model output integrations, specific ETL modules will have to be designed specifically for each model desired to be integrated into the system. As it is showed in Figure 6, the collected data is transformed to be suitable for the system and loaded into the system data repository.

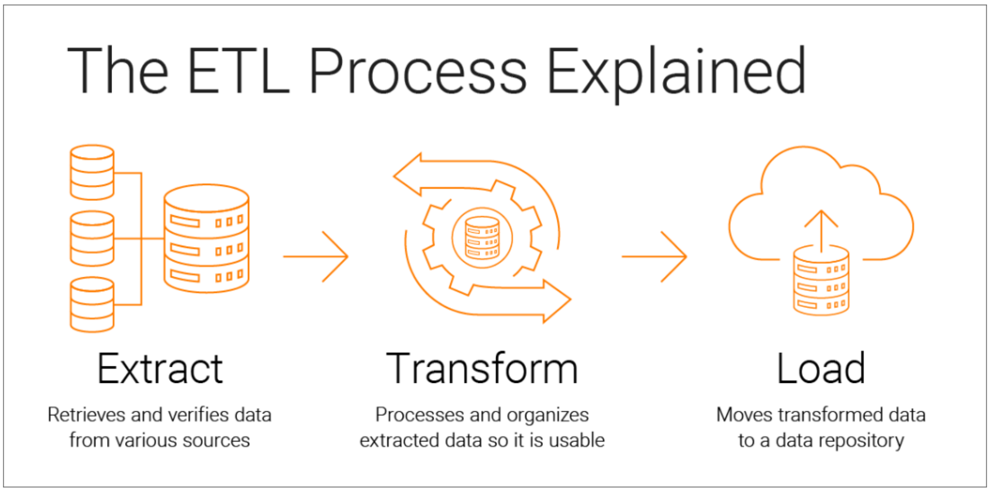

Figure 6 - ETLs process.

Due to the specificities of the model, the transformation process must be adapted to its results, transforming the model outputs to the format required by the new system.

In the case of the fully integrated model, the selected model will require integrating a transformation process for the input and output data. In addition, the integration of the model will require invoking the model programmatically, including its configuration as an editable file. Due to system maintenance, it is also recommended that the selected model provides a log file that includes any problems during its execution.

It is worth mentioning that this issue will be further analysed in Work Package (WP) 2 and in the report on Part 2 of this project.

3.4. Options to provide the location of the oil spill into the GIS oil spill model

The objective of this section is to identify and assess options to provide in an easy and user-friendly way the location of the oil spill into the GIS oil spill model e.g. aerial observations, geographical coordinates, polygons from satellite images, images from RPAS.

This functionality will allow running the oil spill model with updated information about the spill response. Field observations and aerial images provide a confident initial starting point for the oil spill modelling. If this information is available periodically during an emergency, the model can be re-initiated as new information is received, which can represent a continuous improvement for the modelling. In addition, this information can also be used to launch one simulation per polygon and therefore allowing to simulate indirectly the split of the slicks.

The geospatial location of an oil spill is understood as one or several polygons that provide the geospatial limits of the spill. Two options could be implemented to obtain the oil spill geometry: (1) geometry digitization or (2) geometry load.

Geometry digitization is based on the implementation of importing georeferenced imagery and mapping tools to digitize the geometry of the oil slick (i.e. drawing and editing).

On the other hand, the geometry loading will be based on the processes of transformation and loading of several standard GIS formats (shp, json, xml, kmz, etc.) (see Figure 7). Therefore, results from the identification oil spills through state-of-the-art remote sensing techniques will be able to be integrated in the system.

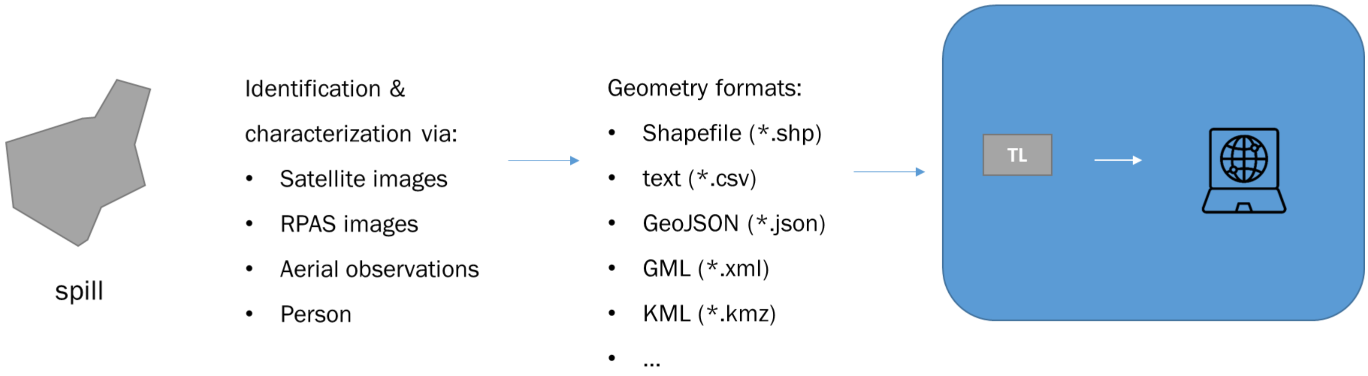

Figure 7 - Integration of polygons (geometry load).

It is worth mentioning that this issue will be further analysed in Work Package (WP) 2 and in the report on Part 2 of this project.

3.5. Options to calibrate the oil spill model

The objective of this section is to identify and assess options to adjust or “calibrate” the model output by using “real” data e.g. from satellite images, aerial observations, RPAS images.

The aim of the model calibration is to find the optimal values of the model parameters to minimize the difference between actual data and numerical trajectories. As mentioned, in a lagrangian model the oil spill motion is computed by means of the transport induced by surface currents, wind, wave fields, and turbulent diffusion. Usually, this is done using parameters to link the forcing to the oil slick’s movement. Accordingly, to simulate the movement of an oil slick, we assume the transport to be composed of an advective and a diffusive velocity. The advective velocity depends on the currents and wind velocity, and the sea state (see Eq. 1). The most important parameter of this term is the wind drag coefficient (C_D), which varies from 2.5% to 4.4% of the wind speed, with a mean value of 3–3.5% (ASCE, 1996). The diffusive velocity depends on the sea turbulence characteristics (see Eq.

4). Usually, the latter is simulated as a Brownian motion of particles by means of a random walk procedure, which depends on the diffusion coefficient (*D*) that ranges between 1- 100 m²/s (ASCE, 1996). Therefore, C_D is the key coefficient to adjust the advection and *D* the key coefficient to adjust the dispersion of the oil slick.

To show the relevance of the calibration, Figure 8 shows two simulations of an oil spill drift, using different wind drag coefficients. The oil spill was supposed to be 65 km off the Galician coast. The simulated trajectories stand for 3-day predictions. Panel left and panel right show the results using wind drag coefficients of 0.025 and 0.044, respectively. It is clear that for the 0.044 wind drag coefficient, the oil slick moves faster. Both simulations predict oil stranding on the northern coast of Galicia. However, the arrival points are separated by about 20 km. It has to be remarked that both wind drag coefficients are in the interval reported by the bibliography (ASCE, 1996). Any of these values could be used to predict an oil spill trajectory, and as has been shown, different results in time and location of the oil landing can be obtained. This simple experiment makes clear the importance of obtaining the best agreement model coefficients for the region of application of the model.

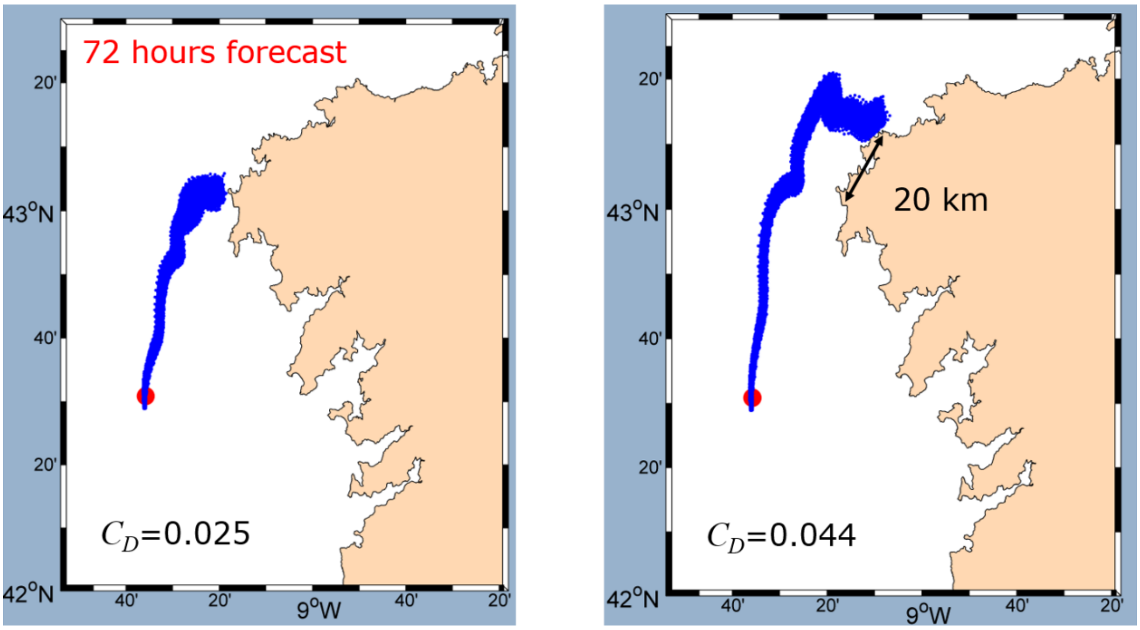

Figure 8 - Example of model calibration. Oil spill simulation with CD= 0.025 (panel left) and 0.044 (panel right) (red circles indicate the initial position). It can be observed that the stranding point strongly depends on the wind drag coefficient selected (Abascal et al., 2009a).

The calibration of the model can be carried out with observations provided by satellite images, aerial observations or RPAS images. It is also recommended the calibration of the model with drifting buoys (e.g. Abascal et al. 2009a,b; 2015; De Dominicis et al., 2013b). The model calibration can be performed in two different ways:

- Option 1: Manual calibration by means of a trial and-error procedure. In this process the simulated trajectories are fitted to the real buoys' paths to adjust the model parameters.
- Option 2: Automatic calibration by the application of optimization methods that allow to find the best model coefficients.

The application of calibration techniques in real time is not a common practice and it is usually carried out offline (e.g. Abascal et al. 2009a,b; 2015; De Dominicis et al., 2013b). The manual calibration (Option 1) is less complex than the automatic calibration and will allow the user to modify C_D and *D* to adjust, as far as possible, the advection and diffusion of the oil slicks. It is proposed to focus the calibration of the model on the main parameters that affect advection and diffusion: C_D and *D*. Including other parameters such as the coefficient for currents, a deflection angle, or a coefficient for waves (Castanedo et al., 2006; Abascal et al., 2009a; Duran et al., 2018) may complicate the manual selection of coefficients and the interpretation of the results. In Option 1, the user interface (front-end) will provide the required interfaces to interact with the system, modify the model parameters, and compare actual and numerical trajectories to select the parameters that best fit the numerical trajectories.

The main advantage of the automatic calibration (Option 2) is that it allows the use of a great amount of data and the calibration of a higher number of parameters, e.g. including parameters to take into account the uncertainty in currents and waves (e.g. Abascal et al., 2009a). In this case, it is proposed to use an optimization algorithm to find automatically the best model parameters. The main disadvantage is that to be effective, the method must rely on a great amount of data (oil observations or drifting buoys) which implies, on one hand, the availability of this information, and on the other hand, the management and integration into the system of different sources of data. Therefore, the main concerns about automatic calibration are twofold: first, in situ observations are scarce. Secondly, the variability of data sources (formats, etc.) from different data providers is very high, which complicates the automatic integration of observed data considerably.

3.6. Integration of GIS layers

The objective of this section is to explore the possibility of integrating various GIS layers (e.g. environmental sensitivity maps, bathymetry, shipping lanes, location of wind and fish farms, AIS data).

In the field of offshore oil pollution response operations, geographical position is a crucial factor. It will therefore be necessary to acquire and manipulate geographic data to represent the real world in a digital environment. Geospatial technologies will be one of the pillars of the new system, enabling complex issues to be analysed and communicated to a wider audience.

GIS standards for data interoperability will be mandatory to make location information FAIR – Findable, Accessible, Interoperable and Reusable. Interoperability will act as a broker between the system and data providers (Emodnet, Copernicus, etc.), and between the different subsystems, components and tools.

Two methods of integration should be envisioned: (1) standard interoperability protocols and (2) standard GIS formats (see Figure 9). Standard interoperability protocols (OGC and INSPIRE compliant) will allow viewing and downloading of geospatial data through standard web services such as Web Map Service (WMS), Web Coverage Service (WCS) and Web Feature Service (WFS), among others. On the other hand, standard GIS formats (shp, json, xml, gml, etc.) will be transformed and loaded into the system to provide cartographic functionalities.

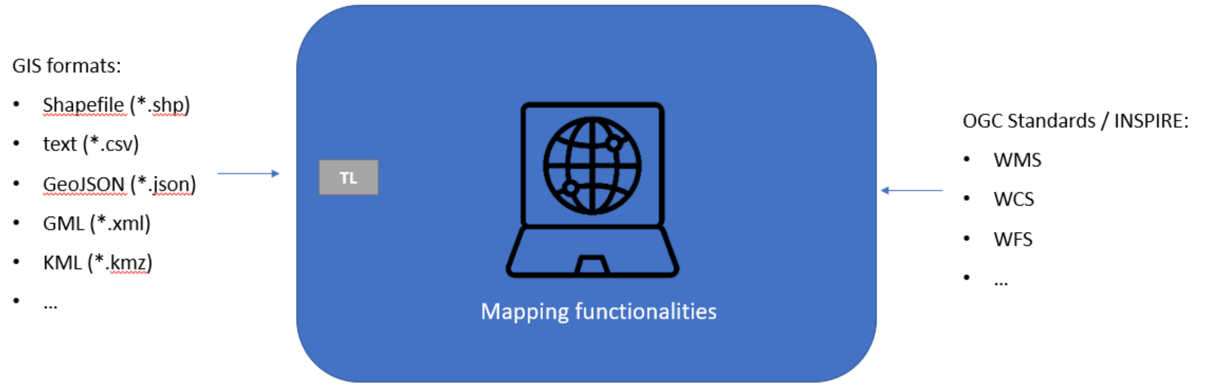

Figure 9 - Integration of GIS layers.

End users will interact with the system through Geospatial interfaces with common mapping functionalities, which will allow data access, analysis and visualization of geodata and geoinformation. The Geospatial User Experience will have to be designed according with end user needs and end user knowledge.

It is worth mentioning that this issue will be further analysed in Work Package (WP) 2 and in the report on Part 2 of this project.

4. OIL SPILL RESPONSE OPERATION AND STATE OF THE ART RESPONSE CALCULATORS

Numerous variables are involved in the evolution, trajectory, and behaviour of an oil spill. When an oil spill occurs at sea and is detected, the available response systems are immediately alerted to respond to this emergency event. Oil spill response aims to minimize impacts and reduce the time for environmental recovery by containing and removing the oil as soon as possible.

In that way, an effective response to an oil spill will largely require the preparation of agencies and the mobilization of the most appropriate assets in the shortest possible time. Being able to predict, organize and anticipate events to have the right assets in the right place is the most valuable information to be known during any effective response. Over the last decade, oil spill response simulators have been developed, trying to provide this valuable information to the actors in charge of this type of emergency response.

The main objective of this section is to analyse the relevant aspects that influence the simulator to calculate the efficiency of oil response operations at sea.

4.1. Overview of oil spill response operations

This section provides an overview of the relevant aspects that influence the oil spill operations, taking into account the basic response techniques, the phases of the response, the factors that influence the operability of the operations, and the factors that influence the efficiency of the recovery. These relevant aspects will be considered in the development of the methodology presented in Section 5 and in the analysis carried out in the following sections.

4.1.1. Oil spill response techniques

The main response methods include mechanical recovery, in situ burning, and dispersant application. A brief description of these techniques is presented below:

- In Situ Burning: this is a very restricted and limited technique in Europe and should be considered under very specific conditions. In situ burning involves the controlled burning of the oil spilled, at the location of the spill. When conducted properly, in situ burning significantly reduces the amount of oil on the water and minimizes the adverse effect of the oil on the environment (https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/in-situ-burning.html). In situ burning requires two basic equipment: fire booms to collect and concentrate the oil spill and ignition kits.
- Surface Dispersant Application. Dispersants are a class of chemicals specifically designed to remove oil from the water surface. They work by breaking up oil slicks into lots of small droplets. These tiny droplets have a high surface-area-to-volume ratio, making them easier for oil-eating microbes to break them down (through the process of biodegradation). Their small size also makes the oil droplets less buoyant, allowing them to scatter throughout the water column more easily. Dispersants can be applied by vessels or by aircraft. This technique is very restricted in Europe and not all countries allow its application. The basic equipment used for surface dispersant application are:
  - Dispersants (chemical products). The most common are Type II and Type III (3rd generation)
  - Dispersant Applications System: systems to spray the dispersant that can be portable systems or vessel application arms. Aircraft could be adapted too to apply dispersants.
- Mechanical Oil Recovery: the goal of mechanical recovery is to remove oil from the surface of the water by corralling it and using specially designed recovery (skimming) devices and to store the recovered fluids until they can be safely disposed or recycled. Recovery devices are most effective on thick slicks; hence containment booms are used in open water to contain and concentrate an oil slick. The main components of a containment and recovery system are:
  - a boom to encounter and contain the oil
  - a recovery device (to remove the oil and normally equipped with a pump to transfer the collected oil
  - combinated systems to containment and recovery (sweeping arms, [redacted].)
  - a temporary storage capacity/device

4.1.2. Phases of the spill response operation

Response operations do not only involve direct spill response actions. The notification and start-up of the assets, the travel times to the location, the effective deployment of the components, the endurance of both the equipment and the transport (vessel and aircraft), the working conditions, and the capacity and staff needs, are what determine the technical and logistic aspects associated with the deployments in the event of a spill.

The spill response involves the following phases:

- Mobilization of the equipment: activation of the resources, and transit times from home stations to scene stations. This refers to the time it takes for response assets to get ready, the crew on board, load equipment, refuel, etc.
- Transit times and auxiliary operations: transit times and auxiliary operations to carry out the activity required. Including transit time from the scene station to the emergency location and deployment equipment (booms, skimmer…). It refers to the response assets traveling to the oil spill with response equipment on board, from the homeport to the spill location.
- Recovery operation: once the system is deployed, the recovery operation is the effective time of active operations (skimming, dispersant application, burning, etc.). Recovery operation will last until its storage capacity or endurance is reached, or working time is ended (daily hours or brake time) and will then stop the operation to start next.
- On Scene Stand by: it refers to the time a vessel is on the scene but not conducting response operations due to night conditions or weather unexpected conditions or taking a break in the middle of continuous deployment.
- Transit up to discharge or unload: this starts when a skimming vessel at capacity departs the scene to offload recovered product or an aircraft transiting to load more dispersant after deploying one load, up to the discharge or unloading point. This time normally includes a time to un-deployment the equipment (skimmer, booms...), before leaving.
- Discharge or Reload operation: it refers to the time to transfer the recovered product to storage platforms. It also accounts for reload of dispersant on a vessel or aircraft. This stage normally includes the time for a crew change, refuelling, or other activities and it last until the vessel/aircraft is ready to start again the transit time back to the oil spill.

4.1.3. Operability of the response operation

Oil spill response operations are affected by met ocean conditions. In nearly all environments, there will be periods during which on-scene conditions may preclude the safe or effective implementation of conventional oil spill response techniques. Such a ‘response gap’ exists when an effective response cannot be achieved, either because technologies available will not be effective or because conditions preclude their deployment due to operational or safety limits (WWW, 2007).

The response techniques (mechanical recovery, dispersant application, and in-situ burning) require the support of aircraft, vessels, and trained personnel to properly deploy and operate them. Then, the same environmental conditions that contribute to oil spill risks (e.g. high winds or low visibility) can also make spill response operations very difficult or ineffective.

Thus, weather conditions can affect the oil response operation in several ways:

i) affecting the general operability by conditioning whether the vessels and aircraft can operate or not and
ii) affecting the operability of the response techniques.

Specifically:

- Vessels and aircraft can be limited by high winds, high waves, low temperatures, and low visibility. Regarding temperatures, it has been taken into consideration cold air temperature effects upon personnel and equipment performance. The final factor involving the effects of cold climates on staff is extremely important as it impacts the time that people can work efficiently and in safe conditions.

- The operability of the response techniques is limited by the met ocean conditions and the oil properties: i) in-situ burning is limited by wind, waves, oil thickness, and emulsification; ii) dispersants are limited by viscosity and wind and iii) mechanical recovery is limited by wind, waves, and oil thickness.

4.1.4. Efficiency of the oil recovery

The main aspects that influence the efficiency of the oil recovery are the following:

- Weather conditions and characteristics of the weathered oil: the effectiveness of each technology depends on the timeframe in which it is used. This time-dependent effectiveness is called the “window of opportunity.” The window of opportunity is determined by the properties of the spilled oil, and by how these oil properties change over time after a spill. It is critical to understand both how oil properties change over time, and how the effectiveness of response options change as a function of oil properties (Federici and Mintz, 2014). Moreover, weather conditions are a key factor in the deployment of resources. On the one hand, and related to the chemical properties of the product, the environmental conditions during the spill influence the evolution of the oil. On the other hand, weather conditions influence the efficiency of the response techniques. In moderately rough or choppy water, skimmers tend to recover more water than oil. Likewise, the forces exerted by currents, waves, and wind may also impair the ability of a boom to hold oil (EPA, 1999).
- Encounter rate: Once the oil has spread, the effectiveness of a recovery system becomes more dependent on the rate at which oil is encountered. The rate at which one can encounter a specific volume of floating oil is one of the most important parameters in the overall assessment of a given response system’s ability to access and eliminate spilled oil (Allen, 2018). The volume encounter rate will depend upon the system’s swath (i.e., the width of its passage through or over oil), its speed while accessing the oil, and the average thickness of the oil encountered. The product of a system’s swath and speed is simply the rate at which it sweeps out area, while the product of swath, speed, and oil thickness gives the rate at which that system can access a volume of oil with that average thickness across its entire swath. Conventional containment methods are normally effective in achieving a high encounter rate in scenarios where containment operations begin early in weathering or develop near the surface of a continuous discharge. In scenarios where the oil has spread and fragmented significantly, or where maneuverability is required, high-speed containment systems (i.e. Current buster concept, [redacted] are more useful and can achieve a higher encounter rate than conventional methods of containment.
- Recovery capacity: The nameplate recovery rate (m^3/h) is the maximum rate at which a skimmer system can recover and process oil under ideal conditions. This value, calculated in favourable conditions (calm seas and light winds), is overestimated. The recovery rate in adverse conditions, where the size and disposition of the waves, or strong winds, can significantly reduce the efficiency rate of the equipment and collect much more water than initially estimated, with very high oil loss rates.

  Defining the real efficiency of the skimmers is one of the challenges of the response operation tools. This value can be obtained from previous works (e.g. Dale, 2011) or established based on expert criteria.

  Finally, characteristics of the oil and the oil/water emulsion are also important, specifically:

  - Thickness: to very low thicknesses the efficiency of a collection system will be null.
  - Viscosity: the viscosity of the oil is a primary limitation on the efficiency of most recovery devices. If the ambient temperature is below the pour point, the oil will become semi-solid and, hence, will be difficult to recover, since it will not readily flow towards the skimmer. The problems arising from increasing viscosity over time due to weathering of the oil require a continued revaluation of response strategies, including the use of the most applicable skimmer and pumping arrangement.
  - As the amount of water absorbed increases due to emulsification, the density of the emulsion approaches that of seawater, and the viscosity increases, making the emulsion progressively more viscous and stable. Due to the absorption of water, the volume of the pollutant may be increased by a factor of up to four or five times.

4.2. Review of available response calculators

Nowadays, there are a few systems to support oil pollution response operations at sea. This section presents a brief introduction of the most important available systems, as well as an assessment of their weaknesses and strengths, and the main approach applied to the mechanical recovery.

A review of the state of the art has been carried out, selecting the most important and well-documented systems:

- Estimated Recovery System Potential Calculator (ERSP Calculator) was developed by the Bureau of Safety and Environmental Enforcement (BSEE), in collaboration with Genwest, Inc. ERSP, as well as in situ burning (EBSP), and surface-applied dispersants (EDSP) are intended as planning tools for estimating the potential of different oil spill response systems to mitigate (recover, burn or disperse) discharged oil relative to one another. ROC is the evolution of this system.
- Response Operations Calculator (ROC) was developed by Genwest, Inc. funding from the US Department of the Interior, Shell Oil, and the American Petroleum Institute, and input from NOAA, USCG, and industry personnel. This system, as RC, provides estimations for the three basic types of oil spill response techniques: mechanical, dispersant, and burning.
- Response Calculator (RC) is a software tool developed by RPS for EMSA to understand and quantify, at a regional level, Europe's capacity to respond to a significant marine oil spill. The tool provides a comprehensive database of oil recovery resources and equipment. The RC is based on some assumptions and simplifications that are planned to be improved by the development of the new system required by EMSA. The RC simulates three basic types of oil spill response techniques: mechanical oil recovery, surface dispersant application, and in-situ burning.

4.2.1. Estimated Recovery System Potential Calculator (ERSP)

The ERSP Calculator is primarily a planning tool for estimating the potential for mechanical recovery of spilled oil by an advancing skimming system. The ERSP Calculator was developed to provide an encounter-rate based estimate of daily recovery potential for advancing skimming systems operating in open waters, in warm or cold climates, without the effects of ice, debris, or extreme weather conditions. It is a model previously based on ROC.

The calculator accommodates a broad range of skimming system configurations and addresses response activities including the accessing, containment, and recovery of oil. It also accounts for the storage and possible decanting of recovered free water, the transiting of a skimming system to and from secondary storage, and the offloading of recovered fluids.

Since it is the base version from where the ROC system was developed and because of sharing a similar methodology, this system is currently deprecated by the extensive use of the ROC and it is discarded for this consultancy. However, further information about this system can be found in the following website: https://www.bsee.gov/what-we-do/oil-spill-preparedness/response-system-planning-calculators.

4.2.2. Response Operations Calculator (ROC)

ROC is a free and open-access oil spill planning and response model that can be used to assess system performance of oil spill response methods, including mechanical recovery, dispersant application, and the in situ burning of oil (https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-options-calculator-roc). ROC predicts how the spilled oil weather over time and the volume of oil that can be recovered, treated, or burned for the response systems selected. As will be commented below, ROC's methodology integrates all the unclassified performance reduction of the recovery process into the Throughput Efficiency (TE) term. Moreover, to take into account the weathering of oil, ROC is based on ADIOS weathering model (NOAA). The viscosity provided by ADIOS, as well as the met ocean conditions, are used to calculate the Recovery Efficiency for different Skimmer Groups (described below).

The results provided by ROC are charts showing the predicted weathering of the simulated oil spill in the defined scenario and the estimated reduction of oil by skimming, dispersing, or burning. It is worth mentioning that ROC is integrated with GNOME as default response development in PyGNOME oil spill model.

The main weaknesses and strengths identified during the revision are listed in Table 4. Documentation of the system can be consulted on its website (https://www.genwest.com/projects/roc/)

Table 4 - Weaknesses and strengths of the Response Operations Calculator.

Weaknesses	Strengths
It does not provide or use trajectories of the oil slick	It considers the three main types of response operations
It is intended for modelling spills in open water outside of the influence of currents, land, ice, or debris.	It provides weathering simulation by the integration of the ADIOS weathering model. ROC uses the viscosity provided by ADIOS to estimate the Recovery Efficiency.
The response at multiple oil slicks cannot be simulated	It provides a connection to ADIOS oil database
It does not simulate more than 5 days	It is based on ASTM standards and guides
It does not make a cost estimation	Oil changes and reductions are hourly evaluated
Mobilization time and first transit time is user-defined	Open-access system
	Integration in oil spill model (PyGNOME)
	It can be used online

ROC methodology for the estimation of the recovery product is based on the Encounter Rate (EnR) (Dale, 2011). ROC methodology is supported by the following affirmation: “It is not possible to recover, disperse, or burn more oil than that which is encountered.” For that reason, the first step of the methodology is to calculate the Encounter Rate, defined as a function of the average thickness of the oil slick (*t*), the speed of advance of the response system (*v*), and the swath (*w*) of the response system.

The total fluid volume that a skimming system recovers can include oil, stable emulsion, and free water. According to ROC, Throughput Efficiency (TE) is the percent oil or stable emulsion recovered on board the skimmer from the volume of oil or stable emulsion encountered. The ROC default value for TE is 75%.

Recovery Efficiency (RE) is the percentage oil or stable emulsion in the total fluid volume recovered on board the skimmer. For example, if the total volume of a skimmer recovers half oil/emulsion and half free water, then RE = 50%. ROC groups skimmers into 3 groups. Group A, associated with the highest recovery efficiencies, includes the oleophilic skimmers – drum, disc, brush, belt, and rope-mop. Group B includes paddle belt, fixed and moving submersion plane skimmers. Group C, the least efficient, includes air conveyor, wier, direct suction, and vortex skimmers. ROC Recovery Efficiencies are based on the Skimmer Group, the wind speed, and the viscosity of the oil (see Section 4.2.2). These diagrams are based on tank tests and field trials for recovery systems. According to ROC, the user is urged to use these efficiency plots simply as rough approximations for a given system when more accurate information is unavailable.

Based on the ROC methodology, Oil/Emulsion Encounter Rate (EnR) can be calculated as:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s) \quad (5)$$

where *t* (oil thickness), *w* (swath), and *v* (vessel velocity) have been previously defined.

The Oil/Emulsion Recovery Rate (ORR) is the volume of oil/emulsion recovered on-board the skimmer per unit time:

$$ORR\ (m^3/s) = EnR\ (m^3/s) \times \mathrm{TE}/100 \quad (6)$$

The Total Fluid Recovery Rate (TFRR) is the volume of oil/emulsion plus the volume of free water recovered on board the skimmer per unit time. The Oil/Emulsion Recovery Rate may also be expressed as:

$$ORR\ (m^3/s) = TFRR\ (m^3/s) \times \mathrm{RE}/100 \quad (7)$$

Therefore,

$$TFRR\ (m^3/s) = EnR \times \mathrm{TE}/\mathrm{RE} \quad (8)$$

Figure 10 summarizes the ROC methodology to estimate the mechanical recovery response. This methodology allows the estimation of very optimistic Total Fluid Recovery Rates, estimating levels which may not be realistic, reaching the Nominal Plate Capacity of the skimmer which is well known to be over-estimated due to it being measured under high-controlled conditions by the manufacturer (usually in a pool pumping clean water with no waves and no winds). No further information about a sequential estimation of the Throughput Efficiency has been found.

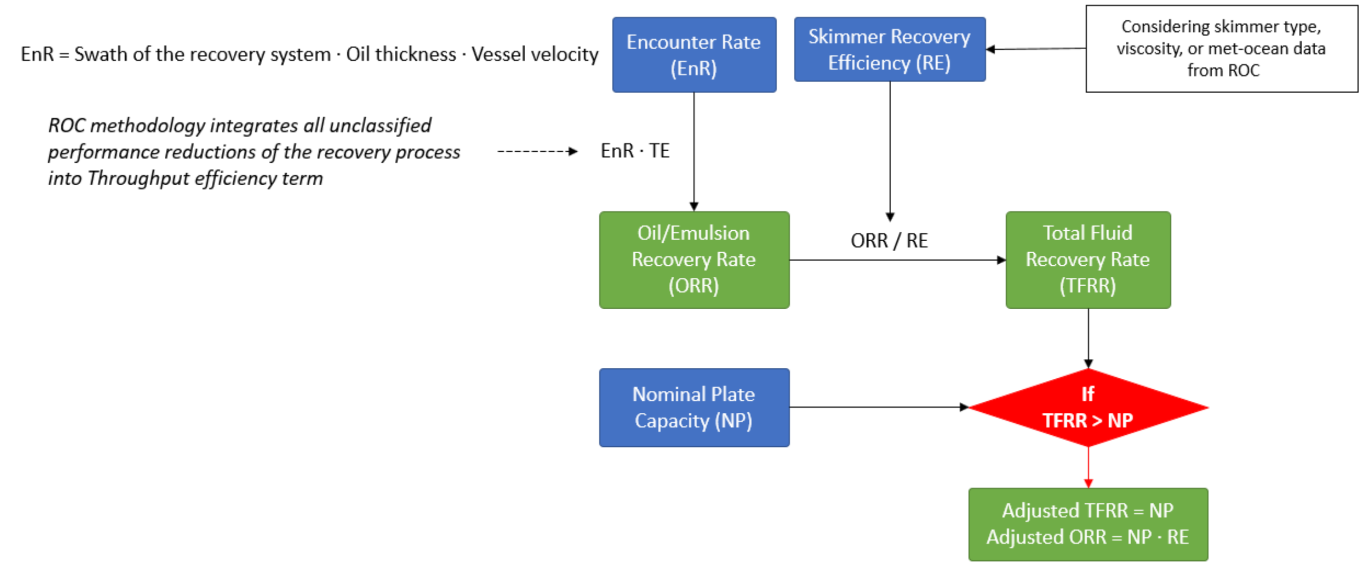

Figure 10 - ROC methodology to estimate mechanical recovery response.

Figure 11 shows a graphical example in order to illustrate the main terms involved in a methodology for mechanical recovery.

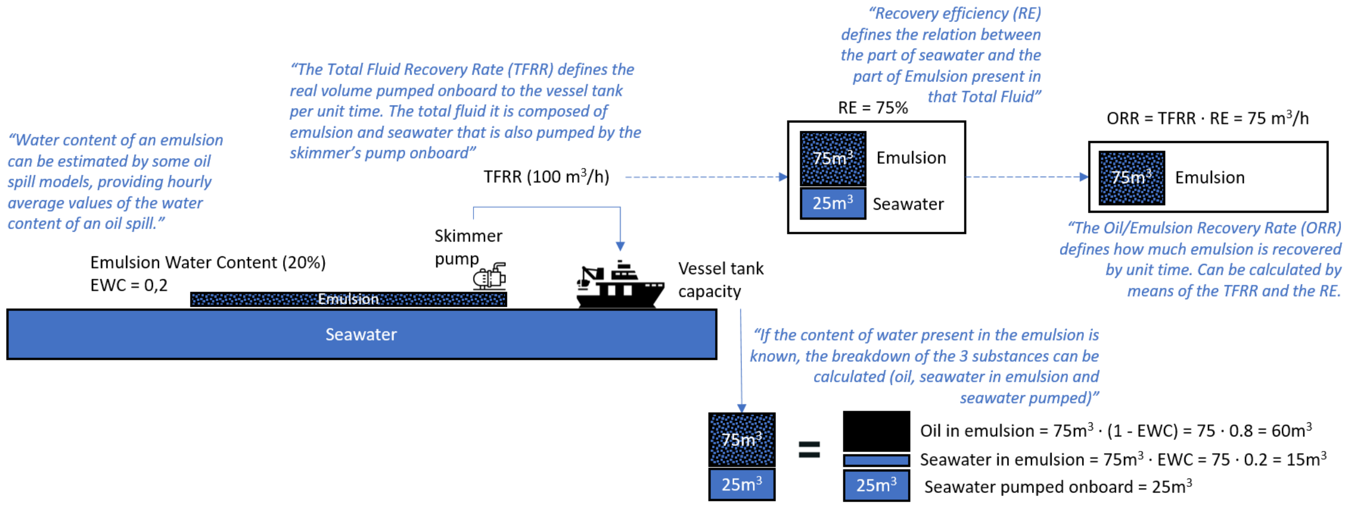

Figure 11 – Graphical example to illustrate the main terms involved in a methodology for mechanical recovery.

4.2.3. Response Calculator (RC)

Response Calculator estimates the amount of recovered oil and associated costs for removing the oil from the sea surface by using the oil pollution response resources from EMSA and the Member States. The tool uses as a basis for its calculations weathered oil, which has changed its original physical and chemical properties and has an impact on the removal efficiency of the response assets. The system does not include geospatial visualization or any spatial analysis different from the mobilization and transit times to the point where the spill remains static over the entire simulation.

The system provides highly intuitive charts where the evolution of the oil/emulsion product with and without recovering operations, and the total product recovered are shown, combined with a Gantt chart and a cost summary of the operations.

Response Calculator was based on several assumptions to simplify the complex and permanently evolving process of a response operation at sea. The main weaknesses and strengths identified during the review are summarized in Table 5.

Table 5 - Weaknesses and strengths of the Response Calculator.

Weaknesses	Strengths
Met ocean data is considered as constant values representative for winter or summer seasons	It applies skimmer rules to evaluate the effectiveness of the response
Oil slick location remains static	It includes mobilization time and cost estimation
Oil thickness is not considered	It applies adequate rules for pairing stand-alone equipment with adequate vessels
The encounter rate is not considered	It includes a comprehensive database of equipment and their properties
Pairing equipment rules are only implemented as a recommendation in the documentation	It simulates the three basic types of oil spill response techniques
The model is not re-initialized after recovery operations or with new information about the spill observations.	It estimates oil recovery based on the skimmer performance by several specific reductions
Mobilization time and first transit time is estimated based on path-finding algorithms	It is based on the wide experience of the Members States
Response at multiple oil slicks cannot be simulated	

Response Calculator estimates skimming operations based on a sequence of reductions over the skimmer nominal plate capacity. The methodology used in RC is based on the manufacturer skimmer's nominal plate capacity. Sequentially, several reductions are applied in order to approximate the recovery rate of the skimmer to the actual performance observed in operations during this kind of emergency (see Figure 12).

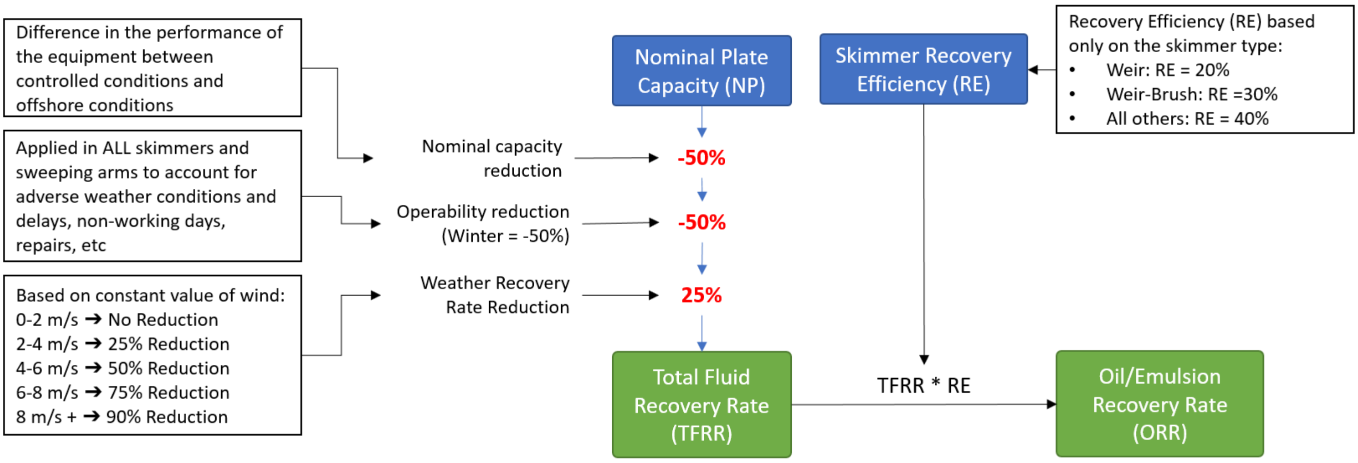

Figure 12 - Response Calculator methodology to estimate mechanical recovery capacity.

4.2.4. Comparison of the response systems

Following the review of the top cut-edge response systems available, the comparison of the main aspects and characteristics is summarized in Table 6.

Table 6 - Response systems comparison.

Main aspects of the system	RC	ROC
Met ocean conditions	Time-constant	Time-constant or time-varying
Recovery Rate estimation	Constant value for the entire response	Time-varying value (hourly)
Max simulation days	No limit	5 days
Oil slick thickens used	Not considered	Constant value or hourly value
Encounter rate estimation	No	Yes
Skimmer Recovery Efficiency is based on	Skimmer type	Skimmer type and weather conditions (wind or wave) or product viscosity. Efficiency used is the most unfavourable of both possibilities
Oil database integrated	None	ADIOS oil database
Oil spill trajectory model integrated	None (it can use OILMAP results)	None (but ROC is integrated into PyGNOME)
Multi-spill approach	No	No
Pairing stand-alone equipment rules	Well documented rules but not automatically implemented	Few fixed pairings and users can create new ones.
Estimation of mobilization time and first transit time	Yes, using path-finding algorithms	User-defined
Cost estimation	Yes	No

Based on the comparison of the RC and ROC systems, the following potential improvements regarding to the state-of-the-art for the future new system have been identified (more details in Table 7):

- The first improvement is related to the capabilities of the system to simulate the oil spill in a more realistic approach, considering the dynamic evolution of the slicks and the simulation of multiple slicks.
- The second improvement relates to the implementation of the encounter rate. As mentioned, the rate at which one can encounter a specific volume of floating oil is one of the most important parameters in the overall assessment of a given response system's ability to access and eliminate spilled oil. The encounter rate can be calculated as a function of the system's swath, the vessel velocity, and the average thickness of the oil encountered.
- The third improvement proposed is to apply recovery rate reductions due to adverse weather based on hourly met ocean forecasts provided by the European forecasting systems, instead of a constant pre-defined value for the entire operation. Section 6 presents a detailed description of the European met ocean services and the recommended data sources for this analysis.
- Finally, the fourth improvement concerns the implementation of a daily operability assessment based on the aforementioned weather forecast systems. This assessment will allow us to determine which days will be not feasible to conduct the response operations and to assess the user on the window of opportunity for oil spill response at sea considering the weather conditions and the characteristics of the weathered oil (oil spill thickness).

4.2.5. Conclusions

As a conclusion of the review carried out, the following specific improvements to be considered in the new system have been identified (see Table 7):

Table 7 – Specific improvements for the new system.

	Potential improvements for the new system	Remarks
Regarding Oil Spill Modelling	■ To integrate an oil spill model to simulate the transport and fate of the oil spilled (temporal evolution) ■ To import data from third-party oil spill models ■ To run several independent spills to take into account the division of the oil spill into several slicks ■ To incorporate the temporal evolution of the oil thickness ■ To re-initialize the simulation with new information regarding the slick evolution (e.g. polygons obtained from observations)	■ Oil spill models do not simulate the division of the oil spill. It can be approached by the simulation of multiple independent slicks; ■ The thickness estimation is complex and may include uncertainties. Besides the information provided by the model, the system will also allow the user to select a constant value (e.g. obtained from observations). ■ To re-reinitialize a simulation using the previous weathering conditions provided by the model (oil density, thickness, viscosity, emulsification…) is not a common functionality in oil spill models. Oil substance properties (density, water content, viscosity…) would be needed to set up for each simulation.
Regarding Met ocean conditions	■ To use weather forecasts (wind, waves, currents, temperature…) provided by met ocean forecast systems.	■ Forecast temporal horizon is limited approximately to 5-6 days at regional scale and 10 days at global scale (this value may vary depending on the data source). ■ The spatial resolution of regional systems is appropriate at regional scale (open sea) ■ To better characterize the weather conditions near the coast, and therefore to improve the simulations in coastal areas, high-resolution met ocean data are required, especially downscaled currents provided by coastal and local hydrodynamic models.
Regarding the operability of the response operation and the window of opportunity	■ To integrate operability assessment based on weather forecasts to determine which days will not be feasible to conduct the response operations due to adverse met ocean conditions or insufficient oil spill thickness to ensure the recovery of the oil/emulsion product.	■ The temporal forecast period of the operability assessment and the window of opportunity will depend on the forecast temporal horizon of the met ocean data source. ■ The spatial resolution of regional systems is appropriate at regional scale (offshore).

	Potential improvements for the new system	Remarks
	■ To integrate the estimation of the window of opportunity based on weather forecasts, oil weathering provided by oil spill models, and the operability limits for the response techniques.	
Regarding the Recovery Rate estimation	■ To estimate a time-varying recovery rate. ■ To use met ocean forecasts (hourly temporal resolution) to estimate the skimmer's performance reductions.	
Regarding the Encounter Rate estimation	■ To integrate the estimation of the encounter rate to limit the maximum oil/emulsion recovery rate.	
Regarding the Skimmer Recovery Efficiency	■ To consider the option of integrating recovery efficiency based not only on skimmer type (using met ocean and oil properties based on ROC recovery efficiency charts).	■ ROC documentation indicates that these charts are a rough approximation to be used when no more accurate information is available.
Regarding the Pairing stand-alone equipment rules	■ To integrate pair equipment rules automatically to support the user on the selection of the most adequate assets to be used and avoid incompatible or inefficient pairings.	
Regarding oil and resources databases	■ To integrate an oil database from EMSA (if available) or a public database (e.g. ADIOS) ■ To integrate the resources database (from RC) ■ The user should manage both databases (e.g. add new elements, modify, delete, copy….)	

The feasibility to integrate these improvements in the new system is analyzed in Section 3 (issues related to the oil spill model), Sections 4 and 5 (issues related to the response simulator) and Section 6 (issues related to the met-ocean data). In these sections, different technical solutions are provided, analyzing their advantages and dissadvantages. Moreover, the feasibility of the technical solutions proposed will be further analysed in the report on Part 2.

5. METHODOLOGY FOR THE RESPONSE SIMULATOR

A new methodology to simulate response operations during an oil spill emergency involving EMSA collaboration is defined in this section. Firstly, a conceptual diagram is shown in Figure 13 to summarize the main user interaction with the system and the key steps that the methodology will achieve to estimate the response operations.

The user interaction with the system interface will facilitate the loading of the results of an oil spill simulation (including the evolution of the centre of mass of the spill and the evolution of the main properties of the oil substance: density, viscosity, thickness…) into the system. Moreover, the user will have to select the met ocean databases desired to take into account during the simulation of the response. Finally, the user will have to assign the response assets based on compatible resources and equipment to be used during the recovery simulation.

The system will provide a default working day to allow schedule operations, which will be the base for the calculations carried out for the total *N* days of the simulation. This working day definition would be changed optionally by the user to satisfy the requirements of the different Member States and actors involved in the operations.

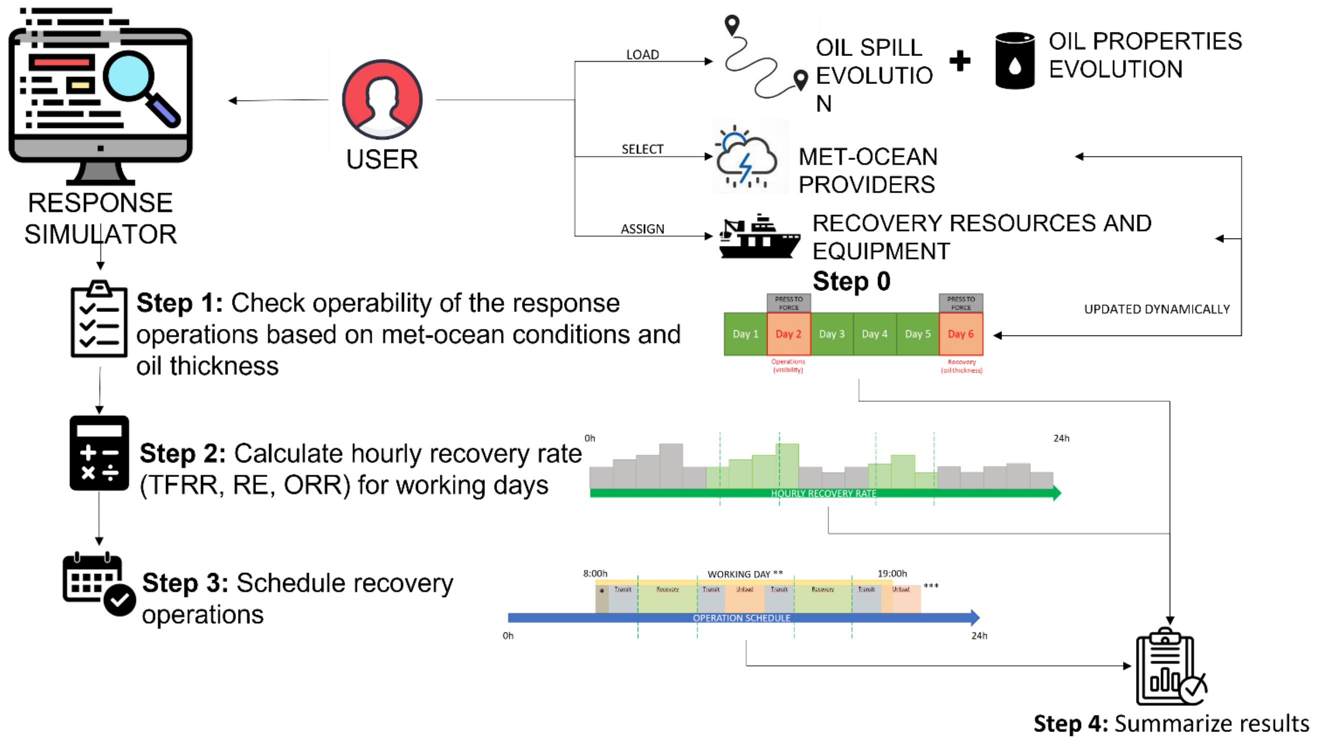

Figure 13 - Conceptual design of the Response Simulator and the user interaction to estimate the mechanical recovery response.

The methodology proposed for the RS can be divided into a so-called "step 0", which focused on the initial mobilization of resources, plus four more steps, focused on the operations in the emergency scene:

- **Step 0 – Assignment of resources:**
  This step has to be automatically triggered when an oil spill simulation result is loaded in the RS. Based on the initial point of the centre of mass of the spill, a sorted list for each recovery equipment has to be visualized in the GIS interface to support the user in the selection of the resources. This list will be sorted by taking into account the minor mobilization time required for each piece of equipment. In the case of the skimmers, the viscosity of the oil will be also considered to sort this kind of equipment. Options for pairing stand-alone equipment (identified in the database of response assets) with adequate vessels are provided in Section 5.1.

- **Step 1 – Check if recovery operations are feasible on the specific working day of the simulation:**

Once selected the response technique and the assets, this step will check if recovery operations are feasible on the specific working day of the simulation. The operability limits of the general aspects for safety, such as environmental temperature and visibility, will be considered. Complementary, specific met ocean relevant variables will be checked to ensure that each specific equipment will be used under its required conditions. Based on this information, the system will provide the window of opportunity for the response operation (see Section 5.2). Before running the simulator, the user shall confirm the feasibility of the operation. If the operation is not feasible for a working day, the user will have the opportunity to force the working day despite the recommendation regarding windows of opportunity and operational limits.

- **Step 2 – Calculate hourly recovery rates for that specific working day:**
  Total Fluid Recovery Rate (TFRR) and the Oil/Emulsion Recovery Rate (ORR) will be calculated based on the new methodology for mechanical recovery response. This new estimation takes into account the encountered rate as the maximum oil volume possible to be recovered per hour (see Section 5.3 and Section 5.4). Methodology for the estimation of dispersant application and in-situ burning remains as proposed in the Response Calculator.

- **Step 3 – Schedule recovery operations for that specific working day:**
  Once hourly recovery estimation is calculated, it is possible to define the schedule of the recovery operations, usually defined in blocks of transit – recovery – transit – unload. It is proposed to add a daily time backup to take into account possible maintenance of the equipment, delays, and other unpredictable and inefficient periods. It is also desirable to accept the unload of the recovery product outside the working day (optionally). This would be up to the user to consider.

- **Step 4 – Summarize results for the simulation time horizon:**
  At this step, all the information required to define the final results is calculated at hourly time resolution. The results provided by the RS will be: (1) the amount of oil removed/dispersed/burned, (2) the operation schedule, and (3) the cost summary of the operations.

The different elements of the methodology are analysed in the following sections.

5.1. Options for pairing stand-alone equipment

The objective of this section is to identify and assess options for pairing stand-alone equipment (identified in the database of response assets) with adequate vessels. This issue is addressed in Step 0 of the proposed methodology.

5.1.1. Definition of resource properties

First of all, the main properties of vessels, stand-alone equipment, and the different configurations for each response technique have to be established and, as far as possible, to be incorporated into the databases of response assets.

On one hand, for marine operations vessels can be classified into two groups:

- Specialized Oil Spill Recovery Vessel (OSRV) is a dedicated vessel always equipped with oil spill response equipment to carry out mechanical recovery, in situ burning, or dispersant application autonomously. These vessels are fully equipped and do not require to be complemented with other assets.
- Vessel of Opportunity (VOO) is a non-dedicated vessel for oil response operations. These vessels are dedicated to different activities (normally sea rescue activities, research, fishing vessels, bulk tank…) to respond during major oil spills so during the emergency they can be equipped with compatible stand-alone equipment for realizing mechanical recovery (booms and skimmers), in situ burning (fire booms and ignitor), or dispersant application (dispersant application system, DAS). These vessels can be very different types and the jobs VOO may be assigned will depend on the oil spill response and their capacities.

The following information would be required to have an approach to their capabilities to be paired with the equipment:

  - Deck space (m^2)

- Available deck space to storage (m^2)
- Loading capacity (tons)
- Lifting appliances/ crane (tons)
- Tow or Deploy capabilities
- Towing capacity (tons)
- Storage capacity (m^3)
- Other capabilities (specific equipment, crew number...)

On the other hand, stand-alone equipment refers to the necessary assets to carry out the different response options (booms, fire booms, combined equipment, trawl-nets, skimmers, dispersants, and dispersant application systems). Each piece of equipment has its basic properties and requirements to be loaded and deployed, such as:

- Storage space needed (i.e. 20ft container: 38,54 m^2)
- Clear space to operate (i.e. 3-4 meters in front of the container doors)
- Open gunwale to deploy/recover (i.e. yes/no)
- Lifting appliances/ crane to deploy/recover. (yes/no)
- Weigh (tonnes)
- Tow Speed (m/s)
- Number of vessels to tow and deploy
- Crew needed to deploy and control.
- Total meters available and sections of 250 m. (to containment booms)

This information shall be included in the database of the resource properties. These data are normally available in the equipment's data sheet or can be facilitated by owners.

Regarding the configuration for each response technique, Table 8 shows an overview of the potential configurations of the equipment in each specific case.

Table 8 - Potential configuration of the equipment for each response technique.

Mechanical recovery	Dispersant	In Situ burning
■ Only Booms ■ Booms + Skimmer ■ Booms + Skimmer + Storage ■ Combined equipment: containment booms & skimmer (i.e. [redacted]…) ■ Combined equipment + Storage ■ Trawl nets: containment & storage ■ Only Storage	■ Dispersant ■ Dispersant application system	■ Fire boom + ignition kit

5.1.2. Pairing stand-alone equipment with vessels

Once defined the aforementioned properties, the stand-alone pairing equipment with adequate VOO can be established taking into account the following aspects:

- Operation Mode of the VOO

During the operations at sea, the vessel adopts a role or mode based on the activity that is carried out (tow mode or deploy mode) and depending on its characteristics.

As previously mentioned, the database of resource properties shall include the different capabilities of each vessel. If this information is not available, based on the rules defined in the RC, mode operation could be approached with the deck space (K). This value can be used to define whether the vessel can tow or tow and deploy equipment. Deck space is calculated with VOO length (L) multiplied by its breadth (B), deck space equation reads as follows:

$$K(m^2) = L(m) \cdot B(m) \tag{9}$$

Table 9 - Tow and deploy capabilities of VOO based on its deck space.

Deck space (K)	Allowed capabilities
K < 200	Tow (only)
K > 200	Tow and deploy

The operation mode of the VOO will define what kind of equipment can be paired with:

- If a VOO just can tow, just equipment for towing can be selected (storage, booms, or fire booms). Based on RC assumptions, when a VOO is in Tow Mode, cannot afford Dispersant response.
- If a VOO can tow and deploy, the selection of equipment is wider (skimmer, fire booms, booms, combined equipment, storage, dispersant, or a dispersant application system).

The selection of the equipment also depends on the deck available area. As established in RC, it has to be into account that from the total dimensions of the vessel, 15% of the deck must be available for storing and operating the equipment. If this 15% is not available, the VOO just is disposed to tow operation without charging equipment.

- Selection of the equipment for the VOO

Two options are proposed for the selection of the equipment:

- Option 1: based on the information previously mentioned. This option provides a more realistic approximation since it is based on the properties of the vessels and the size of the stand-alone equipment. This option requires the elaboration of a complete database of resources and equipment properties with all the information required.
- Option 2: based on the rules of the Response Calculator, which establishes the classification of all the stand-alone equipment as Large or Small. This option requires less information about the properties of the resources.

OPTION 1

A vessel just can deploy one type of response at once, although different types of responses are on board. For proper distribution of the equipment to deploy a complete response, the following general criteria based on the resource properties are proposed:

- For a chosen VOO the system will provide only that equipment that by its size (storage space + operation space needed) can fit with the available deck space, does not exceed the maximum weight, or meet the special needs required (as a crane).
- When a complete response is loaded in a VOO (i.e. boom + skimmer + storage), but there is still available space, another response could be added (i.e. add dispersant + DAS) if possible.
- Some VOO already has some type of built-in response (that should be indicated in the resource properties). To these VOO, new assets can be added, to complete the response already integrated (i.e. a VOO with dispersant application system can be complemented with dispersants) or to create another response. The storage available indicated in the resource properties of these VOO must be the real one, with those assets integrated.

Thus, for each type of response a piece of equipment can be selected until a full response is complete (i.e. if the user selects a boom, the rest of the booms are cancelled so he can complete the response with skimmer + storage). The response is complete when:

- The user determines that the response is complete.
- The maximum weight or the maximum storage space available of VOO is overcome. In this case, a second vessel should be activated to be completed with the remaining necessary equipment.

To conclude, the user has to be able to select the characteristics in a sequence response +vessel + equipment (available) (see Table 10):

- Selection of the response technique (based on the operability assessment and the window of opportunity or other criteria considered by the user).
- Selection of vessels (OSRV or VOO) from each sub-group list (sorted by mobilization time). Vessel > Type > Sorted list of vessels. In the case of dispersant response, aircrafts available too.
- Operation Mode: Tow or Deploy (and tow), according to the information selected in previous steps.
- Specific response equipment from desired response types. Specific response > Type > List of equipment. The system will provide a list of equipment according to the information selected in previous steps, i.e. compatible with the response technique, the location of the selected vessels, the operation mode, and the characteristics of the vessel. As mentioned, the system will provide the list of equipment that can fit with the available deck space, does not exceed the maximum weight, or meet the special needs required (as a crane). Note that the available deck space will be recalculated taking into account the integration of each asset.

Table 10 - Sequence of the selection of the equipment.

Selection sequence	Main category	Type
Response selection	Response types	Mechanical recovery
		Dispersant
		In situ burning
Vessel	Vessels	OSVR
		VOO
	Aircraft (just to Dispersant response)	Aircrafts
Operation Mode of the VOO (based on the capabilities of the VOO)	Operation Mode	Tow (for mechanical recovery and In situ burning)
		Deploy (and Tow) (for Mechanical recovery, In situ burning, and Dispersant)
Specific equipment available based on the vessel characteristics (i.e. required space, available crane,…)	Mechanical recovery equipment	Booms
		Skimmer
		Combined equipment
		Storage
		Trawl nets
	Dispersant application equipment	Dispersant application system (DAS)
		Dispersant
	In situ burning equipment	Fire boom

OPTION 2

Based on the RC the stand-alone equipment is defined as small or large equipment and VOO are classified into small or large VOO in the “size” property of the RC database (the criteria for the definition of small or large VOO are not provided in the RC). Based on vessel classification and equipment size the following rules can be applied directly for large VOO (Table 11) and small VOO (Table 12).

Table 11 - Large VOO capacity rules.

Deck space	Operation mode	Equipment size	Equipment capacity	Allowed equipment
K < 200	Tow	Small/Large	1 piece of each type	Storage, boom (up to 500 m), fire-boom
K > 200	Tow	Small/Large	1 piece of each type	Storage, boom (up to 500 m), fire-boom
K > 200	Deploy	Small/Large	1 piece of each type	Skimmer, boom (up to 500 m), Hi-speed containment systems storage, fire boom, small dispersant system (DAS and up to 4 m3 of dispersant), or large dispersant system (DAS and up to 20 m3 of dispersant)

Table 12 - Small VOO capacity rules.

Deck space	Operation mode	Equipment size	Equipment capacity	Allowed equipment
K < 200	Tow	Small	1 piece	Storage, boom (up to 250 m), fire-boom
K > 200	Tow	Small	1 piece	Storage, boom (up to 250 m), fire-boom
K > 200	Deploy	Small	1 piece	Skimmer, boom (up to 250 m), sweeping arms, storage, fire boom, small dispersant system (DAS and up to 4 m^3 of dispersant)

This option is less realistic than Option1 as it does not take into account the available deck space of the vessel and the size and needs of the equipment. Moreover, it only allows the selection of the equipment specified in (Table 11) and (Table 12), regardless of the available deck space left. However, it requires less information about the properties of the resources, which can be an advantage when the availability of information is limited.

5.2. Operability assessment and window of opportunity

The objective of this section is: i) to analyze the aspects that influence the operability of the response operation and ii) to identify and assess the possibility of having a warning message displayed to the user on the window of opportunity for oil spill response at sea considering the weather conditions and the characteristics of the weathered oil. These aspects are addressed in step 1 of the proposed methodology.

Response operations are strongly impacted by met ocean conditions as any operation at sea. The operability assessment provides the met ocean conditions in which these specific operations can be carried out to ensure the safety and performance of the personnel and the equipment. Operability assessment has been divided into two main sections: 1) general operability related to general factors such as visibility, met ocean or environmental temperature; and 2) operability limits for each response technique based on weather conditions and the characteristics of the weather oil.

Moreover, the window of opportunity defines the time periods for effective utilization of marine oil spill response technologies and methodologies in clean-up operations (Norvidvik, 1999) and mainly depends on the changes in the physical and chemical properties of the oil (oil weathering) and the weather conditions. The window of opportunity will be estimated based on the operability limits established for the response operations techniques as part of the operability assessment.

5.2.1. General operability

This section presents the main factor affecting the general operability of the response operation. The most important variables constraining the operability of the response are the met ocean conditions that ensure the safety of the personnel and the safety of the navigation. In Table 13, the collection of variables and operability limits regarding navigation and personnel safety are shown. Wind velocity for small and large VOO as well as for OSRV has been established based on RC. The general value of the wave height for all vessels has been considered taking into account the operability limits for booms and assuming that vessels do not operate if the equipment cannot be deployed. Temperature and visibility values have been obtained from the Circumpolar oil spill response viability analysis technical report (EPPR, 2017). It is important to highlight that Table 13 presents general values that can vary for specific types of vessels. Furthermore, staff safety is of paramount importance. Ultimately, these operational limits must be set by the corresponding Maritime Authority.

Table 13 - General operability topics, variables, and limits.

Topic	Variable	Operability limit
Navigation (Small VOO)	Wind velocity	< 5 m/s
Navigation (Large VOO)	Wind velocity	< 10.8 m/s
Navigation (OSRV)	Wind velocity	< 10.8 m/s
Navigation (All vessels)	Wave Height	< 3 m
Personnel safety	Temperature	> -18 ºC
Navigation (All vessels)	Visibility	200 – 900 m

Operability assessment will be evaluated for each day of simulation. In order to be flexible with the usual uncertainties and outliers of any forecast, it is proposed to use a statistical value as representative of the working day, e.g. 80% percentile, which allows exceeding the limit value defined for each variable during a maximum of 20% of the working day is proposed. The user will be allowed to modify this percentile value to create a more flexible or restrictive assessment of the operability.

5.2.2. Operability for each response type

Differences between each type of response and the equipment and operations involved determine the accomplishment of some specific limits to ensure the safety and success of the works. To enhance the clarity of the document these specific operability limits have been grouped by response type as follows:

- In situ burning

The application of this response in the EU has to be approved by the competent authority, after the authentication of several strict requirements related to minimum distances from populated areas or special protection areas and the safety of the operators.

Once this type of response is authorized, the time window for ignition and sustained burning will vary, depending on environmental conditions, physical properties, and chemical composition of the spilled oil. Once the initially hazardous and high fire risk situation has passed, the time window of opportunity for the use of in situ burning as an oil spill response opens, and in situ burning will become a feasible response. The time window of opportunity for the use of in situ burning will eventually close when the slick becomes impossible to ignite due to the oil layer thickness drops below a critical minimum, the oil has lost a substantial proportion of its more volatile and flammable components by evaporation, and when the oil has incorporated water to form an emulsion.

For a successful in-situ burn the layer of oil on the sea surface needs to be at least 2-3 mm thick to counter the cooling effect of the wind and sea and maintain a fuel source for the fire (API, 2015, https://www.itopf.org/knowledge-resources/documents-guides/response-techniques/in-situ-burning/). The ignition and sustained burning of weathered oil using conventional ignition technology is restricted by approximately 25% evaporation and or a 25% water content (API 2015) and wind velocity and wave height (Fingas, 2011; API 2015).

Table 14 shows the specific variables and operability limits for this response based on API (2015).

Table 14 - Specific variables and operability limits related to In situ burning response (API, 2015).

Topic	Variable	Operability limit
Oil/Emulsion characteristics	Evaporation	< 25%
Oil/Emulsion characteristics	Thickness	> 2 to 3 mm thick (2 to 3 times thicker for highly weathered/emulsified oil).
Oil/Emulsion characteristics	Emulsification	< 25% (can vary for different types of oil).
Ignition and correct burning	Wind velocity	< 9.2 m/s for ignition; sustained burning possible with higher wind conditions.
Ignition and correct burning	Wave height	< 3 m swells or 1 m wind waves (may be higher with fresh and un-emulsified oil

- Dispersant application

This technique has also very restricted use in the EU and not all Members States allow its use. Dispersants are applied from aircraft or vessels, through dispersant applications systems.

As oil weathers at sea, its viscosity increases until it is no longer dispersible. Emulsification and evaporation processes increase oil viscosity and decrease its dispersibility. The time during which oil remains dispersible is called “the window of opportunity for dispersion.” It varies according to the type of oil and the environmental conditions. This period is mainly dependent on the oil viscosity (see Table 14).

A viscosity of 10,000 cSt is often used as an indication of oil’s dispersibility (IMO, 2011; EMSA, 2009). Oils with viscosity (at seawater temperature) of up to 10,000 cSt are considered to be potentially dispersible, though dispersion of oils with viscosities above 20,000 cSt is reported (IPIECA-IOGP, 2014).

Table 15 - Specific variables and operability limits related to dispersant application response.

Topic	Variable	Operability limit
General met ocean conditions	Wind velocity	Limits of the aircraft or vessel
Oil/Emulsion characteristics	Viscosity	<10.000 – 20.000 cSt

- Mechanical Recovery

This type of response is by far the most utilized by all the Member States to face large oil spill emergencies. The operability limits of this response can be divided into two main operations: boom deployment and skimmer operability.

The deployment and use of the booms to drag oil and facilitate the skimming actions require mainly good weather conditions. Table 16 presents the met ocean operability limits regarding wave height, wind, and current velocities to ensure the correct deployment and use of the booms. Note that these values are general values that may vary for specific booms, configuration deployment, or skimmer types.

Several documents have been consulted to determine the ratio in which the waves produce failure in booms. *Oil spill response field manual* from ExxonMobil (2014) establishes that splash over failure may occur in choppy water when wave height (H) is greater than boom freeboard and the wavelength/height (L/H) ratio is less than 10:1, where height/H is an indirect measurement of the roughness of the sea. Fingas (2011) referred to Van Dyck and Bruno

(1995), where is indicated that a wavelength/height ratio is not a limiting parameter when is 12:1 or greater. NOAA (2012) states that for mechanical recovery, effectiveness drops significantly because of entrainment and/or splash-over as short-period waves develop beyond 2–3 ft (0.6–0.9 m) in height. Koops and Huisman (2002) give a priori limits of Beaufort 6 (10 – 14 m/s) for skimmers and another mechanical recovery. Koops (1988) gives the limit of skimmers as 1.5 m wave heights and notes that swell has no effect on the capability to mechanically recover.

Current velocity limit values are the other main factor related to droplet entrainment and drainage failures. Entrainment failure generally occurs at current velocities between 0.7 and 1.0 kts (0.4-0.5 m/s) (Fingas, 2011; ITOPF, 2012; ExxonMobil, 2014).

Lastly, the ability to contain and recover oil decreases rapidly as the slick thickness becomes less than a thousandth of an inch or 0.00254 mm (NOAA 2012, ROC technical manual)

Oil viscosity is another factor to take into account in skimmer operability. Although the operability as a function of the viscosity will depend on the type of skimmer, there are several skimmers prepared to work in a huge range of viscosities regardless of the skimmer type. All skimmers work in optimal conditions in medium viscosities. However, a very high viscosity could produce problems or inoperability. Based on international standard *ISO 21072:2020 Performance testing of oil skimmer*, the ratios to light/medium viscosity are up to 50.000 cP and high viscosity oil above 50.000 cP and up to 1.000.000 cP, so this could be the upper limit skimmer operability.

Table 16 - Specific variables and operability limits related to mechanical recovery response.

Topic	Variable	Operability limit
General met ocean conditions (booms and skimmers)	Wave height	< 1 – 1.5 m
General met ocean conditions (booms and skimmers)	Wavelength/wave height ratio	<10:1 or 12:1
General met ocean conditions (booms and skimmers)	Wind velocity	< 10 – 14 m/s
General met ocean conditions (booms and skimmers)	Current velocity	< 0.5 m/s
Oil/Emulsion characteristics	Thickness	> 0.00254 mm
Oil/ Emulsion characteristics	Viscosity	High-viscosity and depending on the skimmer (not clear reference found)

5.2.3. Window of opportunity

As mentioned at the beginning of this section, the window of opportunity defines the time periods for effective utilization of marine oil spill response technologies, which depends on the oil weathering and the weather conditions.

The window of opportunity will be established by taking into account:

i) the hourly met ocean forecasts provided by the European forecasting systems (e.g. Copernicus Marine Service) described in Section 6,
ii) the temporal evolution of the oil weathering provided by oil spill numerical models, and
iii) the operability limits previously established for each response technique.

Based on this information, the system will provide the window of opportunity in a user-friendly way, to support the response authorities to decide and select on which assets to mobilise.To obtain a warning message about the window of opportunity for offshore oil spill response, four subsystems must work in a coordinated manner:

- (1) back-end subsystem that provides the oil characteristics,
- (2) back-end subsystem that provides the forecast of the met ocean conditions,
- (3) back-end subsystem that evaluates the window of opportunity making use of the previous subsystems and
- (4) front-end subsystem that is designed to provide a user experience in line with the information required for the end-users. The use of traffic lights across a forecasting timeline is a commonly used solution implemented for operation and maintenance systems. To illustrate this kind of graph, Figure 14 shows an example of an operability assessment in an oil terminal to support the end-user about the operability conditions for oil load and unload operations.

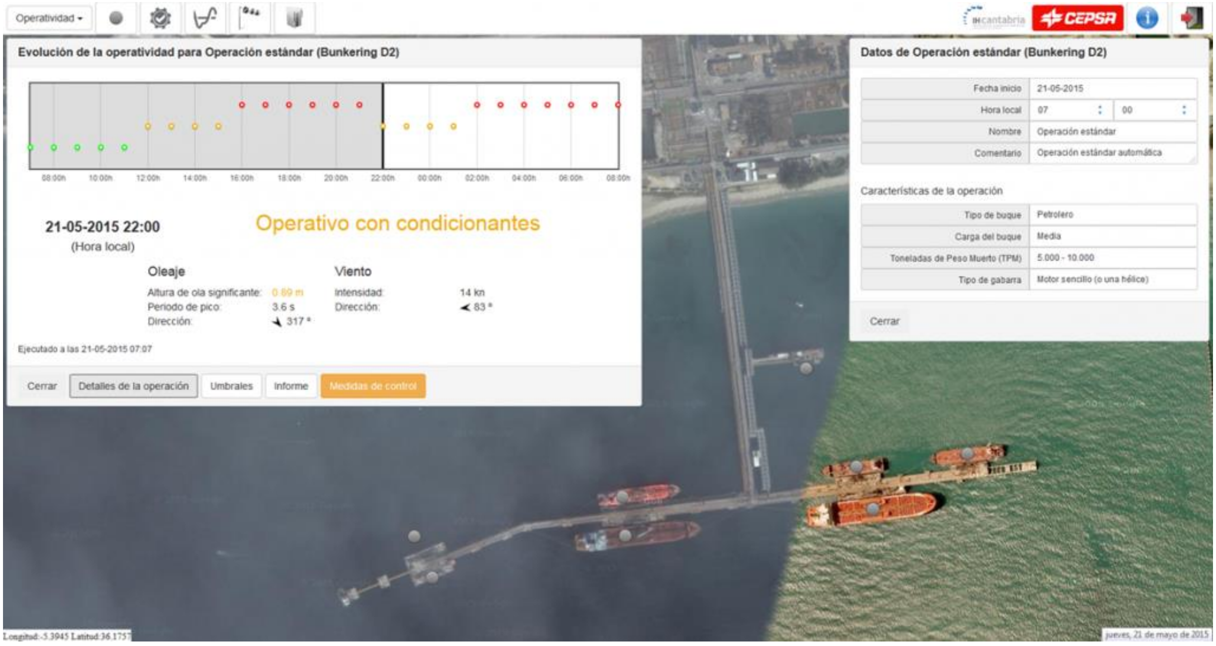

Figure 14 - Example of operability assessment for loading/unloading operations in oil terminals.

End users will interact with the front-end to invoke the window opportunity analysis and obtain the final evaluation (i.e. a warning message).

5.3. Aspects that influence the efficiency of oil spill response operations

The objective of this section is to gather information and discuss the different aspects that influence the efficiency of oil response operations at sea that could be integrated into the system (weather conditions and characteristics of the weathered surface oil), as well as to propose technical solutions to incorporate it in the system. These aspects are addressed in step 2 of the proposed methodology.

As stated in the previous section, weather conditions and oil weathering are important properties to determine the feasibility and the window of opportunity of the oil spill response techniques. Besides the operability limits that established the feasibility or not of the response operation, weather conditions and oil weathering also influence its efficiency.

Specifically for mechanical recovery, the reduction of the efficiency due to weather and oil weathering is especially important. As mentioned in Section 5.3, the Nominal Plate Capacity provided by the manufacturer in the technical documentation of the skimmer is overestimated as is calculated under controlled conditions, which are far from a real response at sea. To pass from idealized pumping performance to real pumping performance, the skimmers are affected by several factors, which have to be applied as reductions to the Nominal Plate Capacity, as shown in Figure 15.

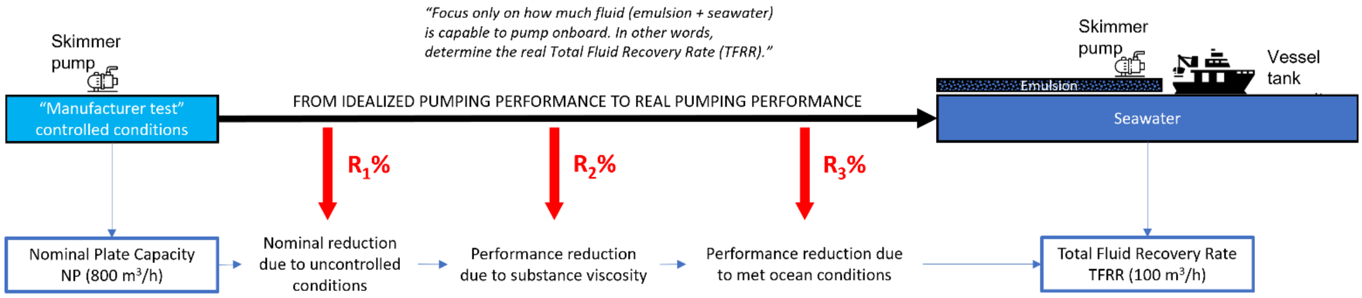

Figure 15 - Diagram of the most relevant reductions in the performance of a skimmer during a mechanical recovery response.

Thus, the following factors are suggested to take into account the nominal plate capacity reduction:

- Uncontrolled conditions (Reduction 1 – R_1): this term refers to factors different from weather conditions and weathered oil that can reduce the skimmer performance. For example, in a real response, the presence of ice (Fingas et al., 2011), or debris can reduce the performance of the skimmer even producing a failure and the consequent reparation. Moreover, the equipment is never used at full pumping capacity. Thus, this reduction is intended to be applied to simulate possible losses of performance due to these uncontrolled factors. This parameter should be stated based on expert criteria since there is not a clear and sound quantification of these reductions in the state-of-the art.

- Oil viscosity (Reduction 2 – R_2): the viscosity of the oil is a primary limitation on the efficiency of most recovery devices. Oils with high pour points, including some heavy crudes and fuel oils, generally do not flow easily. If the ambient temperature is below the pour point, the oil will become semi-solid and, hence, will be difficult to recover, since it will not readily flow towards the skimmer (ITOPF, 2012). Thus, viscosity is an important factor for skimmer performance. Not all skimmers are efficient for all viscosities. Some guidelines (e.g. ExxonMobil, 2014) defines qualitatively the performance of the different type of skimmers taking into account the oil viscosity as can be observed in Figure 16. This qualitative information can be used in addition to expert criteria to define the reductions associated with oil viscosity.

		Skimmer Type																
		Weir Skimmers					Oleophilic Skimmers								Hydro-dynamic Skimmers			*
		Simple Weir	Self-Leveling Weir	Weir with Integral Screw Auger	Advancing Weir	Weir Boom	Drum	Disc	Grooved Drum/Disc	Fabric-Coated Drum/Disc	Rope Mop	Zero Relative Velocity Rope Mop	Sorbent Lifting Belt	Brush	Water Jet	Submersion Plane/Belt	Rotating Vane	Paddle Belt
Operating Environment	Open Water	●	●	●	◑	◑	◑	◑	◑	◑	○	○	○	◑	●	●	◑	●
	Protected Water	◑	●	●	○	○	○	○	○	○	○	○	○	○	◑	◑	○	○
	Calm Water	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	High Current >1 knot (> 0.5 m/s)	●	●	◑	○	◑	●	●	●	●	◑	●	◑	◑	◑	◑	◑	●
	Shallow Water <1 foot (< 0.3 m)	○	◑	●	●	●	◑	◑	◑	◑	○	●	●	◑	●	◑	◑	○
	Debris (Including ice)	●	●	○	◑	●	◑	◑	◑	◑	○	○	○	○	◑	◑	◑	○
Oil Viscosity	High Viscosity	●	●	◑	●	●	◑	●	◑	◑	●	●	○	○	○	◑	◑	○
	Medium Viscosity	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Low Viscosity	○	○	◑	○	○	◑	◑	○	○	◑	◑	●	●	○	◑	○	◑

○ Good ◑ Fair ● Poor

Figure 16 – Qualitative assessment of several skimmer types based on oil viscosity (ExxonMobil, 2014).

- Met ocean conditions (Reduction 3 - R_3): met ocean conditions also reduce the performance of the skimmers. As previously mentioned, wind-waves are the main factor that can produce a loss in the performance of the skimmer. Since wind is an indicator of sea state, it is often used to define performance reductions. Based on the RC's methodology, the following ranges for wind are proposed to define the met ocean conditions (see Table 17):

Table 17 - Met ocean reductions based on RC.

Wind range	Reduction
0 – 2 m/s	No reduction
2 – 4 m/s	25%
4 – 6 m/s	50%
6 – 8 m/s	75%
8 m/s	90%

After these reductions, the Total Fluid Recovery Rate (TFRR) is calculated. Since the methodology proposed in Section 5 is based on hourly weather forecasts provided by European Centres (e.g. Copernicus Marine Service), the TFRR can be calculated every hour to obtain hourly time series of TFRR. As was mentioned before, TFRR is the total volume recovered on board, this volume is composed of oil or emulsion and of seawater.

Once the TFRR is estimated, the Recovery Efficiency of the skimmer has to be taken into account. RE is defined as the percentage of emulsion recovered by a skimmer with reference to the total volume of fluids recovered (emulsion + seawater). The quantification of these coefficient is complex because the natural process involves met ocean conditions, the particularities of each skimmer and the viscosity of the emulsion mainly. Therefore, the real quantity of emulsion recovered without consider the seawater pumped aboard is defined as Oil/Emulsion Recovery Rate (ORR).

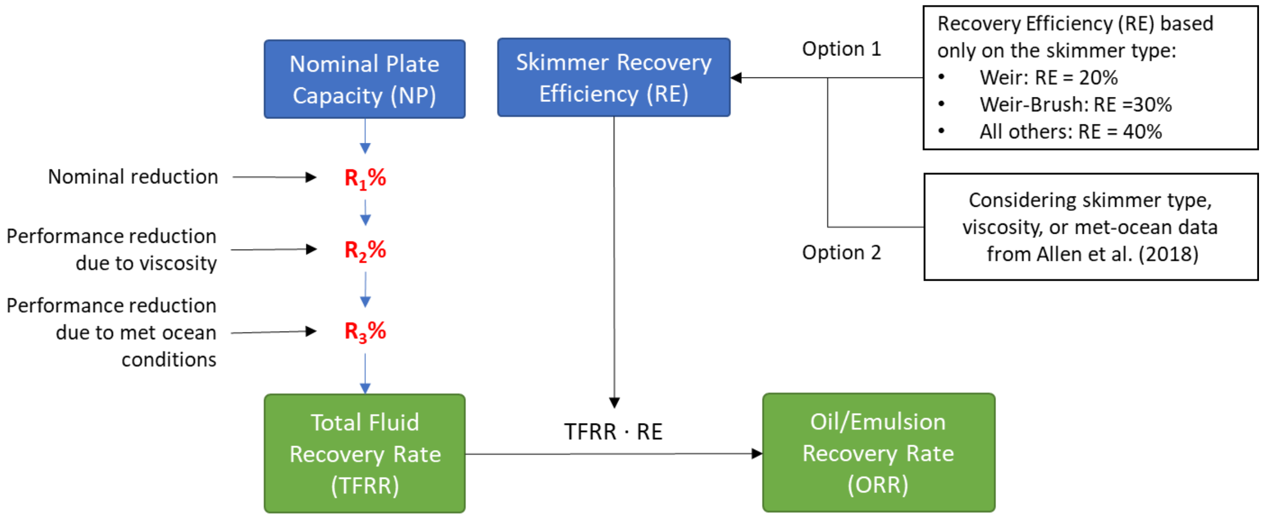

Figure 17 – Conceptual scheme about the implication of the recovery efficiency coefficient

Two potential options are suggested in order to obtain RE percentage:

- Option 1: current RC classification of the Recovery Efficiency based exclusively on the skimmer type (Table 18)

Table 18 - Skimmer's Recovery Efficiency (RE) classification of the Response Calculator.

Skimmer type	Recovery Efficiency (RE)
Weir	20%
Mix type (weir-brush)	30%
Other oleophilic types (brush, disc, belt…)	40%
High-speed systems (current buster)	70%

- Option 2: to adopt the use of the Recovery Efficiency charts provided in ROC (see Figure 18) that takes into account the minimum value obtained by both charts. Figure 18 (left panel) relates the type of skimmer with the met ocean conditions and Figure 18 (right panel) relates the type of the skimmer with the viscosity of the oil/emulsion. As mentioned, to obtain a RE for a skimming system ROC compares RE vs. met ocean conditions and RE vs. viscosity and uses the lower of both values.

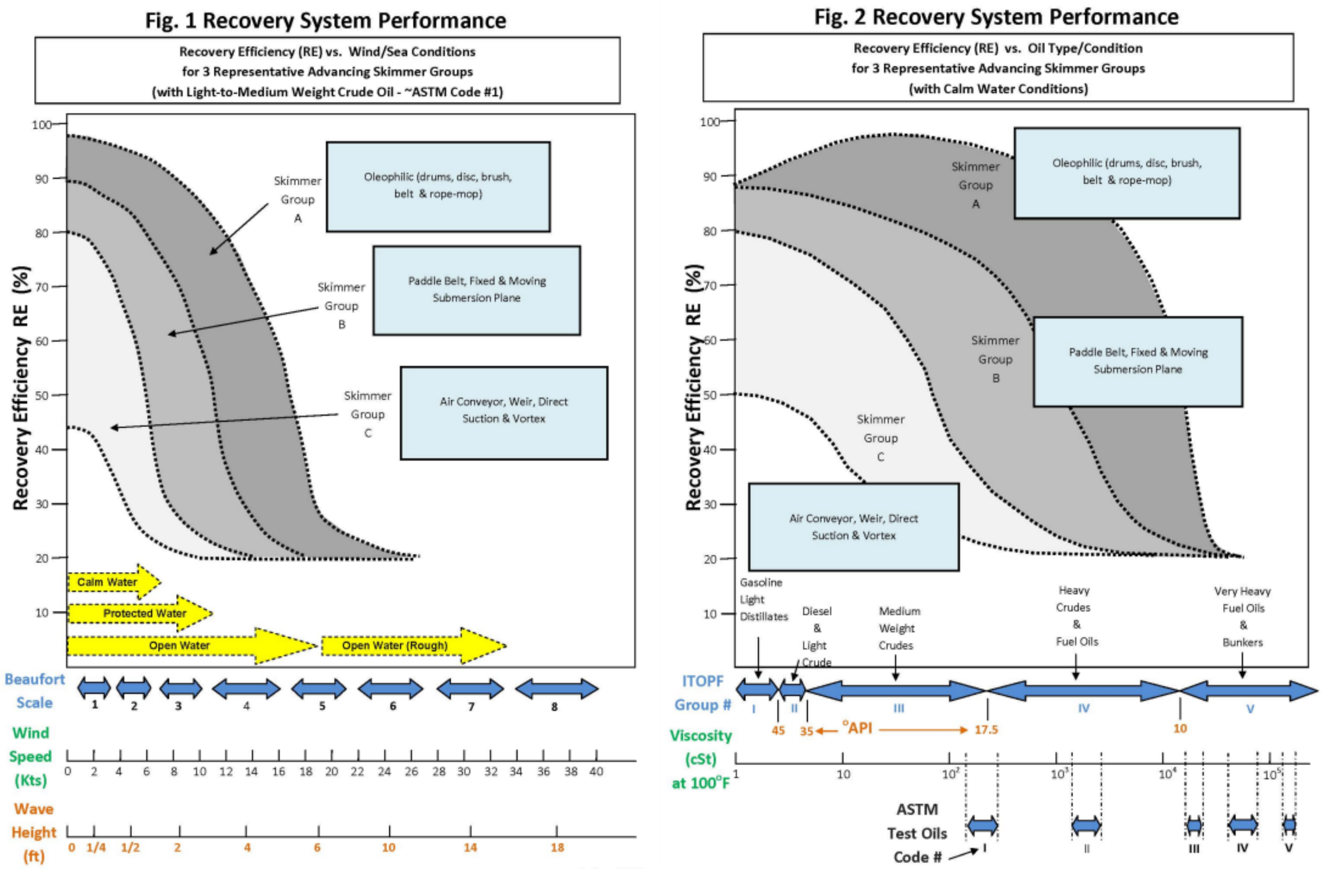

Figure 18 - Recovery Efficiency charts provided by ROC (left-chart: based on skimmer type and met ocean conditions; right-chart: based on skimmer type and oil viscosity).

5.4. Estimation of the encounter rate

The objective of this section is to identify, assess, and present one or more technical solutions for capturing the encounter rate of the response asset with the oil slick in the simulator's calculation in a realistic manner. These aspects are addressed in step 2 of the proposed methodology.

The rate at which one can encounter a specific volume of floating oil is one of the most important parameters in the overall assessment of a given response system's ability to access and eliminate spilled oil (Allen et al., 2018). The volume encounter rate will depend upon the system's swath (i.e., the width of its passage through or over oil), its speed while accessing the oil, and the average thickness of the oil encountered.

Thus, the encounter rate (see Figure 19) defines the amount of emulsion encountered by the recovery system per time during the effective skimming period. It is usually defined as a function of the average thickness of the oil slick (*t*), the speed of advance of the response system (*v*), and the swath (*w*) of the response system as defined in Eq. (5). For the purpose of clarity, Equation 5 is presented again below:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s)$$

where *t* is the oil thickness, *w* is the swath length, and *v* is the tow velocity.

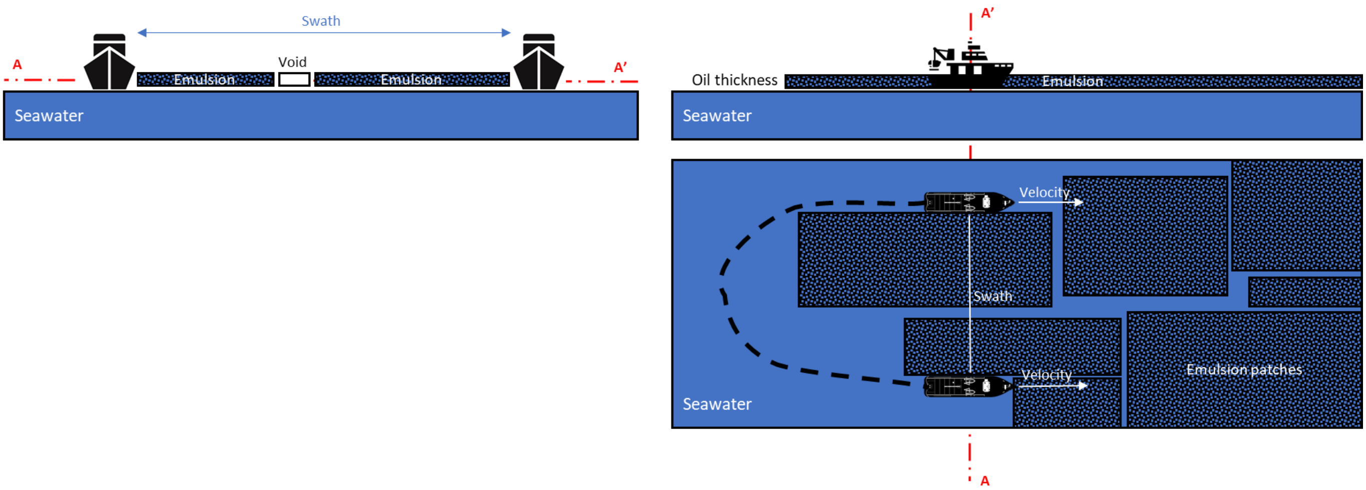

Figure 19 - Diagram of the encounter rate variables.

The estimation of the encounter rate according to Equation 5 is based on the following simplifications: i) the oil thickness is constant in all the areas of the slick, ii) the oil slick is a homogeneous body and the slick always covers all the swath section and iii) there is not any loss of oil from the system. However, in real spill response, the oil is usually fragmented into patches and the boom failures are common due to different causes, such as the excess of the first loss speed while towing and because the effect of the wind-waves mainly that produce the splash over the boom.

To calculate the encounter rate more realistically the aforementioned factors have to be considered in the analysis. Regarding the oil thickness, the oil spill models generally provide an average oil slick thickness, so there is little room for improvement in this issue.

Therefore, to improve the calculation of the encounter rate (Eq. 5) the following aspects can be considered:

- Fragmentation level of the slick: the oil slick is usually encountered disaggregated in several non-homogenous patches of emulsified product as it is represented in Figure 19. The quantity of gaps or discontinuities is defined by some authors as level of fragmentation of an oil slick. This value could be considered as a reduction percentage in Equation 10, as follows:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s) \times (1 - FP) \quad (10)$$

where *t*, *w*, and *v* are defined in equation 5 and FP is the fragmentation percentage (0 to 100%) of the slick. Since oil spill models do not provide the level of fragmentation of the slick, FP could be defined by the user taking into account, for example, the field observations. Default value will be pre-defined as 0% of fragmentation.

- Boom losses: two options are provided to quantify the boom losses. The first one (Option 1) is to consider a reduction percentage in Equation (11), as follows:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s) \times (1 - FP) \times (1 - \mathrm{BLP}) \quad (11)$$

where *t*, *w*, *v*, and FP are defined in Equation 9 and BLP is the boom loss percentage (0 to 1) due to boom failures, which has to be defined based on expert criteria. Several guidelines and reviews in mechanical recovery define qualitative performance (good/poor, Figure 20) of the booms under specific conditions (Fingas et al., 2011; Exxonmobil, 2014). The reduction percentages can be defined based on the qualitative assessment available in the state-of-the-art and applying expert criteria.

Wind	Waves	Current	Boom Performance
0–10 kts (0-20 km/hr)	Calm, swells	0–0.5 kts (0.25 m/s)	Good
> 20 kts (>40 km/hr)	< 3–4 ft (<1 m)	> 1 kt (>0.5 m/s)	Poor

Figure 20 – Qualitative assessment of the boom performance under wind, waves, and currents (Exxonmobil, 2014).

The second one (Option 2) is based on the work proposed by Kim et al (2019). In this work, the authors state a formulation for the quantification of these loss rates due to boom failures (Kim et al., 2019). The implementation of this formulation can be carried out to better evaluate these losses and subtract this rate directly from the encounter rate at each time step of evaluation.

$$EnR\ \left(m^3/s\right) = \left(t(m) \times w(m) \times v(m/s) \times (1 - FP)\right) - BLR(m^3/s) \quad (12)$$

where *t*, *w*, *v*, and FP are defined in equation 2 and BLR is the boom loss rate (m^3/s) due to boom failures.

The implementation of this formulation is based on complex equations that require the following variables: water density, oil density, gravitational acceleration, oil-water surface tension, oil boom draft, oil relative density with the water, wave steepness, buoyancy-weight ratio of the boom. It is worth mentioning that, as far as the authors of this report are aware, there are no applications of this methodology in response simulator systems or software.

Finally, the estimation of the oil recovered by the mechanical recovery system can be calculated by taking into account the Encounter Rate, as well as, the Nominal Capacity Reductions (R1, R2, and R3) and Recovery Efficiency proposed in Section 5.3. The maximum oil or emulsion recovered by the skimmer and pumped on board will depend on the capacity of the skimmer and the oil encountered (see Figure 21). If there is not enough oil/emulsion encountered, then the maximum ORR rate possible will be equal to the Encounter Rate and the rest of ratios can be derived based on this fact.

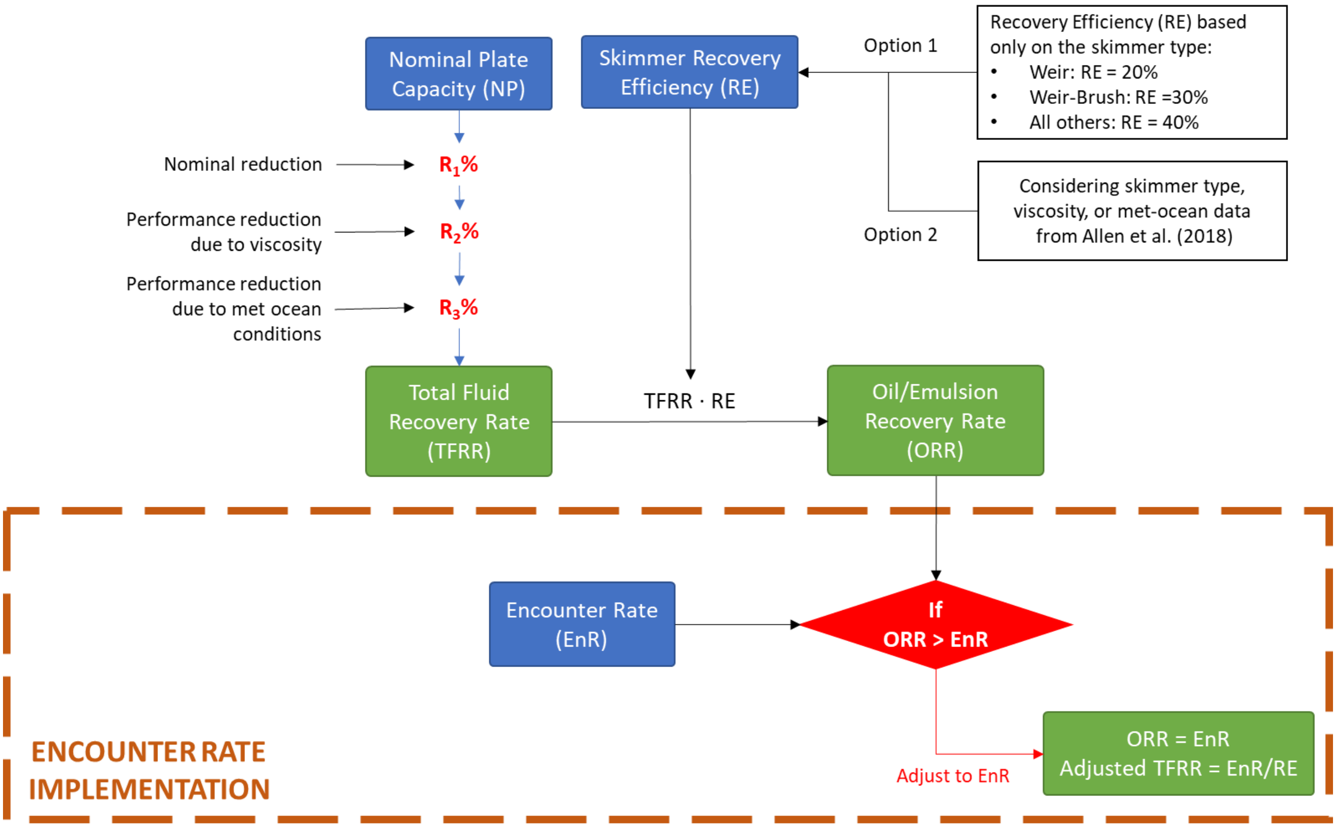

Figure 21 - Conceptual scheme of the complete methodology for calculating recovery rates including the limit imposed by the encounter rate.

5.5. Technical and logistic aspects associated with the deployment of response assets at sea

The objective of this section is to identify and assess the technical and logistic aspects associated with the deployment of response assets at sea, as well as to identify the critical issues and propose solutions on how to integrate them into the system. These aspects are addressed in step 3 of the proposed methodology.

Once recovery estimation is calculated, it is possible to define the precise schedule of the recovery operations, usually defined in blocks of transit – recovery – transit – unload (see Figure 22). The working hours are set by default for the entire EU region, but they can also be defined by the user.

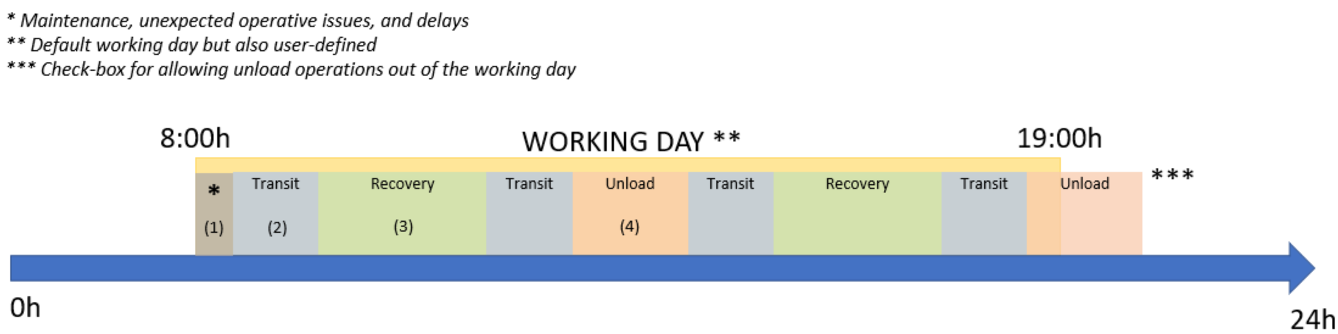

Figure 22 - Schedule of the recovery operations.

A brief review of the main operations shown in Figure 22 is provided below.

- Mobilization Time

This period takes into account the necessary time to activate the resources, prepare equipment, and travel from home base to the emergency base. Therefore, it is suggested the use of pathing algorithms to calculate these transit times. The activation and preparation times are properties of each resource. The resources will not be scheduled at the response until reach the emergency base, once this point will be achieving the schedule for this resource will be calculated for each following day as is shown in Figure 22.

$$MT(h) = VV(m/h) \cdot \mathrm{D}_{\mathrm{home-emergency}}(m) + AT(h) + PT(h) \quad (13)$$

where *MT* stands for Mobilization Time, *VV* stands for vessel velocity, $\mathrm{D}_{\mathrm{base-emergency}}$ is the path to travel from the home base to the emergency base, *AT* stands for the Activation Time and *PT* for the Preparation Time.

- Backup Time (1)

A daily backup time to take into account maintenance of the equipment, delays, and other unpredictable and inefficient times is proposed. By default, the system is suggested to define a small percentage relative to the complete working day to standardize this parametrization. It has to be highlighted that this time will be excluded from the working day even when operations do not require it. Therefore, it is important to not overestimate this value. A value smaller than 5% is suggested (i.e.: 5% of an 8h working day results in 25 min backup time, and for a 10h working day in 30 minutes). However, this backup time (default value) should be defined according to expert criteria and user will be allowed to modify it. Backup-time (*BT*) can be defined as:

$$BT(h) = WD(h) \cdot BTP(\%) \quad (14)$$

where *WD* stands for the hours of the Working Day, and *BTP* for Backup-Time Percentage.

- Transit Time (2)

Transit time is the time needed to navigate to the scene where the oil slick is located, and the recovery operations will be carried out. This navigation can be calculated at the vessel navigational speed and based on pathfinding algorithms. This time will take into account the update of the oil slick location based on the centre of mass evolution provided by oil spill numerical models. Information about the evolution of the centre of mass of the spill is calculated by oil spill models and the estimation of the transit time (when needed) can be performed using modelled location provided by the oil spill model. Transit time (*TT*) will be estimated by means of the vessel velocity (*VV*) and the distance ($D_{port\text{-}spill}$) from the centre of mass of the oil spill and the reference port of the vessel at required time this phase. This phase also will include the deployment or recovery of all the necessary resources (Auxiliary time) like booms and skimmer deployment before starting the skimming operations or its recovery before transit to discharge the vessel tank at the port, as follows:

$$TT(h) = VV(m/h) \cdot \mathrm{D}_{\mathrm{port-spil,t}}(m) + \ Aux\ Time(h) \quad (15)$$

- Recovery period (3)

The recovery period (3) is the effective time during which the skimmer is actively pumping fluid on board. Based on RC rules, the recovery period is limited when: i) the storage is full (90% total capacity); ii) endurance of vessel is over; ii) daily work hours are over or iii) the total oil spill is recovered (whichever occurs first). Thus, the amount of oil recovered can be calculated based on hourly rates for each hour as:

$$Recovered\ Volume\ of\ Oil/Eulsion\ (m^3) = Recovery\ Time\ (h) \times Oil/emulsion\ Recovery\ Rate\ (m^3/h) \quad (16)$$

and the total amount of volume recovered on board can be calculated, also based on hourly rates for each hour as:

$$Total\ Volume\ \mathrm{recovered}\ (m^3) = Recovery\ Time\ (h) \times Total\ Fluid\ Recovery\ Rate\ (m^3/h) \quad (17)$$

When a vessel is deployed conducting mechanical recovery, it will recover oil to fill its on board storage capacity. The storage capacity will determine the maximum working time in which the collection operation can be carried out. Thus, using the total fluid recovered ratios for each hour of work ($TFRR_t$), and the precise recovery time (*RT*) needed during the last hour of recovery to reach the storage capacity ($RT_{t=n}$), the maximum Total Recovery Period (*TRP*) will be reached, as reads the following condition (RT_t = 1 hour and $RT_{t=n}$ < 1 hour):

$$SC(m^3) = \sum_{t=0}^{t=n-1}(TFRR_{\ t} \cdot RT_t) + (TFRR_{\ t=n} \cdot RT_{t=n}) \quad (18)$$

Some vessels are equipped with on board decanting capacity that enhances their capacity to remain longer on the scene. According to RC, only OSRV vessels can perform decanting based on two rules: i) 30 % of the daily total amount of water in the recovered product can be decanted if heating is available and ii) if heating is not available 15% of the total amount of water in the recovered product can be decanted.

Finally, during recovery operations of dedicated vessels a specific break does is not included in Figure 22 can occur and it is called “On scene stand by”. This term refers to hours of non-effective work on scene due to night conditions, unexpected weather conditions, or simply taking a break in the middle of continuous deployment or recovery operations.

- Discharge, unload, or reload operations (4)

It refers to the transfer of the recovered oil/emulsion from skimmers to storage platforms. Time is based on the discharge rate of the asset, following RC rules, discharge time is estimated with a 60% performance of the total discharge capacity of the asset:

$$DT(h) = DR(m^3/h) \cdot 60\% \quad (19)$$

where *DT* stands for Discharge time, and *DR* for the asset discharge rate. In the case of the reload operations for other techniques a fixed time will be established to consider the recharge of dispersants and other resources.

Furthermore, it is important to consider the possibility that the response operation may not be completed or may need to be modified due to:

- Breaks and failures of the equipment (normally associated with skimmer/pumps/booms due to high currents, presence of debris, maintenance failures, bad practices…)
- Improvement of the met ocean forecast to obtain reliable forecasts
- Add new relevant information collected during the first stages of the response as aerial/satellite imagery, oil properties measurements…

These problems make it necessary to re-evaluate the chosen alternatives, make changes to the selected equipment, activate new assets... All these situations are considered to be allowed by a re-initialization functionality of the simulations as described in Section 5.6.

5.6. Integration in the simulator’s calculations the changes in time to the surface oil

The objective of this section is to propose a technical solution for the integration in the simulator’s calculations the changes in time to the surface oil: changes due to weathering of the oil and the changes (reduction) to the surface oil as a result of the deployment and operation of oil spill response assets at sea.

As mentioned in Section 2.2, the system should integrate an oil spill model, and therefore, should be able to run oil spill simulations to predict the trajectory, dispersion, and weathering of oil spills at sea considering the met ocean conditions at the spill site or to import data from third-party oil spill models. In both cases, the oil spill numerical model will provide the temporal and spatial evolution of the trajectory and dispersion of the oil spill as well as the temporal evolution of the oil weathering (e.g. evaporation, emulsification) and the physicochemical properties of the oil (density, viscosity).

To take into account the reduction of the surface oil as a result of the deployment and operations at sea, the new system will be able to re-initialize the oil spill simulation with new information regarding the slick evolution, e.g., polygons obtained from observations (aerial observations, satellite images or RPAS images). A technical solution is shown in Figure 23 to reinitialize the model and update data and inputs for both oil spill model and response simulator. This process could be used to integrate the field data obtained during the emergency such as:

- New oil spill properties (viscosity, density, content of water…)
- Oil slick shape obtained from aerial imagery (satellite, flights, RPA…)
- Automatically updated met ocean forecasts (to improve forecast accuracy)
- Update equipment (assign new pieces or quit resources due to damages or failures)

The re-initialization process will allow to load the information of the previous simulation and to include the new information provided by the user. However and as shown in Table 7, the re-initialization of a simulation using the previous results provided by the oil spill model (particles distribution that represent the oil location) and weathering conditions (oil density, thickness, viscosity, emulsification…) is not a common functionality in oil spill models. As shown in Figure 23, the update of the oil location can be addressed with the observations. To facilitate the integration of the weathering conditions (oil density, thickness, viscosity, emulsification…) this information can be included as a modification of the oil parameters in the oil database so that oil substance properties (density, water content, viscosity…) would be needed to set up for each simulation.

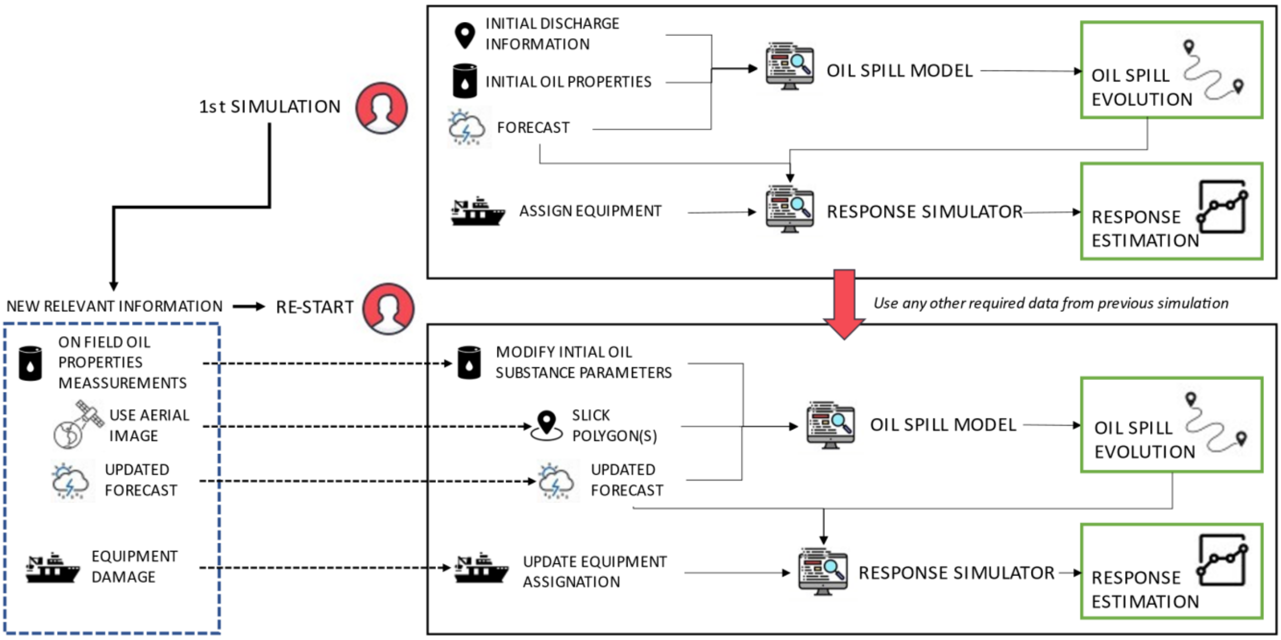

Figure 23 - Re-initialization approach to update information and re-evaluate the response from a specific time.

5.7. Feasibility of having the simulator GIS based

The maturity of geospatial technologies makes it possible to integrate GIS functionalities into any system/simulator that collects, manages and exploits geospatial information. Spatial data may also include attributes that provide more information about the entity it represents. This helps users understand where things happen and why they happen there.

As explained in previous sections, the use of Geospatial technologies for analysis and visualization is mandatory for the proposed system. Therefore, the front-end will include a GIS solution to interact with the different geospatial features that take place in any oil pollution response at sea.

6. EXTERNAL DATA SOURCES

6.1. Relevant environmental data parameters needed for the oil spill model and the simulator

The objective of this section is to gather a list of relevant environmental data parameters needed for the oil spill model and the simulator that could be integrated in the system bringing it closer to the actual operations at sea.

The amount of data managed and required for the system and the numerical models involved depends largely on the complexity of the process to be simulated and the capacity of the models to take into account the different process that describes the evolution of the oil spills.

For oil spill modelling, geospatial information is needed to determine coastline limits and bathymetry of the area where the emergency occurs being mandatory data for any calculation or set-up of an oil spill model. Moreover, met ocean data are also required to calculate the movement of the oil once spilled into the sea. The main variables required are: i) wind velocity at 10 m, ii) ocean current velocity (surface currents, depth-averaged current velocities, and/or 3D current velocities), and iii) the wave-induced Stokes drift, which is calculated as a function of the gravity, significant wave height, period, wave number and/or wave celerity (see Equations 2 and 3 in Section 3.1). The wave parameters are usually associated to swell conditions and are provided by operational wave forecasting systems.

Wind and ocean currents fields provided by operational forecasting systems are mandatory since oil trajectories are mainly driven by wind and currents, especially offshore. The wave-induced Stokes drift is, especially offshore, less relevant compared to the dominant effect of wind and currents in oil transport. The wave height has also a large influence on the dispersion of oil into the water column. This variable is recommended to be provided by numerical models. However, it can be also computed from wind speed. Temperature and seawater density (or salinity) are also key variables during the weathering processes of the oil and for the oil transport in the water column. These variables can be provided by numerical models or taken into account in a simplified manner (e.g. constant values provided by the user or obtained from climatological data). Regarding river flows, the effect of the river discharge in currents is provided by the hydrodynamic model. However to include these local effects, coastal hydrodynamic models are required as explained in Section 6.4. Table 19 shows the list and prioritization of the environmental parameters needed for the oil spill model. The prioritization has been established providing the higher value (5) to the variables that are mandatory to simulate the oil trajectory offshore (wind and currents) and the lower value (2) to the variables that can be provided in a simplified manner (e.g. constant values).

Table 19 - List of environmental variables for oil spill modelling.

Oil spill model	Rank	Justification
Ocean current velocity fields (surface, depth-averaged, 3D currents)	5	Main input for the simulation of the oil transport (2D surface, or 3D depth average or depth layered)
Wind fields at 10m above the sea surface	5	Main input for the simulation of the oil transport
Bathymetry	4	To define water/land automatically and to create the grid model. Otherwise, the user has to introduce into the system the grid model.
Coastline	4	To define water/land automatically and to create the grid model. Otherwise, the user has to introduce into the system the coastline.
Wave fields (total significant height, mean period, direction, swell/sea direction, swell/sea significant height, swell/sea period)	3	■ To calculate the wave-induced Stokes drift. ■ To calculate the entrainment of the oil into the water column. However, the wave height required for the entrainment can be computed from wind speed.
Seawater salinity	2	Important variable for weathering processes, to estimate seawater density. However, it can be considered in a

Oil spill model	Rank	Justification
		simplified manner (constant value provided by the user or obtained from climatological data).
Seawater temperature	2	Important variable for weathering processes. However, it can be considered in a simplified manner (constant value provided by the user or obtained from climatological data).

For the response simulator, evaluating the response met ocean variables performs a key role to assess the operability of the recovery operations, but also to determine the efficiency of the recovery resources. Table 20 shows the list and prioritization of the environmental parameters needed for the oil spill model. The prioritization has been established providing the higher value (5) to the most important variables for the operability assessment and the window of opportunity (i.e. wind, waves and currents) and the lower values to the variables that are less relevant or less common.

Table 20 - List of environmental variables for the Response Simulator.

Response Simulator	Rank	Justification
Ocean currents velocities	5	Main input for the operability assessment and the window of opportunity.
Winds at 10 m above the sea surface	5	Main input for the operability assessment and the window of opportunity. It is also important for the estimation of the efficiency reductions.
Wave fields (total significant height, mean period, direction, swell/sea direction, swell/sea significant height, swell/sea period)	5	Main input for the operability assessment and the window of opportunity. It is also important for the estimation of the efficiency reductions.
Visibility	3	Important input for the operability assessment in cold climate, but less common that wind, waves and currents.
Environmental temperature	3	Important input for the operability assessment, but less common that wind, waves and currents.
Bathymetry	3	Important for pathing algorithms and transit times automatically.
Coastline	3	Important for pathing algorithms and transit times automatically.

Table 21 summarizes the list of environmental variables required for the oil spill model and the Response Simulator, indicating the benefits and efforts of including this information into the new system.

Table 21 - List of environmental parameters needed for the oil spill model and the Response Simulator.

Oil spill model and Response Simulator	Rank	Benefit	Effort
Ocean current velocity fields (surface, depth-averaged, 3D currents)	5	■ Main input for the simulation of the oil transport (2D surface, or 3D depth average or depth layered) in the OSM. ■ Main input for the operability assessment and the window of opportunity in the RS. ■ Visualization: to understand transport and operability conditions.	Raster data model will use WMS and WCS (**) 2D will require visualization of vectors with magnitude and direction

Oil spill model and Response Simulator	Rank	Benefit	Effort
			(***) 3D will require specific libraries for visualization (i.e. Cesium)
Wind fields at 10m above the sea surface	5	■ Main input for the simulation of the oil transport in the OSM. ■ Main input for the operability assessment and the window of opportunity, and important for the estimation of the efficiency reductions in the RS. ■ Visualization: to understand transport and operability conditions.	Raster data model (**) 2D will require visualization of vectors with magnitude and direction
Wave fields (total significant height, mean period, direction, swell/sea direction, swell/sea significant height, swell/sea period)	5	■ Main input for the operability assessment and the window of opportunity, and important for the estimation of the efficiency reductions in the RS. ■ Important to calculate the wave-induced Stokes drift and for the entrainment of the oil into the water column in the OSM. ■ Visualization: to understand operability conditions.	Raster data model (*) WMS and WCS for sea direction
Bathymetry	4	■ To define water/land automatically and to create the grid model in the OSM. Otherwise, the user has to introduce into the system the grid model. ■ Important for pathing algorithms and transit times automatically, however, always regular shipping lanes will be prioritized. ■ Visualization: to understand beaching (over the model grid)	Raster data model WMS and WCS (*) WMS for visualization and WCS to create the grid model
Coastline	4	■ To define water/land automatically and to create the grid model. Otherwise, the user has to introduce into the system the coastline. ■ Important for pathing algorithms and transit times automatically, however, always regular shipping lanes will be prioritized. ■ Visualization: to understand beaching (over the model grid)	Vector data model (*) WMS for visualization and WFS to create the grid model
Visibility	3	■ Important input for the operability assessment (RS) in cold climate, but less common that wind, waves and currents.	Raster data model (*) WMS for visualization and WCS for operability assessment
Environmental temperature	3	■ Important input for the operability assessment (RS), but less common that wind, waves and currents.	Raster data model (*) WMS for visualization and WCS for operability assessment

Oil spill model and Response Simulator	Rank	Benefit	Effort
Seawater salinity	3	■ Important variable for weathering processes (OSM), to estimate seawater density. However, it can be considered in a simplified manner (constant value provided by the user or obtained from climatological data). ■ Visualization: general information, e.g. to obtain the mean conditions for the oil spill model.	Raster data model or a single data input (*) WMS for visualization and WCS for weathering processes
Seawater temperature	3	■ Important variable for weathering processes (OSM). However, it can be considered in a simplified manner (constant value provided by the user or obtained from climatological data). ■ Visualization: general information, e.g. to obtain the mean conditions for the oil spill model.	Raster data model or a single data input (*) WMS for visualization and WCS for weathering processes

6.2. Potential data sources and potential exchange mechanism

The objective of this section is to identify potential sources for each type of data including the potential exchange mechanism from the source to the future IT system.

Regarding potential sources, first, the geospatial data sources are presented. Next, the main sources for the met ocean data are provided. Met ocean data is without any doubt the most important source of uncertainty in any oil spill simulation. Taking this assumption into account, the selection of the most accurate forecasts and robust providers is critical. Europe has been making big efforts during the last decades to monitor and forecast the environment and as a result of this work, currently exists active European actors in charge of developing this kind of data. In this section, the best data providers and datasets will be selected including some alternatives as a backup of the European providers and when possible, adding some sub-regional forecasts of specific Member State institutions. Finally, besides the geospatial and met ocean data sources, this section also includes potential sources for in-situ instrumental measurements and satellite imagery. In terms of real-time or near-real-time monitoring in-situ instrumental measurements, satellite and aerial imagery is important information for helping during the decision-making process. Specifically, satellite and aerial imagery allow the continuous re-evaluation of the evolution and response operations when new data is available.

Regarding the potential exchange mechanism, the environmental parameters identified for the oil spill model and response simulator make use of two data models: raster data model and vector data model. The use of standard interoperability protocols significantly reduce the effort of environmental data integration. Data providers such as Copernicus, EMODnet or NOAA provide standard interoperability protocols to access and download the information (WMS, WCS, WFC, among others).

Two approaches should be further analysed in order to define the final system architecture design:

- Repository of met ocean data replicated. In this approach, all met ocean information from data providers must be hosted in the new system. This approach requires the software and hardware to host all the met ocean data operationally.
- Access to repositories on the fly. In this approach, only the required information is requested to the data providers. This approach requires robust interoperability protocols to access the required met ocean data on the fly.

For the management of geospatial databases, such as bathymetries, topo-bathymetries and coastlines, two approaches can be taken. The first option would be the same approach as with met ocean data, the system could make use of interoperability protocols to access datasets managed by data providers. However, it should be noted that these datasets are not constantly updated, so there is no need to establish a communication mechanism to download and constantly update them. The second option would be to store these datasets in the system and provide this information to the different subsystems without accessing the web services of the data providers, avoiding this dependency.

It is worth mentioning that the exchange mechanism will be further analysed in WP 2- Conceptual and physical system architecture for the tool and in the report on Part 2 of this project.

6.2.1. Geospatial data sources

Coastlines coordinate definition and bathymetry information are needed to develop an oil spill simulation. Several regional databases are freely provided by many institutions, usually of their areas of interest. In the case of Europe, the European Marine Observation and Data Network (EMODnet, emodnet.ec.europa.eu/en) provides a high-resolution bathymetry (~115m) updated in 2020 (Figure 24). EMODnet also provides a recent development based on the combination of information of satellite data (typically Sentinel-2 and Landsat-8) and the Global Tide Surge Model (GTSM) to define digital coastlines for the European seas at LAT (Lowest Astronomical Tide), MSL (Mean-Sea-Level), and MHW (Mean-High-Water).

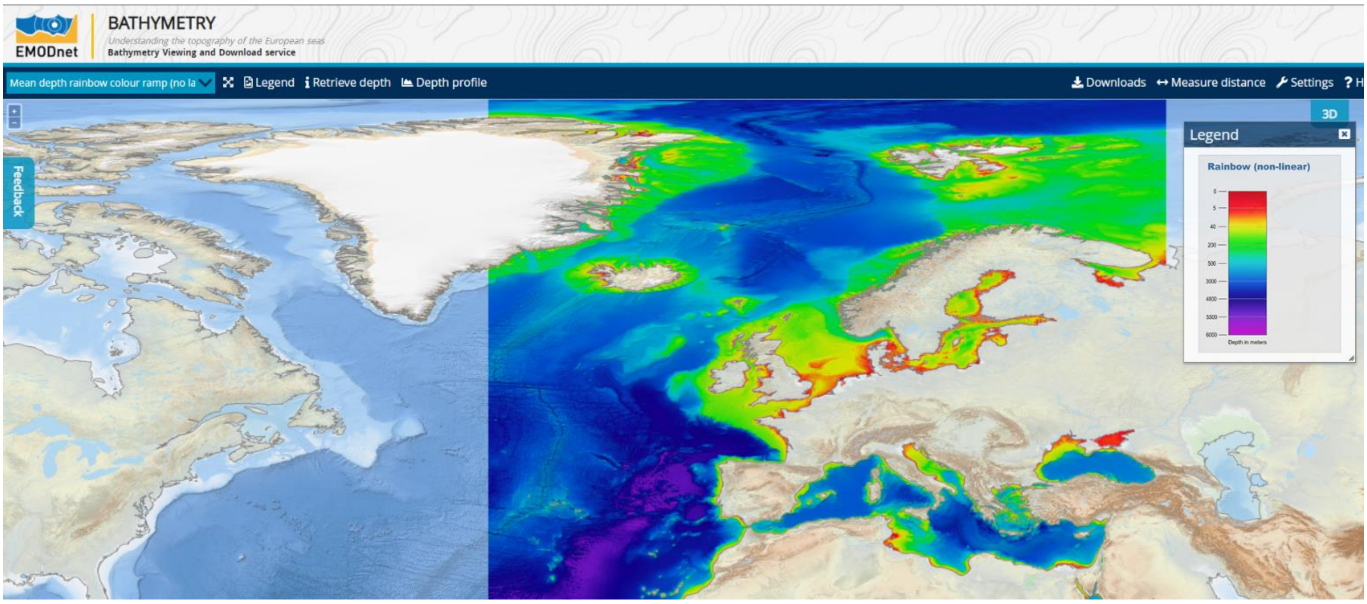

Figure 24 - EMODnet Bathymetry viewing and download service (https://portal.emodnet-bathymetry.eu/).

Additionally, global geospatial data is selected as background for the European regional information. In this case, the bathymetry product is provided by the General Bathymetric Chart of the Oceans (GEBCO, www.gebco.net/) that provides a 15 arc-second resolution updated in 2021. Global coastline definition is selected from Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG, www.soest.hawaii.edu/pwessel/gshhg/)

Geospatial databases selected at the date of elaboration of this consultancy and their main characteristics are summarized in Table 22.

Table 22 - Geospatial databases sorted by priority and their main characteristics.

Provider	Type	Scale	Name	Spatial resolution	Format
EMODnet	Bathymetry	Regional	Digital Terrain Model	3.75" arc (~444m)	ESRI ASCII, XYZ, CSV, NetCDF, GeoTiff and SD

Provider	Type	Scale	Name	Spatial resolution	Format
EMODnet	Coastline	Regional	Satellite-Derived	Variable	ESRI Shapefile
GEBCO	Topo-bathymetry	Global	GEBCO grid	15" arc (~115m)	ESRI ASCII, NetCDF, and GeoTiff
GSHHG	Coastline	Global	GSHHG	Variable	ESRI Shapefile and Native binary files

6.2.2. Oceanic data sources

Mainly, the production of the physical oceanic data is derived from current circulation models and wave propagation models that usually run coupled to atmospheric models. In the case of Europe, the agency in charge of this general forecast is the European Centre for Medium-Range Weather Forecasts (ECMWF, https://www.ecmwf.int/) which provides a global atmosphere and wave forecasts.

However, the European Union has developed during the last decades a robust service called Copernicus Marine Environment Monitoring Service (CMEMS, marine.copernicus.eu/) providing free, open, regular, and systematic reference information on the blue (physical), white (sea ice), and green (biogeochemical) ocean state, variability and dynamics across the global ocean and European regional seas. Furthermore, during the last years, the evolution of this service is evolving to reach different scales: global, regional, and sub-regional datasets. Global and regional providers are already successfully used in many downstream services and currently, CMEMS is under the development of a new step forward to reach sub-regional and local scales.

CMEMS products that satisfy the system demands have been selected as top-priority providers. Alternative to these products, the German Weather Service (DWD, openskiron.org/en/icon-gribs) offers a comprehensive sub-regional grid European-collection of winds and waves forecasting (see Figure 25) in grib2 format that cover almost the entire EU.

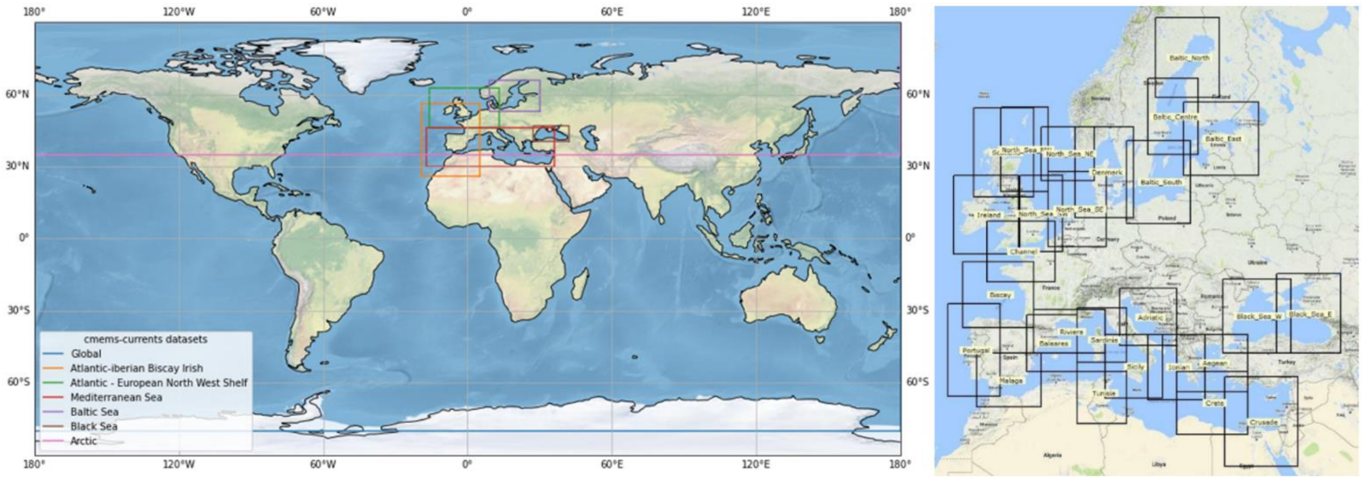

Figure 25 - Ocean forecast grids provided by CMEMS (left) and DWD (right).

The list of analysed providers at the time of elaboration of this consultancy is presented in Table 23.

Table 23 - Oceanic databases sorted by priority and main characteristics.

Provider	Scale	Name	Variables	Resolution		Temporal horizon	Exchange services	Access
				Spatial	Temporal			
CMEMS	Regional	Atlantic-Iberian Biscay Irish	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	0.028º	hourly	5 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Atlantic-Iberian Biscay Irish (waves)	Significant wave height (Hs), Wave peak period (Tp) and Wave mean direction (Dir) of total spectrum, swell 1 and sea	0.05º	hourly	5 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Mediterranean Sea	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	0.042º	hourly	10 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Mediterranean Sea (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	0.042º	hourly	10 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Atlantic – European North West Shelf	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	0.03º	hourly	6 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Atlantic – European North West Shelf (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	0.014ºx0.03º	hourly	6 days	Subsetter (https) Opendap	open

Provider	Scale	Name	Variables	Resolution		Temporal horizon	Exchange services	Access
				Spatial	Temporal			
							FTP WMS	
CMEMS	Regional	Baltic Sea	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	2km	hourly	6 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Baltic Sea (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	2km	hourly	6 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Black Sea	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	0.025º	hourly	10 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Black Sea (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	0.025º	hourly	10 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Regional	Arctic	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	12.5km	hourly	11 days	Subsetter (https) Opendap FTP WMS	open

Provider	Scale	Name	Variables	Resolution		Temporal horizon	Exchange services	Access
				Spatial	Temporal			
CMEMS	Regional	Arctic (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	3km	hourly	10 days	Subsetter (https) Opendap FTP WMS	open
DWD	Sub-Regional	ICONgrids (waves)	Hs, Tp and Dir of swell and sea	0.063º	hourly (0-78h) 3-hourly (78-120h)	DWD		open
CMEMS	Global	Global	Surface currents, Depth-averaged currents, 3D currents, Potential temperature, Salinity	0.083º	hourly	10 days	Subsetter (https) Opendap FTP WMS	open
CMEMS	Global	Global (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	0.083º	3-hourly	10 days	Subsetter (https) Opendap FTP WMS	open
ECMWF	Global	HRES-WAM (waves)	Hs, Tp and Dir of total spectrum	0.4º	3-hourly (0-144h) 6-hourly (150-240h)	10 days	FTP, AmazonS3, Azure	open
ECMWF	Global	Set - II HRES-WAM (waves)	Hs, Tp and Dir of total spectrum, swell 1 and sea	0.1º	Hourly (0-90h) 3-hourly (93-144h) 6-hourly (150-240h)	10 days	FTP, AmazonS3, Azure Open-access	Under request or payment

6.2.3. Meteorological data sources

Although meteorological numerical modelling was developed before oceanic ones, this data is usually more restricted to be freely accessed. Following the same criterion as the used for oceanic data, the most important and recognized provider in Europe is ECMWF which provides global forecast products to feed regional models of Members States Meteorological institutes. Since the top resolution product is not open, access to this provider has to be requested by EMSA. Additionally, open data products of this provider have a maximum resolution of 0.4º and maximum temporal resolution of three hourly data (see Figure 26). It is important to highlight the relevance of meteorological data for the new system. High-resolution meteorological data, and specially wind fields, are of high-relevance to provide accurate simulations and to have a realistic system. Therefore, to have access to high-resolution meteorological data will be of paramount importance for the future system.

Regional atmospheric forecasts of the state members are difficult to be accessed (restricted under request or payment) and usually, they lack format homogeneity among each other. For that reason, a standard input method will be required following the standards of netCDF format and CF-conventions to allow the Member States to feed the system with its forecasts if fulfil these standards.

Global Forecast System (GFS, https://www.emc.ncep.noaa.gov/emc/pages/numerical_forecast_systems/gfs.php) provided by NOAA is selected as a backup provider because of its extensive use worldwide and free access through NOAA NOMADS distribution system (https://nomads.ncep.noaa.gov/). Finally, DWD European forecasts, which is also a publicly available data source, are considered to provide the system sub-regional grids of the main atmospheric variables needed.

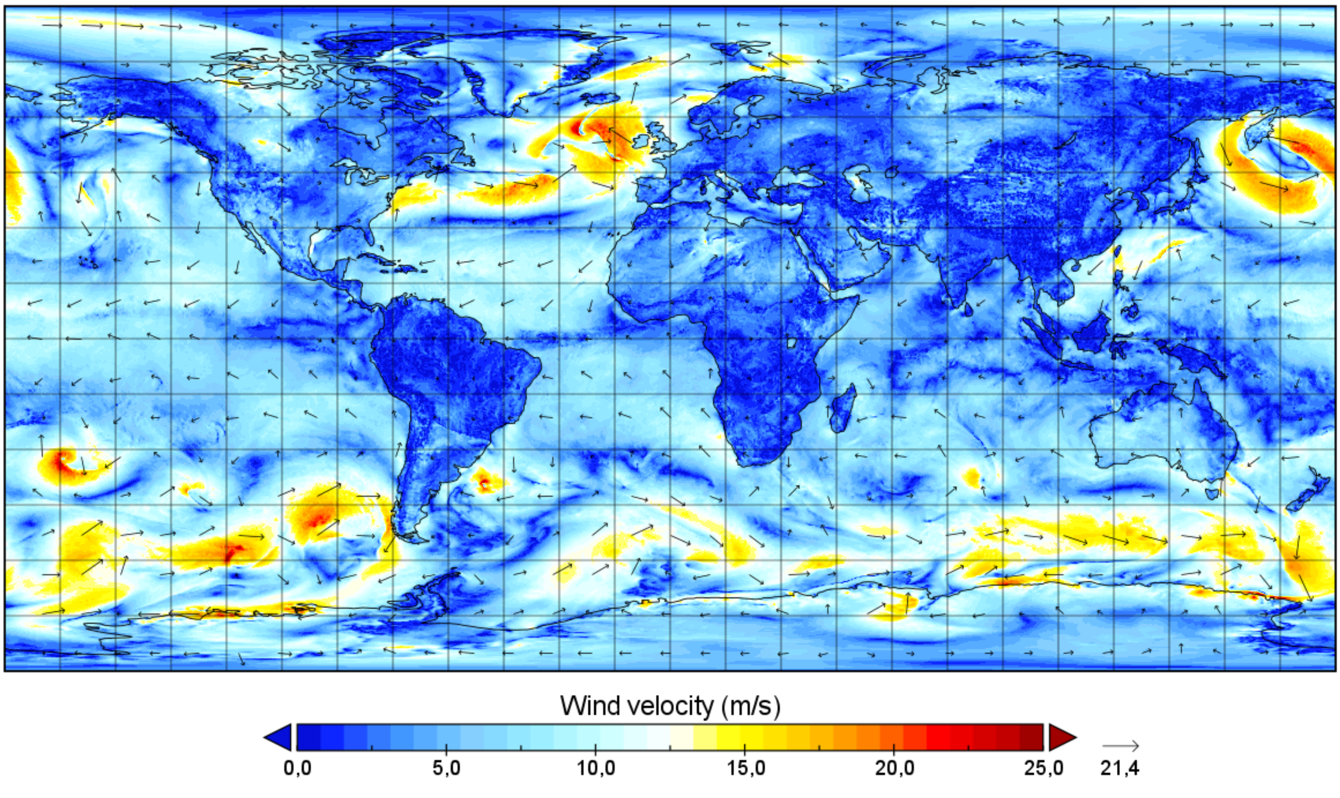

Figure 26 - Visualization of ECMWF HRES open-data (wind at 10m above ground).

In Table 24 the selected databases at the time of the development of this consultancy are summarized with their main characteristics related to their spatial and temporal resolution.

Table 24 - Atmospheric databases sorted by priority and main characteristics.

Priority	Provider	Scale	Name	Variables	Resolution		Temporal horizon	Exchange services	Access
					Spatial	Temporal			
1	ECMWF	Global	Set I - HRES	Winds at 10m Visibility	0.1º	Hourly (0-90h) 3-hourly (93-144h) 6-hourly (150-360h)	10 days	FTP, Amazon S3, Azure	Under request or payment
2	DWD	Sub-Regional	ICONgrids	Winds at 10m	0.063º	hourly (0-78h)	5 days	Direct download grib (https)	open
3	NOAA	Global	GFS	Winds at 10m Visibility	0.25º	Hourly (0-120h) 3-hourly (120-384h)	16 days	Opendap, FTP, https, gribfilter	open
4	ECMWF	Global	HRES (open)	Winds at 10m	0.4º	3-hourly (0-144h) 6-hourly (150-240h)	10 days	FTP, Amazon S3, Azure	open

6.2.4. In-situ instrumental measurements

Near real-time instrumental information during an emergency is highly important to support decision-making. This information can be very useful to help in short-term decisions if can be easily and well visualized. Based on the approach of generating a system managed through a GIS interface, the feasibility of an agile visualization and access to instrumental data is intended.

At this point, another development in the framework of CMEMS is selected. The Copernicus Marine In Situ TAC (http://www.marineinsitu.eu/) provides research and operational framework to develop and deliver In Situ observations and derived products based on such observations, to address progressively global and regional needs for monitoring, modelling, or downstream services development. This development offers open access to a wide range of near-real-time data through its online dashboard (see Figure 27). The complete list of the data categories provided by the In Situ Tac portal vs the desired ones for the system is summarized in Table 25.

Table 25 - CMEMS In Situ TAC categories classified as relevant and non-relevant ones for being integrated into the system.

Relevant categories	Non-relevant categories
High-Frequency Radars (HF)	Saildrones (SD)
Moorings (MO)	Thermistor chains (TX)
River Flows (RF)	Ferrybox (FB)
Tide Gauges (TG)	XBTs (XB)
Profilers (PF)	Mini Loggers (ML)
Gliders (GL)	CTDs (CT)
Drifters (DB)	Thermosalinometer (TS)
Drifters (DC)	Bottles (BO)
	Sea mammals (SM)

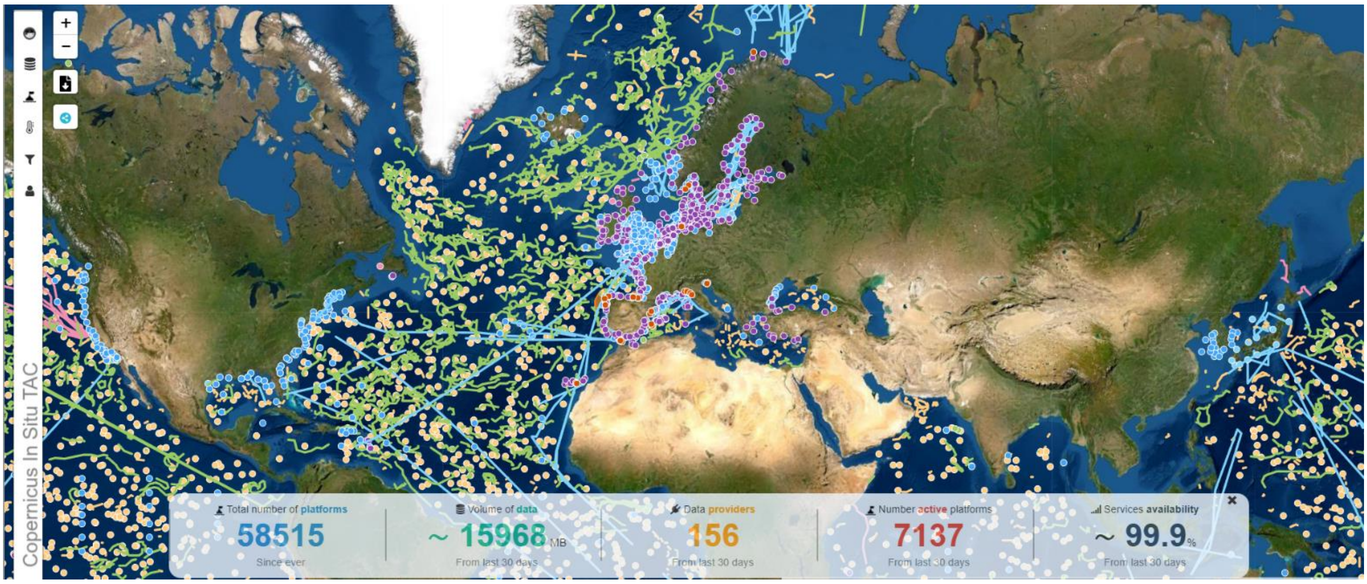

Figure 27 - Snapshot of CMEMS In Situ TAC dashboard (link: http://www.marineinsitu.eu/dashboard/).

6.2.5. Satellite providers

Satellite images are applied to a wide range of applications. It plays a vital role in monitoring environmental changes due to the large areas they can monitor periodically. Two main modes of remote sensing techniques are frequently used for Earth Observation, named active mode and passive mode:

- in active mode, the signals are propagated from the artificial sensors and the corresponding reflected radiations are observed,
- in passive mode, the naturally available radiations due to sun illumination are observed in passive remote sensing.

In terms of their limitations, the passive sensors can be limited on night sensing due to lack of sunlight or clouds. But active sensors are more advantageous with acquiring images all through the day and even under different cloud conditions and season variability. Thus, satellite images differ with respect to their mode of sensing and type of resolution. Further, the availability of these data again varies with the acquisition time period due to different satellite revisit capability. In the case of resolution, they are again categorized into four different types such as spectral, spatial, temporal, and radiometric resolution. Table 26 provides more information about the selected open data satellites, such as the type of sensor, revisit periods and the spatial resolution of their products.

Table 26 – Characteristics of the selected satellites.

Satellite	Type of Sensor	Spatial resolution (m)	Revisit period (days)
Sentinel 1	SAR	9-40	6
Sentinel 2	MSI (13 bands)	10-60	5
Sentinel 3	MSI (21 bands)	300-1200	<3
LandSat 8	MSI (11 bands)	15 - 100	16
LandSat 9	MSI (11 bands)	15 - 30	16
MODIS	MSI (36 bands)	250 -1000	<2
VIIRIS	MSI (22 bands)	375 - 1500	<1
PACE	MSI	1000	2

The use of satellite data is not a priority for the system. However, the ability to observe the European seas using these technologies makes it of great interest to incorporate this information into the system.

Depending on the sensor technologies, we can classify them into multispectral sensors and radar sensors. Radar sensors are active sensors that send a radar signal and receive it, while passive sensors use the reflection of solar radiation to obtain information. This feature is important, since radar sensors are not conditioned by sunless hours or clouds, while multispectral sensors cannot pass through clouds or operate without the reflection of solar radiation.

Other important characteristics are the spatial, temporal and spectral resolution of the sensor. In this sense, one aspect that must be highlighted, in order to monitor the evolution of a spill with these technologies, is the temporal resolution or revisit time of the satellite. To reduce revisit times it is interesting to use as many satellites as possible. For example, in the case of Landsat and Sentinel, the combination of the multispectral satellites allows reducing the revisit times to 2 days in Europe.

As we can see in Table 26, there are three main providers of open satellite data: Copernicus, USGS and NASA. Each provider serve the data in a similar way so the integration effort would be based on the development of three integration processes (ETL).

As previously mentioned, the integration of the data sources will be further analysed in Work Package (WP) 2 and in the report on Part 2 of this project.

6.3. Proposal of minimum data providers

In conclusion, a list of minimum data providers and databases is shown in Table 27, summarizing the most relevant, robust regional providers that covers the EU region (if regional is not available, a global database is selected).

Additionally, Table 28 summarizes the additional information previously analysed that is not a priority for the system but can provide added value to support decision making.

Table 27 - Minimum databases and providers to be implemented in the new system to cover the EU region.

SCALE	PROVIDER	TYPE	NAME
Regional	EMODnet	Geo-spatial (bathymetry)	Digital Terrain Model
Regional	EMODnet	Geo-spatial (coastline)	Satellite-Derived Coastlines
Regional	CMEMS	Oceanic	Atlantic-Iberian Biscay Irish
Regional	CMEMS	Oceanic	Mediterranean Sea
Regional	CMEMS	Oceanic	Atlantic – European North West Shelf
Regional	CMEMS	Oceanic	Baltic Sea
Regional	CMEMS	Oceanic	Black Sea
Regional	CMEMS	Oceanic (waves)	Atlantic-Iberian Biscay Irish (waves)
Regional	CMEMS	Oceanic (waves)	Mediterranean Sea (waves)
Regional	CMEMS	Oceanic (waves)	Atlantic – European North West Shelf (waves)
Regional	CMEMS	Oceanic (waves)	Baltic Sea (waves)
Regional	CMEMS	Oceanic(waves)	Black Sea (waves)
Global	ECMWF	Meteorological	Set I – HRES (need to request access)

Table 28 – Summary of additional databases.

SCALE	PROVIDER	TYPE	NAME
Global	GEBCO	Geo-spatial (bathymetry)	GEBCO grid
Global	GSHHG	Geo-spatial (coastline)	GSHHG Coastlines
Global	CMEMS	Oceanic	Global
Global	CMEMS	Oceanic (waves)	Global (waves)
Global	NOAA	Meteorological	GFS
Global	CMEMS	Instrumental (In Situ TAC)	High-Frequency Radars
Global	CMEMS	Instrumental (In Situ TAC)	Moorings
Global	CMEMS	Instrumental (In Situ TAC)	River Flows
Global	CMEMS	Instrumental (In Situ TAC)	Tide Gauges
Global	CMEMS	Instrumental (In Situ TAC)	Profilers
Global	CMEMS	Instrumental (In Situ TAC)	Gliders
Global	CMEMS	Instrumental (In Situ TAC)	Drifters

SCALE	PROVIDER	TYPE	NAME
Global	COPERNICUS	Satellite (EU)	Sentinel 1
Global	COPERNICUS	Satellite (EU)	Sentinel 2
Global	COPERNICUS	Satellite (EU)	Sentinel 3
Global	USGS	Satellite (EEUU)	LandSat 8
Global	USGS	Satellite (EEUU)	LandSat 9
Global	NASA	Satellite (EEUU)	MODIS
Global	NASA	Satellite (EEUU)	VIIRIS
Global	NASA	Satellite (EEUU)	PACE (launch 2023)

6.4. Possibility of integrating the impact of coastal environmental data

The objective of this section is to identify and assess the possibility of integrating the impact of coastal environmental data (e.g. river outlets, islands/topography, local currents) and tides and near shore bathymetry to better estimate and reflect a spill occurring near the coast.

The success of the application of oil spill numerical models to forecast oil slick trajectories depends on the formulation of the model itself, but more importantly on the input data (wind, currents, and waves) provided by the met ocean forecasting systems.

The evolution of operational oceanography for oil spill response shows that noticeable advances have been made in modelling at a regional scale (O(km)). As shown in previous sections, nowadays there are a high number of operational oceanography systems that provides the forecast of ocean currents at regional scale. For example, Copernicus Marine Service provides the forecast of currents and other ocean variables with a spatial resolution of 2- 3 km, depending on the area. These currents are appropriate to simulate the oil in the open sea but have limitations for the simulation of the oil spill trajectory in coastal and local areas.

To improve the accuracy of the simulations near the coast, taking into account the aforementioned variables (river outlets, islands, local currents, tides, shore bathymetry) downscaled currents are mandatory. To obtain the high-resolution currents required in coastal areas, local hydrodynamic models has to be nested to the regional models (e.g. CMEMS) in order to include the effect of coastal and local hydrodynamics. As an example, Figure 28 and Figure 29 show a surface currents field provided by a regional model (CMEMS - Atlantic-Iberian Biscay Irish) and a coastal model (Puertos del Estado - Spain) in the Gulf of Biscay.

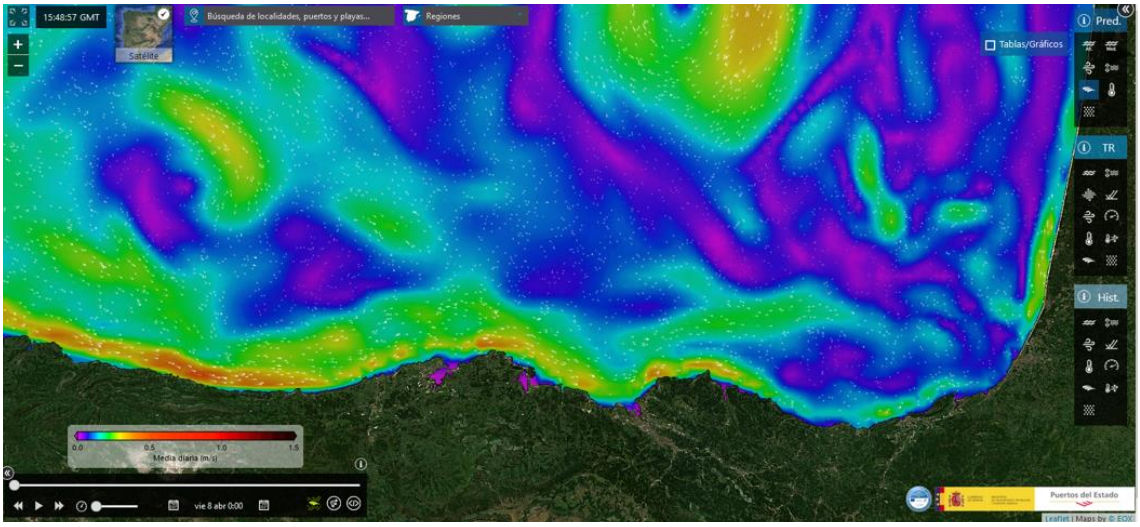

Figure 28- Example of surface currents provided by a regional system (CMEMS - Atlantic-Iberian Biscay Irish) in the Gulf of Biscay.

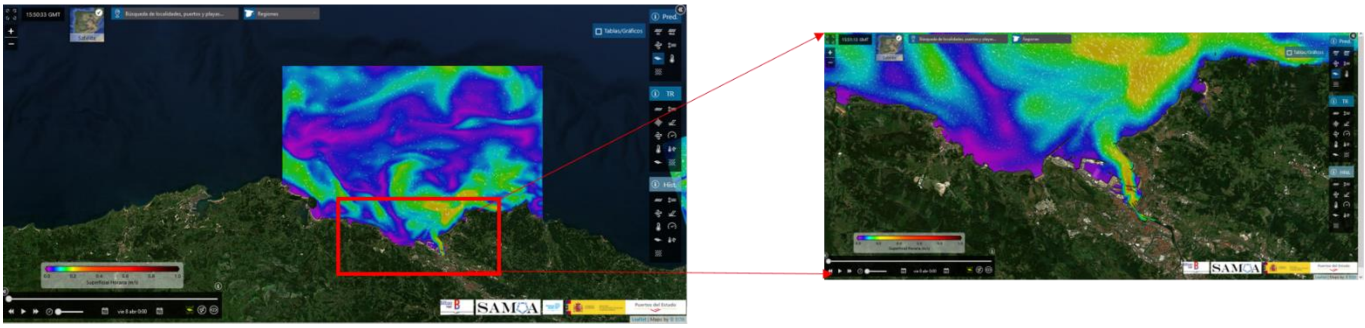

Figure 29 - Example of surface currents provided by a coastal forecast system (Puertos del Estado - Spain) in the Gulf of Biscay.

Therefore, to improve near-shore oil spill simulations, the model has to be forced with high-resolution currents (O(m)) provided by coastal or local hydrodynamic models. In last years, many efforts have been carried out to obtain high-resolution currents in coastal areas. However, the available systems have been developed and are managed by each Member State. This implies that the integration of this data into the system is difficult since the lack of homogeneity and accessibility (in many cases restricted under request or payment). In this way, it is intended that the system will provide a method to feed standard input data based on Network Common Data Form (NetCDF, www.unidata.ucar.edu/software/netcdf/) and Climate and Forecast Metadata Conventions (https://cfconventions.org/) to permit its use.

Besides currents, high-resolution winds and waves are also required to improve the simulations near the coast. High-resolution winds (2 – 5 km) provided by the national agencies of each Member State will contribute to increase the accuracy of the simulations. Regarding waves, it would be also desirable to use high-resolution wave fields. Altough waves play a minor role compared to the effect of the wind and currents on oil transport, they are an important variable for the resonse simulator.

Moreover, a high-resolution grid and coastline for the oil spill model are also required. The cartographic data of the coastal zone are provided by national Spatial Data Infrastructures (SDI) through standard interoperability protocols in accordance with the INSPIRE Directive. Therefore, the system must be able to integrate cartographic information from national agencies in charge of SDIs. The information provided by SDIs is usually "static", not updated hourly or daily. This high-resolution information will allow the model to improve the beaching. However, note that the improvement of cartographic data, which implies an improvement of the grid’s model and the coastline, is irrelevant if there is not an improvement in the forcings, especially in the currents and wind fields through the incorporation of coastal and local hydrodynamics systems.

As mentioned, national meteorological agencies and other institutions that depends on each EU Member State, such as port authorities, oceanographic centres or hydrographic confederations provide coastal environmental data. Unfortunately, the maturity of the interoperability protocols is very diverse. Therefore, while the integration of "static" data provided by national SDIs could be a straightforward process, the integration of data from "dynamic" national or regional data providers requires ad hoc developments. Although the integration of existing EU Member States' met ocean services for the coastal zone require ad hoc developments, the new phase of the Copernicus Marine Service focuses on the design of a Coastal Service for the EU. Therefore, in the near future, the Copernicus Coastal Service would facilitate the use and exploitation of coastal met ocean data.

6.5. Possibility to have real time met ocean data integrated in the system

The objective of this section is to identify and assess the possibility to have real time met ocean data integrated in the tool. e.g. met ocean data from buoys, HF radars, met ocean stations and to discuss if it could be integrated in the oil spill model calculations and in the simulator in order to “calibrate” the tool.

As mentioned in Section 6.2.4, the Copernicus Marine In Situ TAC (http://www.marineinsitu.eu/) provides research and operational framework to develop and deliver In Situ observations and derived products based on such observations, to address progressively global and regional needs for monitoring, modelling, or downstream services development. From the measurements provided by Copernicus, High-Frequency Radars, Moorings, River Flows, Tide Gauges and Drifters have been identified as data of interest to support decision-making.

Integration of real time met ocean data depends on the data providers. As it has been explained before, there is a high diversity of data formats provided by data providers. The Copernicus Marine Service, the *in situ* Thematic Assembly Centre (TAC), is currently making a big effort coordinating the distributed network of production centres, to provide a centralized access to all the monitoring networks in near real time. However, there is still a significant diversity related with each production centre (formats, vocabulary, etc.).Therefore, the status of the CMEMS on-site CT roadmap should be further analysed to ensure the integration of all in situ data providers into the system. The integration of the data into the new system will be further analysed in Work Package (WP) 2 and in the report on Part 2 of this project.

Real time met ocean data will allow the user to monitor the environmental conditions and to carry out visual comparisons between actual and numerical data (e.g. oil trajectories versus drifter trajectories, visualization of weather forecasts, instrumental near-real-time data, etc…). This visualization will be feasible based on the use of a GIS-based interface for the future system as it is planned.

However, the calibration of the system with these measurements is a complex task, which can be explained in two stages:

- The first one is the calibration of the forcings of the oil spill model and the simulator, i.e. the calibration of the wind, currents, and waves provided by the met ocean numerical models. The calibration of hydrodynamic, ocean, and atmospheric models is a complex task that requires a large amount of data (spatial and temporal information) and the application of complex techniques difficult to be addressed by the system in real time. The calibration of the met ocean model’s outputs (wind, waves, and currents) with punctual measurements is not a robust method since the met ocean variables used by the system are dynamic, i.e. spatially and temporally varying.
- The second one is the calibration of the oil spill trajectory model using drifting buoys. The options for the calibration of the oil spill model are explained in Section 3.5.

7. DATABASE OF EUROPEAN OIL POLLUTION RESOURCES AND EQUIPMENT

Complementary to the external data described in Section 6, the system also will require the collection and production of its databases to manage oil substances properties and the equipment and its relevant properties.

It is worth mentioning that the integration of the databases will be further analysed in Work Package (WP) 2 and in the report on Part 2 of this project.

7.1. Database of European oil pollution resources and equipment

EMSA will provide an updated database of European oil pollution resources and equipment to be used as basis. The user should be able to add resources to the database and modify existing ones. This section provides the best way to do it in an easy and user-friendly manner, taking into account the option of having bulk updates via excel files.

The approach to guarantee:

- the use of the oil pollution resources and equipment database by other subsystems or software
- functionalities to add resources to the database and modify existing ones
- having bulk updates via excel files

would be the design and development of the oil pollution resources and equipment subsystem, which should be based on a relational database management system and an API to ensure communications (accesses/updates) with the database (see Figure 30).

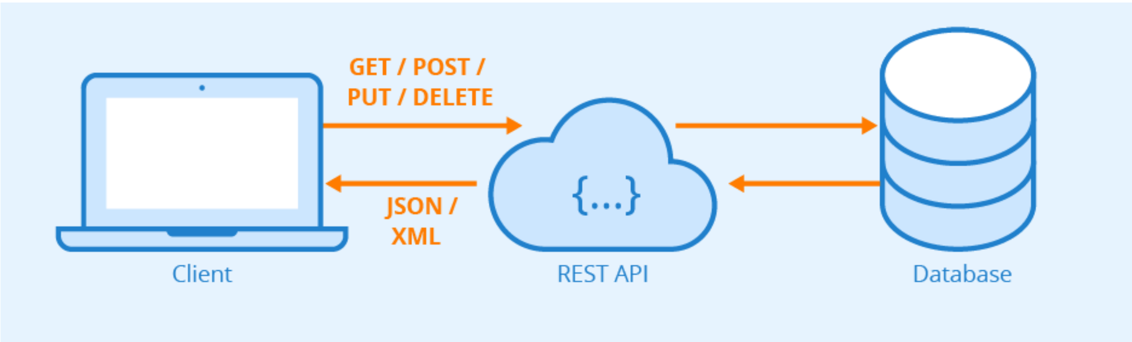

Figure 30 - Database management system approach.

7.2. Database of oils to be used by the oil spill model

The system shall incorporate a database of oils transiting European waters that could be provided by EMSA (if available). The oil database will include the physical and chemical properties of the different oils, such as the density, viscosity, pour point, API, etc. It should be noted that the variables required by oil spill models may differ depending on the model.

As for the resources and equipment database the approach to guarantee:

- the use of the oil database by the oil spill model
- functionalities to add new oils to the oil database
- having bulk updates via excel files

would be the design and development of the oil pollution subsystem, which should be based on a relational database management system and an API to ensure communications (accesses/updates) with the database.

In terms of functionalities for both databases, resources and equipment database and oil database:

- It is proposed the use of a shared database that will be capable to be managed dynamically. This means that based on the user and his role, each user would have specific permissions to get, create, modify, delete, and copy resources of the general database.
- The user should be able to add new products, as well as modify existing ones. The data stored in the oil database must be accessible through an API to obtain, update and add more information. An interface (front-end) should be designed to manage the oil database through the API. Bulk updates via excel files (or other formats) should be included as an extra functionality.

The oil database integrated into the system will allow the user to select an adequate oil at the beginning of the incident when there is no information on the exact type of oil spilled. Note that the properties of the database include general information that allows identifying the oil in general terms, for example, crude or refined oil or light or heavy oil.

If the EMSA database is not available, the following options are suggested to assist the user in the initial stage of the oil spill:

- Option 1: To create an oil database from open-source databases such as ADIOS oil database developed by NOAA.
- Option 2: To create a simplified list with 4 types of oils classified according to their density, viscosity, and API as Crude, Refined, Heavy and Light products. Each group can be constituted by one or several representative oils obtained from available databases or based on the mean values of the selected list of oils.

In case of accident and while detailed information about the oil spilled is not available, these databases (EMSA database, option 1 or option 2) will provide initial information to allow the user to select an oil type.

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EMSATOIL
Part 2

Feasibility study for the development of a software tool to support Member States on oil pollution response operations at sea

Final Report

Date of publication: 28 July 2023

Report prepared for the European Maritime Safety Agency under contract number 2021/EMSA/NEG/5/2021 by the Environmental Hydraulics Institute of Cantabria (IHCantabria)

EMSA

Document History

Version	Date	Changes	Prepared	Approved
1.0	15/06/2022		IHCantabria	
2.0	05/08/2022	Document updated according with the revision of version 1.0	IHCantabria	
2.1	02/09/2022	Comments provided in previous versions, which were deleted, have been included	IHCantabria	
2.2	18/10/2022	Document updated according to revisions provided	IHCantabria	
Final Report	17/11/2022	Document updated according to revisions provided	IHCantabria	
Final Report	28/11/2022	Minor update according to revisions provided	IHCantabria	
Final Report	05/12/2022	Minor update according to revisions provided	IHCantabria	

In December 2021, the Environmental Hydraulics Institute of Cantabria (IHCantabria) was awarded the European Maritime Safety Agency (EMSA) contract 2021/EMSA/NEG/5/2021, call for *"A feasibility study for the development of a software tool to Support Member States on oil pollution response operations at sea"*. In the framework of this contract, IHCantabria will evaluate the feasibility of the development of an enhanced IT tool and will define its functional and technical requirements. To achieve this objective, the scope of the work is divided into two parts:

- Part 1: gathering of information to fully understand the functional aspects of the tool and its limitations.
- Part 2: proposal for options for the definition of the functional, non-functional, and technical requirements of the tool.

This document presents the work carried out for the definition of the functional, non-functional, and technical requirements of the tool (Part 2).

Document Summary

EMSA is currently exploring the feasibility to develop an IT tool, hereinafter referred to as system, to support Member States in their preparedness and operational decision-making process of mobilizing and deploying oil pollution response resources at sea. The main goal of this project is to gather information on existing tools to evaluate the feasibility of the development of an enhanced IT system and to define its functional and technical requirements. As mentioned above, the work is divided into two parts (Part 1 and Part 2). This document is the final report referring to Part 2 of the deliverables: options for the definition of the functional, non-functional and technical requirements of the tool.

To achieve these objectives, this document is focused on the following analysis:

- review of the functional aspects of the tool provided in Part 1;
- review and assessment on the conceptual and physical architecture of the System;
- review and assessment on the functional, non-functional, and technical requirements.
- review and assessment on potential issues

Section 1 englobes the objectives, scope, and structure of the document whilst Section 2 provides the conceptual and physical architecture of the system, which includes the architecture and all its components. Section 3 provides the system requirements, including functional, non-functional and technical requirements. Finally, appendix A provides the software requirements in EMSA's requirements template and appendix B contains the annexes to the requirements of the system.

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List of Abbreviations

API	Application Programming Interface
CF-conventions	Climate and Forecast Metadata Conventions
CMEMS	Copernicus Marine Environment Monitoring Service
ECMWF	European Centre for Medium-Range Weather Forecasts
EMODnet	European Marine Observation and Data Network
EMSA	European Maritime Safety Agency
EODC	Earth Observation Data Centre
ETL	Extract, Transform & Load
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
GIS	Geographic Information System
INSPIRE	Infrastructure for Spatial Information in the European Community
OGC	Open Geospatial Consortium
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
RPAS	Remotely Piloted Aircraft Systems
WCS	Web Coverage Service
WMS	Web Map Service
WP	Work Package

1. INTRODUCTION

1.1. Objectives

EMSA is currently exploring the feasibility to develop an IT system to support Member States in their preparedness and operational decision-making process of mobilising and deploying oil pollution response resources at sea.

The main goal of the project "*Feasibility study for the development of a software tool to Support Member States on oil pollution response operations at sea*", is to gather information on existing tools, to evaluate the feasibility of the development of an enhanced system and to define its functional and technical requirements.

This feasibility study discusses to which extent EMSA's vision and desired functionalities of the tool are technically feasible. It also proposes technical solutions that EMSA may take into account in the preparation of the requirements for the procurement of services for the development of the future IT tool.

The information to be gathered and the assessment to be made within this project will enable the concrete definition of the functional, non-functional and technical requirements of the future IT tool. To achieve these objectives the work is divided into two parts:

- Part 1: gathering of information to fully understand the functional aspects of the tool and its limitations.
- Part 2: proposal for options for the definition of the functional, non-functional and technical requirements of the tool.

This document is focused on technical aspects of the tool and its limitations (Part 2).

1.2. Scope of the document

This document is the final report on Part 2 of the deliverables. This work has been carried out in the framework of Work Package 2 and Work Package 3, with the objective of providing an architectural overview and a list of functional, non-functional and technical requirements for the new tool. To achieve this objective, the following tasks have been undertaken.

WP 2:

- Task 2.1. To propose and present a concept architecture for the tool and its systems.
- Task 2.2. To provide different views of the architecture.
- Task 2.3. To present the IT work required in work packages in terms of components.

WP 3:

- Task 3.1. An analysis of the high-level requirements and propose functional, non-functional and technical requirements according with EMSA's guidance.
- Task 3.2. Identify and discuss potential issues.

1.3. Report structure

The document is organized as follows:

- Section 1 provides an introduction to the project.
- Section 2 provides a conceptual and physical architecture of the new system.
- Section 3 presents the system requirements and potential issues.
- The Appendix A provides the requirements according with EMSA's guidelines.
- The Appendix B provides complementary information related to the requirements of system.

2. CONCEPTUAL AND PHYSICAL ARCHITECTURE

2.1. Architecture

The System proposed is based on a client-server infrastructure, which is composed by two main sections: back-end and front-end. Figure 1 shows a graphical representation of the workflow between front-end and back-end sections for any standard Web application.

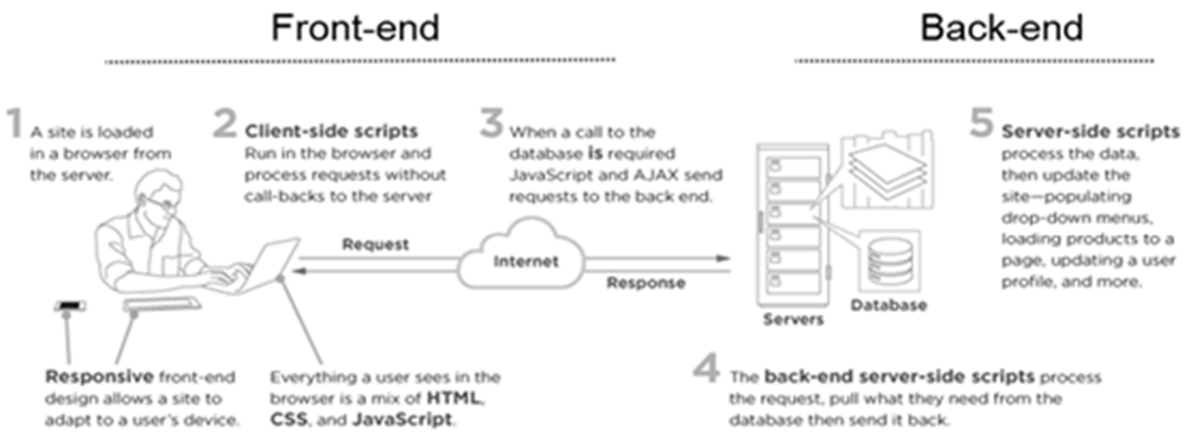


Figure 1 – Client-server infrastructure.

The front-end includes user interfaces and client's computer system used for accessing the Geospatial information through a fit for purpose user interface and interoperability protocols.

On the other hand, the back-end includes servers, data storage system, virtual machines, backup system, processing system, monitoring system and the required software to provide interoperability protocols to provide access to the data. Back-end is in charge of gathering, performing analytical processes, data management and provision of interoperability protocols.

The main objective of the proposed architecture is the collection of environmental data that will be translated into information to increase the knowledge of end users and facilitate decision-making processes.

It is important to highlight that the infrastructure will be based on an API architecture, which will provide a set of software interfaces that will expose backend data and application functionality for use in new applications or testing lab environments for new developments.

The System proposed should be compliant with EMSA's Enterprise Service Oriented Architecture with the objective of providing business and data services to other applications and being flexible and agile in order to easily adapt to change in short time. In this sense, the architecture could be summarized in the management of four types of data products (modelling, satellite, real time, coast), and processing capabilities, which include the oil spill modelling and Simulator analysis to obtain the required information and knowledge, which attempts to ensure end users who receive this visual information gain greater insights and perspectives on the topic (see Figure 2).

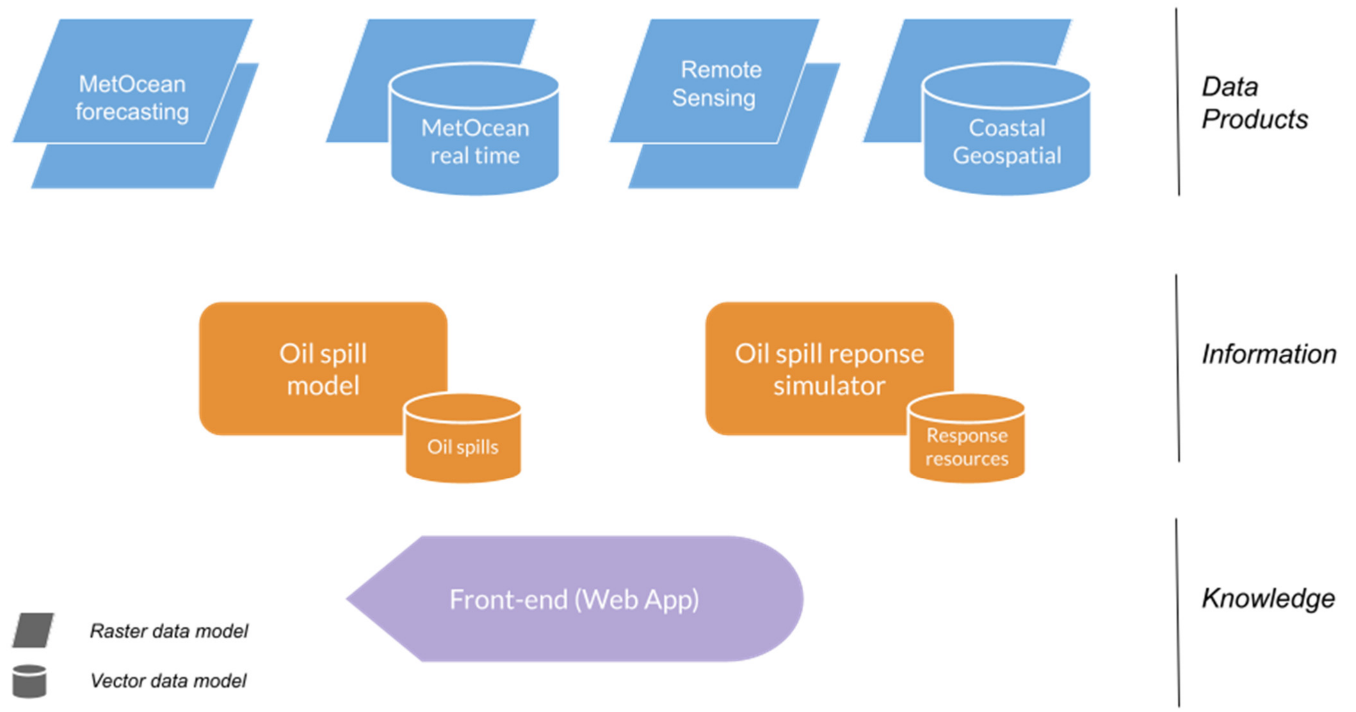


Figure 2 – Subsystems of the proposed architecture.

The subsystems proposed are listed and briefly described:

- The **MetOcean forecasting subsystem** - collect and standardize the access to MetOcean data products in raster format (forecast data).
- The **MetOcean Real time subsystem** - collect and standardize the access to real time data from in situ and remote sensing devices, such as MetOcean buoys or High Frequency Radars respectively.
- The **Remote Sensing subsystem** – make use of systems such as the Earth Observation Data Centre (EODC) and SurvSeaNet, which expose OGC services that provide standardize access to remote sensing products from satellite observations and Remotely Piloted Aircraft Systems (RPAS).
- The **Coastal Geospatial subsystem** - manage geospatial information such as topographies, bathymetries, etc.
- The **Oil spill model subsystem** - estimate the trajectory, dispersion, and weathering of the oil at sea.
- The **Oil spill response simulator subsystem** - account the efficiency of oil pollution response operations at sea, highlighting the adequate response resources and equipment to be deployed.
- The **Front-end subsystem** - provide access to advanced processing techniques coupled with innovative visualization techniques that will enable a wide array of digital decision support aimed at providing actionable information to decision-makers.

Operational Systems (such as the modelling, satellite and the real time subsystems) will require robust and reliable infrastructures that allow them to perform autonomous tasks and workflows periodically. The ability to find out what is happening on the subsystems at any given time will be crucial to provide a high quality Service. In this sense, the system should be monitored, checking hundreds of sensors every 10-15 minutes, among them we should highlight the following sensors: communications, hardware status, space for storage, inputs for models, outputs from models and ingestion of real-time observations. The information obtained from these sensors will have to be exposed to be consumed by the current EMSA's Monitoring system.

Therefore, it is required to have a robust and reliable infrastructure, which will have to be monitored 24 hours a day, 7 days a week, 365 days a year, ensuring business continuity and disaster recovery; with a Recovery Point Objective

(RPO) and Recovery Time Objective (RTO) in accordance with the Service Level Agreement (SLA) for the services provided.

The Architecture proposed is composed by three main layers, see Figure 3: layer 1 is in charge of end user interactions with the system, the User Interface (UI) and User Experience (UX), layer 2 is in charge of the data management processes, and layer 3 is in charge of the required analysis, numerical simulations and Extract Transform and Load processes (ETL).

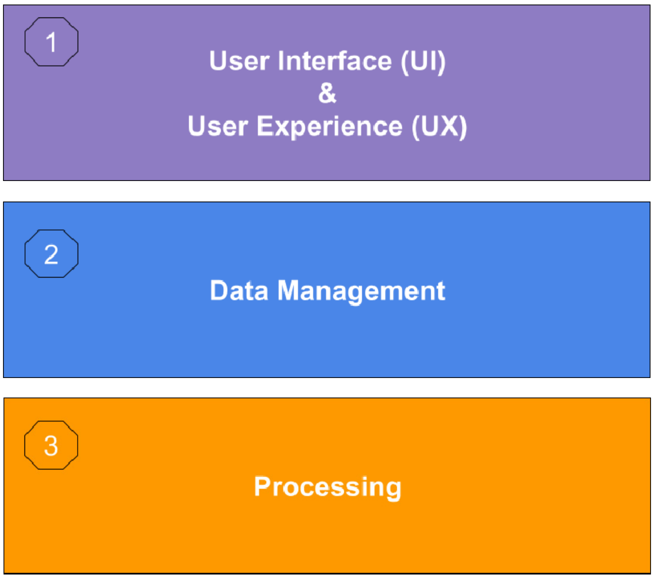


Figure 3 – Layers of the architecture.

<u>Layer 1 – User Interface (UI)</u>

Web technologies must be used to access the system. A Web UI's advantage is that no additional software needs to be installed on client side and minimal demands are placed on the client platform. Web app will be 100% compatible with, at least, Microsoft Edge and Mozilla Firefox (latest versions). In order to avoid creating multiple platform dependent solutions, the app should be based on simple website access, with appropriate changes applied to the UI to take into account the smaller screen size, reduced bandwidth and touch based controls used by mobile devices.

The user experience (UX) and user interface (UI) are key to provide a friendly tool. End user skills and knowledge will have to be identified in order to maximize the access and use of the system. In other words, the system will have to be adapted to best suit end user needs.

<u>Layer 2 – Data Management</u>

Operational decision-making processes require diverse spatial and temporal scale approaches in order to represent its multiple phenomena.

Software development in environmental sciences relays on the way in which environmental data is managed, inhibiting or enabling future analysis. Rather than having silos of information for each specific functionality, the Data Management approach should be based on a centralised data management infrastructure that can be accessible through standard interoperability protocols by other modules (e.g. user interfaces or processing modules). In this sense, the architecture proposed is based on the design and implementation of Application Programming Interfaces (APIs), which will act as a broker between the data (modelling, real time, satellite, etc.) and the different subsystems: oil spill trajectory, simulator and front-end.

The proposed APIs for data management are listed and briefly described:

- API MetOcean – provides methods to access MetOcean products, forecasting and real time observations.
- API Remote sensing– provides methods to access remote sensing data products from satellite observations and RPAS.
- API Coastal Geospatial – provides methods to access coastal geospatial data.
- API Emergency - provides methods to access information managed in the Emergency Data Base (emergency properties, simulations, spill polygons...)
- API Oil DB - provides methods to access information managed in the Oil Data Base (oil characteristics)
- API Resources & Equipment - provides methods to access information managed in the Resource & Equipment Data Base

Layer 3 – Processing

The processing layer will be in charge on all the functionalities that require analysis on the fly and under demand. Four main functionalities are included in the processing layer:

1) Oil spill model - the oil spill model selected will have to be integrated in the system to provide its numerical modelling capabilities.
2) Response simulator model - the response simulator model will have to be integrated in the system to provide its numerical response simulator capabilities.
3) Extract, Transform and Load processes - ETLs processes will have to be integrated in the system to assimilate data from:
    a. different metocean data providers such as Copernicus and NOAA,
    b. inputs required for the oil spill model selected for integration and its outputs,
    c. different results from other externally run oil spill models.
4) Log generator - engine to monitor the status of the system autonomously (24x7). The Log generator will create and expose the information for the EMSA's monitoring system.

Access to the processing functionalities should be provided by APIs, ensuring agnostic access to invoke the models or access their results. The proposed APIs for processing are listed and briefly described:

- API Oil spill – provides methods to invoke the oil spill model dynamically with its range of settings.
- API Simulator – provides methods to invoke the simulator dynamically with its range of settings.
- API Monitor – provides methods for accessing granular data on the state of the system.

Figure 4 summarizes the main components of each of the layers and provides a draft architecture proposal.

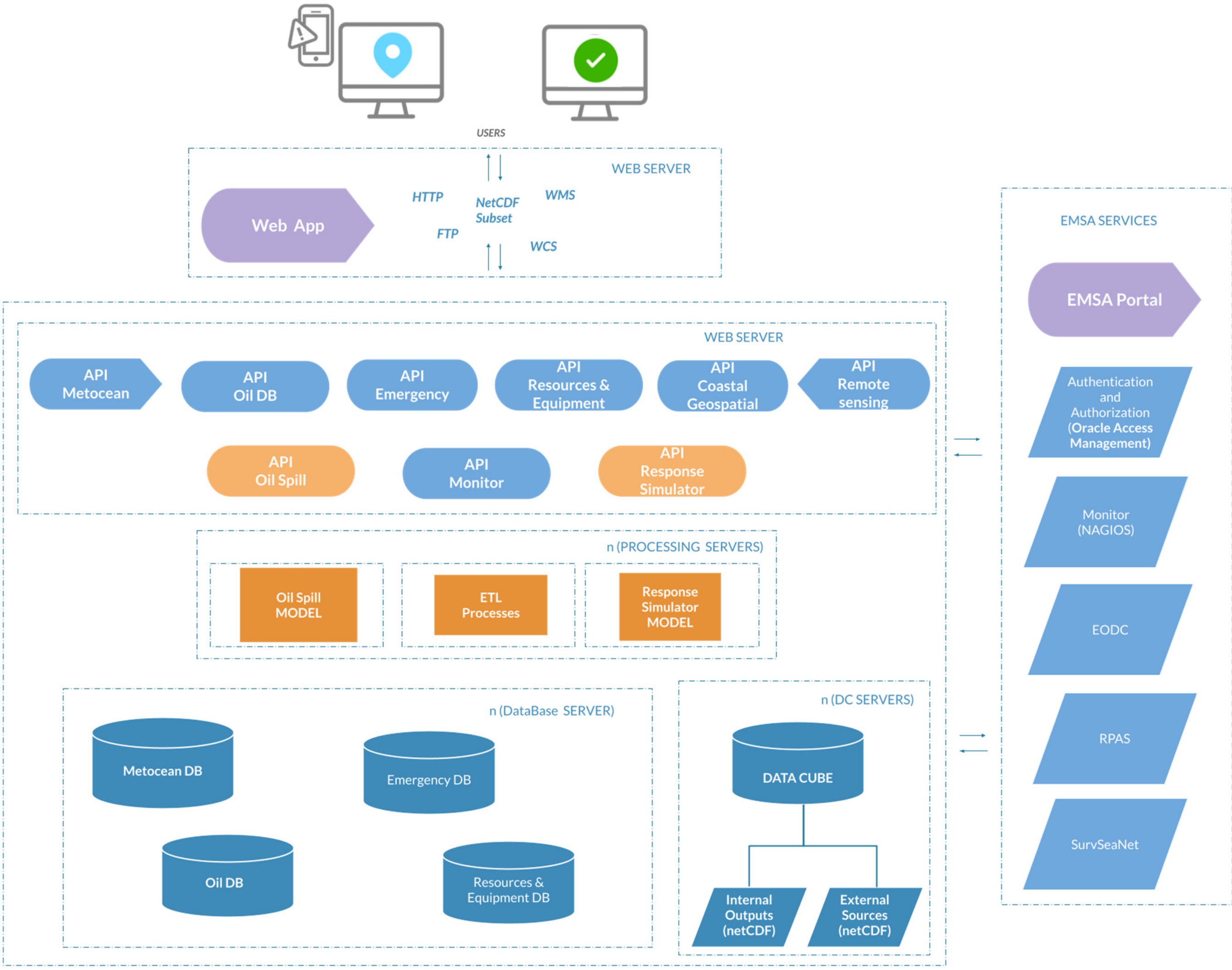


Figure 4 – Proposed architecture.

Therefore, **interoperability** will facilitate the creation of an ecosystem of technical users (developers) who can provide innovative solutions that will be able to be easily integrated in the future. The proposed architecture could be used as an “IT Lab” to design and test new models, functions and algorithms making use of the exposed APIs (Modelling, Real Time, Satellite, oil spill and simulator, etc.).

2.2. Components (WP)

The IT work required for the design, development and implementation of the System is listed as subsystems corresponding with Work Packages (WP), see Table 1 .

Table 1 – Work Packages & Subsystems.

WP	Priority	Subsystem	Subtasks
WP1	5	MetOcean forecasting	Subsystem in charge of the management of MetOcean forecasting products: (1) collect and standardize modelling MetOcean products from different data providers (Copernicus, NOAA, etc.) or end users, (2) provide interoperability access to MetOcean products collected.
WP2	5	Emergency management	Subsystem in charge of the management of Emergencies: (1) set up emergencies (2) manage emergency properties and spill polygons
WP3	5	Oil spill model	Subsystem in charge of: <u>Oil Spill modelling service</u>, which includes: (1) set up of the model, (2) computing capacity, (3) interoperability to run the model and access the modelling results. <u>Oil Spill characteristics database service</u>, which includes: (1) database design, (2) interoperability for data management
WP4	5	Oil spill response simulator	Subsystem in charge of highlighting the adequate response resources and equipment to be deployed, which includes: <u>Oil pollution Response Simulator service</u>, which includes: (1) Algorithms for the analysis, (2) computing capacity, (3) Interoperability to run the algorithms and access their results. <u>Response resources and equipment database service</u>, which include: (4) database design, (5) Interoperability for data management.
WP5	2	MetOcean real time	Subsystem in charge of MetOcean real time observations: (1) collect and standardize real time *in situ* data and (2) provide interoperability access to real time MetOcean products.
WP6	1	Remote sensing	Subsystem in charge of: (1) database design with the products of data providers (EODC and SurvSeaNet) and their OGC services. (2) access remote sensing data products from satellite observations and RPAS.
WP7	3	Coastal Geospatial	Coastal Geospatial Subsystem in charge of: (1) centralize and manage coastal data (bathymetries, topography, etc.).
WP8	4	Front-end	Subsystem in charge of facilitating user interaction with the System: (1) User Interface and User Experience design and development according with end user needs, (2) access management and role/privileges integrated with EMSA's authorization services.

The relationships among the Work Packages proposed are shown in Figure 5: WP 1, 2, 5, 6 and 7 are devoted to data collection and data management. Analysis and some data management (oil characteristics and response equipment) will be undertaken in WP3 and WP4. Finally, WP 8 requires outputs from all the WP. WP5 and 6 are not critical WP for the design and development of the proposed system.

In terms of interactions between WP, results from WP 1, 2 and 7 are fundamental to perform the required analysis by WP3 and WP4. Results from the analysis and the different data products will be accessible through the Web application developed under WP8.

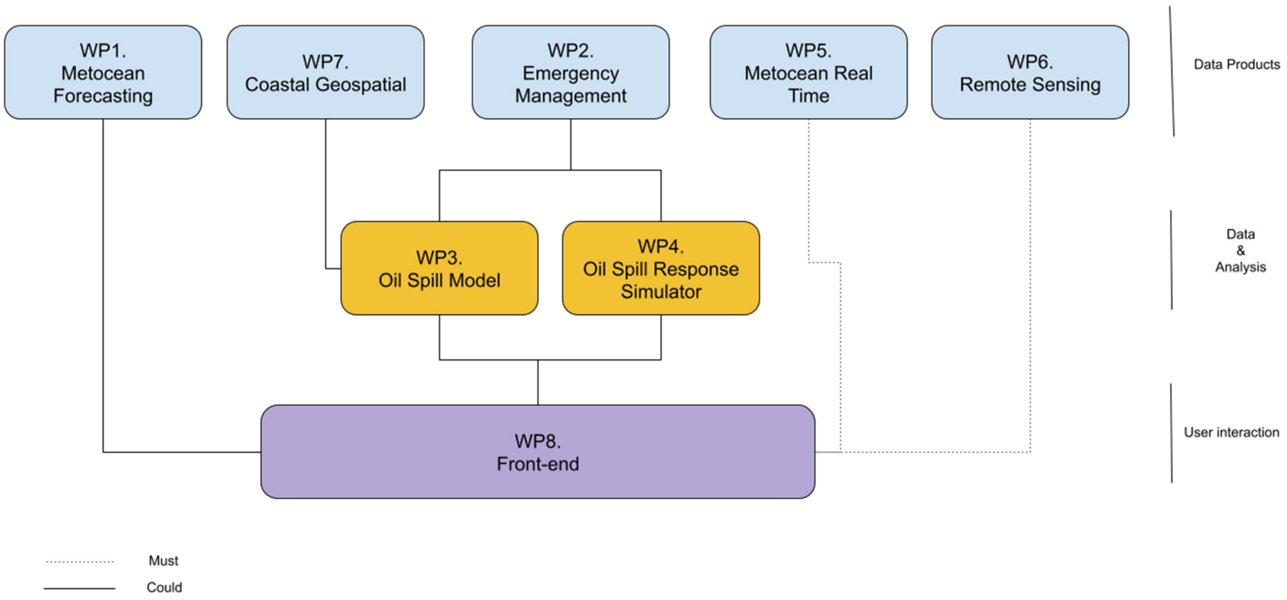


Figure 5 – Relationships between Work Packages.

3. SYSTEM REQUIREMENTS

This section describes high-level requirements and propose functional, non-functional and technical requirements. Based on the software specification phase, the System Architecture has also been designed and described, providing the definition of the architecture, components and modules to satisfy the specifications stated according with EMSA's guidance.

3.1. Functional

To fulfil EMSA's requirements, it will be necessary to design and develop an IT system with the following functional specifications, see Figure 6:

- To run the Oil Spill Model (OSM) and the Response Simulator (RS). The system should be able:
  - To run oil spill simulations to predict the trajectory, dispersion, and weathering of oil spills at sea considering the met ocean conditions at the spill site. The initial oil spill location will be provided from a specific location or polygons obtained, e.g., from aerial observations, satellite images, or RPAS images.
  - To run several independent oil spills simulations to take into account the division of the oil spill into several slicks.
  - To run the response simulator to estimate the amount of oil removed, dispersed, or burned from the sea surface by the deployment of oil pollution response equipment and resources. The output of the 3D oil spill model will serve as the basis for the simulator.
  - It should be flexible to import data from third-party oil spill models and to run the response simulator with this information.

- Management and visualization of external databases: earth observation, MetOcean forecasting, MetOcean real time observations and coastal geospatial information. The system should be able to manage and visualize GIS data:
  - Extract, transform, load, manage and visualize raster data, including scientific formats with n dimensions (such as NetCDFs).
  - Extract, transform, load, manage and visualize vector data.

- Management and visualization of the system databases:
  - It shall integrate a database of oils that are frequently transiting European waters. The database shall gather the physical and chemical properties of the oils required for the oil spill model.
  - It shall integrate a database of European oil pollution resources. In addition, it should be possible the integration of other regional or local sources of environmental data from EU Member States.
  - Interoperability to both data bases must be guarantee, including access and edition related with user privileges

- Management, export, and visualization of the simulation results:
  - OSM: transport and dispersion of the oil spill, as well as, the temporal evolution of the weathering processes.
  - RS: the amount of oil removed/dispersed/burned, the Gantt chart for the schedule of the operations and the total cost for a set response strategy.

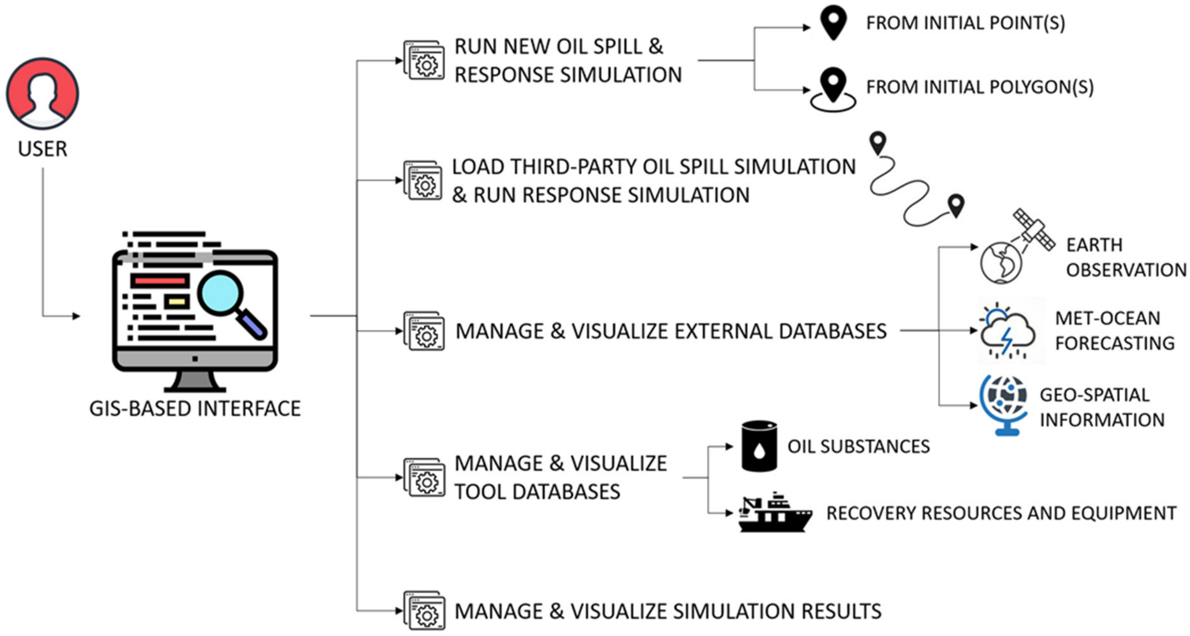


Figure 6 – General overview of the system.

The following lines describe the functionality of the Response Simulator. The user interaction with the system interface will facilitate the loading of the results of an oil spill simulation (including the evolution of the centre of mass of the spill and the evolution of the main properties of the oil substance: density, viscosity, thickness…) into the system. Moreover, the user will have to select the met ocean databases desired to take into account during the simulation of the response. Finally, the user will have to assign the response assets based on compatible resources and equipment to be used during the recovery simulation.

The system will provide a default working day (e.g. 9h to 17h) to allow scheduled operations, which will be the base for the calculations carried out for the total N days of the simulation. This working day definition would be changed optionally by the user to satisfy the requirements of the different Member States and actors involved in the operations.

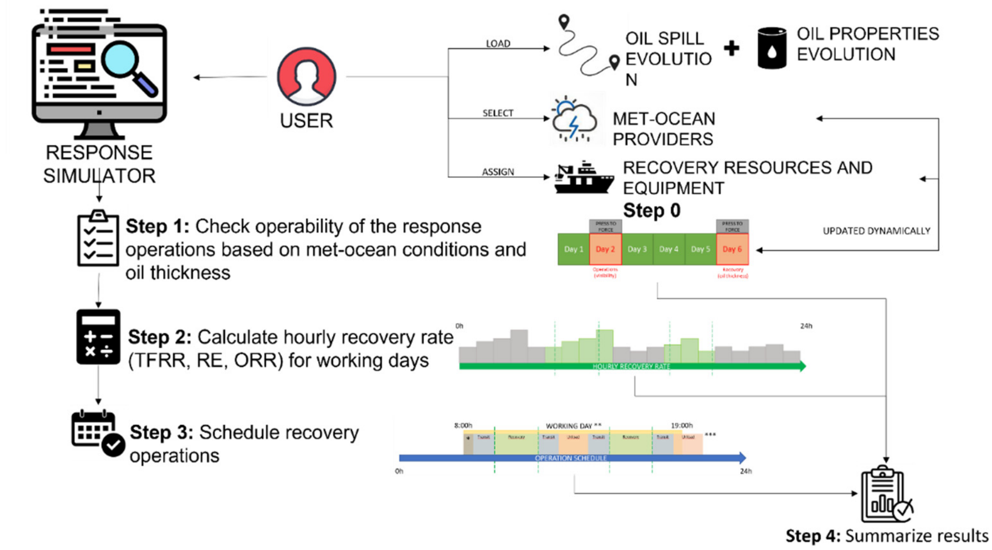


Figure 7 – Conceptual design of the Response Simulator and the user interaction to estimate the mechanical recovery response.

3.2. Non-functional

The following list provides a set of non-functional requirements for the design and development of the proposed system:

- The Scalability - A scalable architecture is an architecture that can scale up to meet increased workloads. In this case, scalability of the software will be achieved through the design and implementation of Web Services. This approach will require to divide services into separate modules which are loosely coupled together, communicating with each other through light-weight mechanisms (for example APIs).

- Open Source - Open source should be adopted as mandatory to guarantee maintenance without additional costs and a potential evolution of the System as an open lab. The System will be based on the current open source geospatial state of the art, avoiding reinventing the wheel and harnessing the full potential of mature open source geospatial technologies. The advantages of opting for open source are well known, highlighting the absence of no vendor lock-in and lower software costs on licencing and maintenance.

3.3. Technical

The following list provides a set of technical requirements for the design and development of the proposed system:

- Interoperability - The system should be based on subsystems that will guarantee a smooth workflow based on Interoperability protocols. Interoperability will ensure the provision of a scalable System.

- The use of application programming interfaces (API) to develop a modular and interoperable system should be granted to access main databases and services.

- The use of OGC and INSPIRE standards should be granted in the data workflow (e.g., access to nautical charts, vessel detection, and traffic density maps).

- Compatible with Nagios monitoring system – The system will expose sensors to monitor the processes and to facilitate the information to a Nagios monitoring system.

- Progressive web app standards will be followed to develop a system compliant with mobile devices.

3.4. Potential issues

One of the main concerns related to the design and development of the proposed system is the management of such a large amount of available operational data (modelling, *in situ* and satellite imagery). Three options have been considered and analysed to tackle this important issue:

- **Option 1** – Design and develop a System that integrates operationally all the required data (modelling, *in situ* and satellite imagery) and provide interoperability access to all the integrated data. The aspects to take into consideration are listed:
  - Software & hardware to host and manage the metocean data providing OGC services (WMS, WCS)
  - Monitor the operational service: service status and available data on time and formats.

- **Option 2** – Design and develop a System that access and transform operationally all the required data (modelling, *in situ* and satellite imagery) for the oil spill model. The aspects to take into consideration are listed:
  - Software to access and transform the data under demand to be used by the oil spill model.
  - Monitor the operational service: service status and available data on time and formats.

- **Option 3** – Design and develop a System that integrates under demand the required data (modelling, *in situ* and satellite imagery) and provide interoperability access to all the integrated data for the area of work selected by the user. The aspects to take into consideration are listed:

- Software & hardware to host and manage the metocean data providing OGC services (WMS, WCS)
- Monitor the operational service: service status and available data on time and formats.

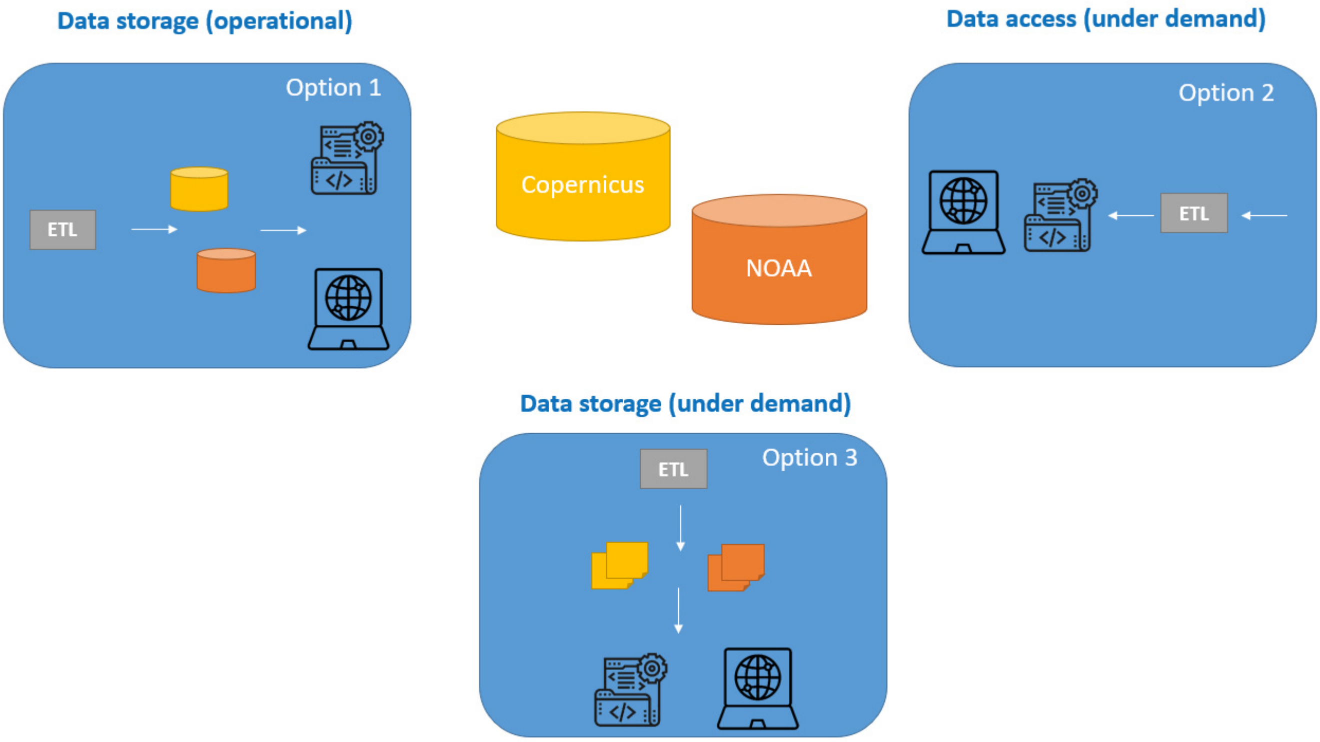


Figure 8 – Options for the management of operational MetOcean data

Option 2 accesses the data through interoperability protocols (e.g., OpenDAP), which means that the system does not download the data and is able to run the oil spill model. This option would be preferred if data providers (e.g., Copernicus, NOAA, ECMWF, etc.) provided OGC interoperability protocols such as WMS, WCS, and WFS to allow visualization of weather and ocean data without their necessary download. On the other hand, option 1 would download all MetOcean products on a regional scale in Europe to integrate OGC services into the Data Management and Visualization System. Finally, option 3 is the same concept as option 1 and 2, but with a defined work area, which will allow initiating the download of those selected products that cannot be accessed through OGC interoperability protocols, instead of autonomously and systematically downloading all products periodically.

Table 2 shows advantages and disadvantages for each of the options.

Table 2 – Options for operational data integration

	Option1	Option 2	Option 3
Alias	Operational integration	Access by demand	Integration by demand
Advantage	Full control and management of all available data (modelling, in situ and satellite), which provides instant access to the data and all capabilities for data mining and visualization. OGC protocols will facilitate access to the data	The ETL will be specially designed for the oil spill model. The system will require less computational capacity and therefore the transformation speed will be faster.	Full control and management of all available data (modelling, in situ and satellite) for the area of interest. OGC protocols will facilitate access to the data.
Disadvantage	The amount of data will be very large. The service will have to be scaled according with the space requirements	Without OGC services, other subsystems (e.g. the front end) will not be able to access the data and use it for other	The oil spill model and other subsystems that rely on metocean data will not be available for immediate use. First, the user will have to set up “the area of work”,

	Option1	Option 2	Option 3
		purposes, such as visualizing winds, currents, waves, etc.	wait for the download process and then all the necessary data will be available to make use of all system functionalities.

Therefore, after analysing all the interoperability protocols provided by the main data providers, see Table 3, we conclude that the best option for the proposed System is option 3. This option will avoid to replicate a large data repository of metocean data and will provide full potential capabilities through the implementation of OGC services such as Web Map Service and Web Coverage Service. However, it should be noted that data providers are currently working to provide the OGC interoperability protocols required in their services, which would facilitate the implementation of Option 2.

Table 3 – Interoperability protocols provided by main data providers

	Protocols provided	Protocols not provided
Copernicus Marine Service (CMEMS)	OpenDap MotuClient FTP DGF Web Map Service (WMS) ERDAP	Web Coverage Service (WCS)
NOAA	OpenDAP FTP Https Grib-filter	Web Map Service (WMS) Web Coverage Service (WCS)
ECMWF	FTP AmazonS3 Azure	Web Map Service (WMS) Web Coverage Service (WCS)

Appendix A - EMSA Requirements

The complete EMSA Requirements will be provided in a Microsoft Excel spreadsheet file. In Table 4 the summary of the complete requirements list is shown. At the end of this report the complete requirements list.

Table 4 - Summary of the system requirements

Nº	Requirement title
UC.1	Use case: User roles and main functionalities of the service
UC.2	Use case: Perform OSM simulation
UC.3	Use case: Perform RS Simulation
UC.4	Use case: perform simulation re-start
UC.5	Use case: digitalize oil spill polygons
1	General view, modules, and sections
2	Main functionalities of the system
3	General structure of the databases
4	Login, authentication, and authorization of users
5	User roles
6	Mapping between roles and actions
7	Visualize geospatial information
8	Web map and geospatial functionalities
9	Drawing Oil spill polygon
10	Uploading Oil spill polygon
11	Visualize Metocean, satellite, and aerial images
12	Upload aerial images
13	Emergency section
14	Define emergency domain
15	Search for metocean and satellite data
16	OSM Module
17	Oil spill modelling functionality
18	Third-party OSM outputs upload functionality
19	ETLs for third-party OSM outputs
20	Metocean data access for OSM
21	Restart from existing OSM simulation
22	RS module
23	RS methodology
24	RS - Window opportunity and response equipment workflow
25	RS – Window Opportunity
26	RS – Assignment of resources
27	RS – Check feasibility
28	RS – Force working in not feasible days
29	RS – Schedule configuration and trigger calculation
30	RS – Schedule recovery operations
31	RS – Recovery rates
32	RS – Summary
33	Restart from RS simulation
34	List of metocean and satellite data
35	ETLs metocean data
36	Metocean Service from ETLs products
37	Time for metocean data download
38	Emergency database section
39	Emergency database service
40	Oil database section
41	Oil database service
42	Resource & equipment database section
43	Resource & equipment database service

Nº	Requirement title
44	Monitor
45	Progressive Web app
46	Mobile device functionalities

Appendix B – Annexes to EMSA Requirements

Annex 1. Required variables

A) Required variables to import an external Oil Spill Model results

Not all the oil spill models save, as result, the same variables, some of them include derived or slightly different variables that can be calculated in many cases through simple physical equations. This specific task should be reviewed when the list of the desired compatible external models will be defined.

Generally, there are two different scopes regarding the results obtained by oil spill modelling, results at particle scale and results at spill scale. For the use of the app, the variables needed are divided into two groups: particle tracking and weathering.

- Variables that define the location of the particles that represent the oil spill, and its related geometrical properties:
  - Particle tracking: position of each particle (coordinates).
  - Center of mass: derived from the particle tracking, not all models include this variable.
  - Area of the spill: derived from the particle tracking, not all models include this variable.

- Variables that define the results of the weathering processes suffered by the substance, and its related physicochemical properties. Some models use a particle scale for some variables, the app requires a spill scale value that can be in any case easily derived from the particle scale:
  - Mass on the surface: total oil mass on the surface.
  - Mass evaporated: total oil mass evaporated to the atmosphere.
  - Mas dispersed: total mass dispersed in the water column.
  - Mass beached: total mass beached, the mass that already has reached the coast.
  - Mass of the emulsified product: the total mass of the emulsion (oil mousse) that considers the water-in-oil mixture and which can be derived from oil mass and the percentage of water content.
  - Viscosity: the spatial mean viscosity of the spill.
  - Density: the spatial mean density of the spill.
  - Thickness: the spatial mean thickness of the oil spill.

B) Required variables to be defined in the Oil database

Not all the oil spill models use, as input, the same oil properties. Thus, this specific task should be reviewed during the integration of the OSM module in the app to ensure that all the variables needed regarding the oil properties are defined in this database. The most common variables to be included in the database are the following:

- Name
- Product type (crude/refined)
- Density @ reference temperature
- Viscosity @ reference temperature
- Kinematic or/and Dynamic viscosity @ reference temperature
- API
- Pour point
- Flash point
- Maximum water content of the emulsion

Annex 2. Operability and pairing stand-alone equipment rules for Response Simulator

A) Operability rules

*This information was extracted from the document **"EMSATOIL Part1 - Feasibility study for the development of a software tool to support Member States on oil pollution response operations at sea (Version 3.1)" section "4.5 – Operability assessment and window of opportunity"** for further information please consult the complete document.*

Operability assessment and window of opportunity

The objective of this section is: i) to analyze the aspects that influence the operability of the response operation and ii) to identify and assess the possibility of having a warning message displayed to the user on the window of opportunity for oil spill response at sea considering the weather conditions and the characteristics of the weathered oil. These aspects are addressed in step 1 of the proposed methodology.

Response operations are strongly impacted by met ocean conditions as any operation at sea. The operability assessment provides the met ocean conditions in which these specific operations can be carried out to ensure the safety and performance of the personnel and the equipment. Operability assessment has been divided into two main sections: 1) general operability related to general factors such as visibility, met ocean or environmental temperature; and 2) operability limits for each response technique based on weather conditions and the characteristics of the weather oil.

Moreover, the window of opportunity defines the time periods for effective utilization of marine oil spill response technologies and methodologies in clean-up operations (Norvidvik, 1999) and mainly depends on the changes in the physical and chemical properties of the oil (oil weathering) and the weather conditions. The window of opportunity will be estimated based on the operability limits established for the response operations techniques as part of the operability assessment.

General operability

This section presents the main factor affecting the general operability of the response operation. The most important variables constraining the operability of the response are the met ocean conditions that ensure the safety of the personnel and the safety of the navigation. In Table 5, the collection of variables and operability limits regarding navigation and personnel safety are shown. Wind velocity for small and large VOO as well as for OSRV has been established based on RC. The general value of the wave height for all vessels has been considered taking into account the operability limits for booms and assuming that vessels do not operate if the equipment cannot be deployed. Temperature and visibility values have been obtained from the Circumpolar oil spill response viability analysis technical report (EPPR, 2017). It is important to highlight that Table 5 presents general values that can vary for specific types of vessels. Furthermore, staff safety is of paramount importance. Ultimately, these operational limits must be set by the corresponding Maritime Authority.

Table 5 - General operability topics, variables, and limits.

Topic	Variable	Operability limit
Navigation (Small VOO)	Wind velocity	< 5 m/s
Navigation (Large VOO)	Wind velocity	< 10.8 m/s
Navigation (OSRV)	Wind velocity	< 10.8 m/s
Navigation (All vessels)	Wave Height	< 3 m
Personnel safety	Temperature	> -18 ºC
Navigation (All vessels)	Visibility	200 – 900 m

Operability assessment will be evaluated for each day of simulation. In order to be flexible with the usual uncertainties and outliers of any forecast, it is proposed to use a statistical value as representative of the working day, e.g. 80% percentile, which allows exceeding the limit value defined for each variable during a maximum of 20% of the working day is proposed. The user will be allowed to modify this percentile value to create a more flexible or restrictive assessment of the operability.

Operability for each response type

Differences between each type of response and the equipment and operations involved determine the accomplishment of some specific limits to ensure the safety and success of the works. To enhance the clarity of the document these specific operability limits have been grouped by response type as follows:

- In situ burning

The application of this response in the EU has to be approved by the competent authority, after the authentication of several strict requirements related to minimum distances from populated areas or special protection areas and the safety of the operators.

Once this type of response is authorized, the time window for ignition and sustained burning will vary, depending on environmental conditions, physical properties, and chemical composition of the spilled oil. Once the initially hazardous and high fire risk situation has passed, the time window of opportunity for the use of in situ burning as an oil spill response opens, and in situ burning will become a feasible response. The time window of opportunity for the use of in situ burning will eventually close when the slick becomes impossible to ignite due to the oil layer thickness drops below a critical minimum, the oil has lost a substantial proportion of its more volatile and flammable components by evaporation, and when the oil has incorporated water to form an emulsion.

For a successful in-situ burn the layer of oil on the sea surface needs to be at least 2-3 mm thick to counter the cooling effect of the wind and sea and maintain a fuel source for the fire (API, 2015, https://www.itopf.org/knowledge-resources/documents-guides/response-techniques/in-situ-burning/). The ignition and sustained burning of weathered oil using conventional ignition technology is restricted by approximately 25% evaporation and or a 25% water content (API 2015) and wind velocity and wave height (Fingas, 2011; API 2015).

Table 6 shows the specific variables and operability limits for this response based on API (2015).

Table 6 - Specific variables and operability limits related to In situ burning response (API, 2015).

Topic	Variable	Operability limit
Oil/Emulsion characteristics	Evaporation	< 25%
Oil/Emulsion characteristics	Thickness	> 2 to 3 mm thick (2 to 3 times thicker for highly weathered/emulsified oil).
Oil/Emulsion characteristics	Emulsification	< 25% (can vary for different types of oil).
Ignition and correct burning	Wind velocity	< 9.2 m/s for ignition; sustained burning possible with higher wind conditions.
Ignition and correct burning	Wave height	< 3 m swells or 1 m wind waves (may be higher with fresh and un-emulsified oil

- Dispersant application

This technique has also very restricted use in the EU and not all Members States allow its use. Dispersants are applied from aircraft or vessels, through dispersant applications systems.

As oil weathers at sea, its viscosity increases until it is no longer dispersible. Emulsification and evaporation processes increase oil viscosity and decrease its dispersibility. The time during which oil remains dispersible is called “the window of opportunity for dispersion.” It varies according to the type of oil and the environmental conditions. This period is mainly dependent on the oil viscosity (see Table 6).

A viscosity of 10,000 cSt is often used as an indication of oil’s dispersibility (IMO, 2011; EMSA, 2009). Oils with viscosity (at seawater temperature) of up to 10,000 cSt are considered to be potentially dispersible, though dispersion of oils with viscosities above 20,000 cSt is reported (IPIECA-IOGP, 2014).

Table 7 - Specific variables and operability limits related to dispersant application response.

Topic	Variable	Operability limit
General met ocean conditions	Wind velocity	Limits of the aircraft or vessel
Oil/Emulsion characteristics	Viscosity	<10.000 – 20.000 cSt

- Mechanical Recovery

This type of response is by far the most utilized by all the Member States to face large oil spill emergencies. The operability limits of this response can be divided into two main operations: boom deployment and skimmer operability.

The deployment and use of the booms to drag oil and facilitate the skimming actions require mainly good weather conditions. Table 8 presents the met ocean operability limits regarding wave height, wind, and current velocities to ensure the correct deployment and use of the booms. Note that these values are general values that may vary for specific booms, configuration deployment, or skimmer types.

Several documents have been consulted to determine the ratio in which the waves produce failure in booms. *Oil spill response field manual* from ExxonMobil (2014) establishes that splash over failure may occur in choppy water when wave height (H) is greater than boom freeboard and the wavelength/height (L/H) ratio is less than 10:1, where height/H is an indirect measurement of the roughness of the sea. Fingas (2011) referred to Van Dyck and Bruno (1995), where is indicated that a wavelength/height ratio is not a limiting parameter when is 12:1 or greater. NOAA (2012) states that for mechanical recovery, effectiveness drops significantly because of entrainment and/or splash-over as short-period waves develop beyond 2–3 ft (0.6–0.9 m) in height. Koops and Huisman (2002) give a priori limits of Beaufort 6 (10 – 14 m/s) for skimmers and another mechanical recovery. Koops (1988) gives the limit of skimmers as 1.5 m wave heights and notes that swell has no effect on the capability to mechanically recover.

Current velocity limit values are the other main factor related to droplet entrainment and drainage failures. Entrainment failure generally occurs at current velocities between 0.7 and 1.0 kts (0.4-0.5 m/s) (Fingas, 2011; ITOPF, 2012; ExxonMobil, 2014).

Lastly, the ability to contain and recover oil decreases rapidly as the slick thickness becomes less than a thousandth of an inch or 0.00254 mm (NOAA 2012, ROC technical manual)

Oil viscosity is another factor to take into account in skimmer operability. Although the operability as a function of the viscosity will depend on the type of skimmer, there are several skimmers prepared to work in a huge range of viscosities regardless of the skimmer type. All skimmers work in optimal conditions in medium viscosities. However, a very high viscosity could produce problems or inoperability. Based on international standard *ISO 21072:2020 Performance testing of oil skimmer*, the ratios to light/medium viscosity are up to 50.000 cP and high viscosity oil above 50.000 cP and up to 1.000.000 cP, so this could be the upper limit skimmer operability.

Table 8 - Specific variables and operability limits related to mechanical recovery response.

Topic	Variable	Operability limit
General met ocean conditions (booms and skimmers)	Wave height	< 1 – 1.5 m

Topic	Variable	Operability limit
General met ocean conditions (booms and skimmers)	Wavelength/wave height ratio	<10:1 or 12:1
General met ocean conditions (booms and skimmers)	Wind velocity	< 10 – 14 m/s
General met ocean conditions (booms and skimmers)	Current velocity	< 0.5 m/s
Oil/Emulsion characteristics	Thickness	> 0.00254 mm
Oil/ Emulsion characteristics	Viscosity	High-viscosity and depending on the skimmer (not clear reference found)

Window of opportunity

As mentioned at the beginning of this section, the window of opportunity defines the time periods for effective utilization of marine oil spill response technologies, which depends on the oil weathering and the weather conditions.

The window of opportunity will be established by taking into account:

i) the hourly met ocean forecasts provided by the European forecasting systems (e.g. Copernicus Marine Service) described in Section **¡Error! No se encuentra el origen de la referencia.**,
ii) the temporal evolution of the oil weathering provided by oil spill numerical models, and
iii) the operability limits previously established for each response technique.

Based on this information, the system will provide the window of opportunity in a user-friendly way, to support the response authorities to decide and select on which assets to mobilise.To obtain a warning message about the window of opportunity for offshore oil spill response, four subsystems must work in a coordinated manner:

- (1) back-end subsystem that provides the oil characteristics,
- (2) back-end subsystem that provides the forecast of the met ocean conditions,
- (3) back-end subsystem that evaluates the window of opportunity making use of the previous subsystems and
- (4) front-end subsystem that is designed to provide a user experience in line with the information required for the end-users. The use of traffic lights across a forecasting timeline is a commonly used solution implemented for operation and maintenance systems. To illustrate this kind of graph, Figure 9 shows an example of an operability assessment in an oil terminal to support the end-user about the operability conditions for oil load and unload operations.

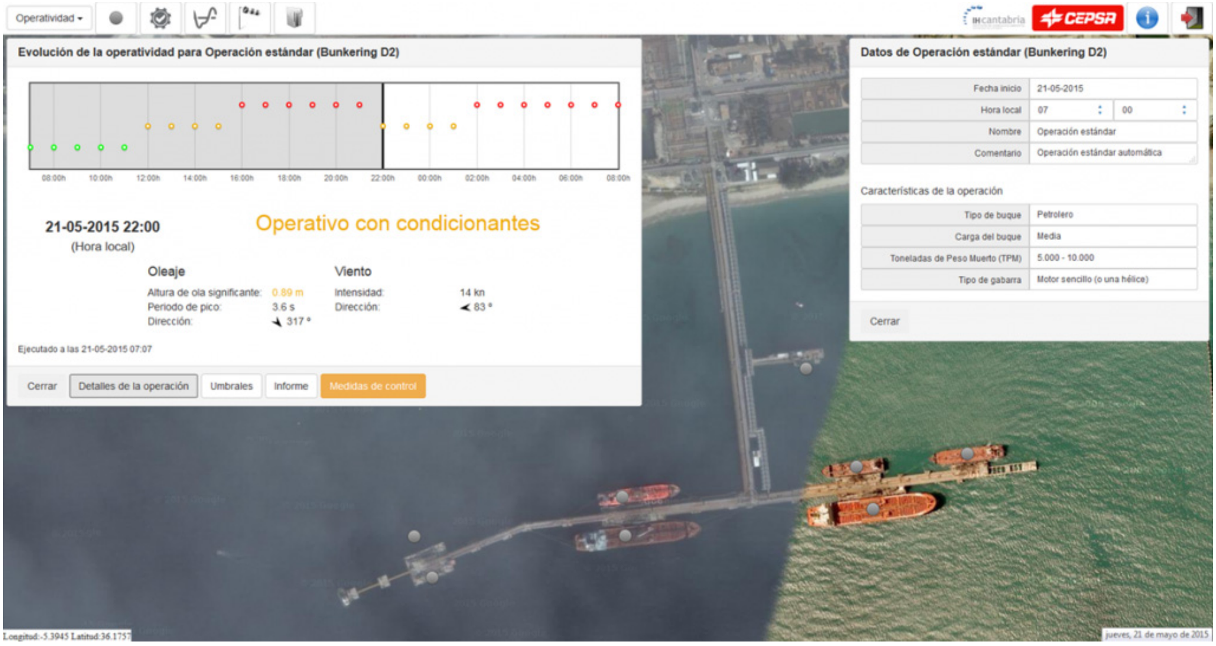


Figure 9 - Example of operability assessment for loading/unloading operations in oil terminals.

End users will interact with the front-end to invoke the window opportunity analysis and obtain the final evaluation (i.e. a warning message).

B) Pairing stand-alone rules

This information was extracted from the document ***"EMSATOIL Part1 - Feasibility study for the development of a software tool to support the Member States on oil pollution response operations at sea (Version 3.1)", section "4.4 – Options for pairing stand-alone equipment"*** *for further information please consult the complete document.*

Options for pairing stand-alone equipment

The objective of this section is to identify and assess options for pairing stand-alone equipment (identified in the database of response assets) with adequate vessels. This issue is addressed in Step 0 of the proposed methodology.

Definition of resource properties

First of all, the main properties of vessels, stand-alone equipment, and the different configurations for each response technique have to be established and, as far as possible, to be incorporated into the databases of response assets.

On one hand, for marine operations vessels can be classified into two groups:

- Specialized Oil Spill Recovery Vessel (OSRV) is a dedicated vessel always equipped with oil spill response equipment to carry out mechanical recovery, in situ burning, or dispersant application autonomously. These vessels are fully equipped and do not require to be complemented with other assets.
- Vessel of Opportunity (VOO) is a non-dedicated vessel for oil response operations. These vessels are dedicated to different activities (normally sea rescue activities, research, fishing vessels, bulk tank…) to respond during major oil spills so during the emergency they can be equipped with compatible stand-alone equipment for realizing mechanical recovery (booms and skimmers), in situ burning (fire booms and ignitor), or dispersant application (dispersant application system, DAS). These vessels can be very different types and the jobs VOO may be assigned will depend on the oil spill response and their capacities.

The following information would be required to have an approach to their capabilities to be paired with the equipment:

- Deck space (m^2)

- Available deck space to storage (m^2)
- Loading capacity (tons)
- Lifting appliances/ crane (tons)
- Tow or Deploy capabilities
- Towing capacity (tons)
- Storage capacity (m^3)
- Other capabilities (specific equipment, crew number...)

On the other hand, stand-alone equipment refers to the necessary assets to carry out the different response options (booms, fire booms, combined equipment, trawl-nets, skimmers, dispersants, and dispersant application systems). Each piece of equipment has its basic properties and requirements to be loaded and deployed, such as:

- Storage space needed (i.e. 20ft container: 38,54 m^2)
- Clear space to operate (i.e. 3-4 meters in front of the container doors)
- Open gunwale to deploy/recover (i.e. yes/no)
- Lifting appliances/ crane to deploy/recover. (yes/no)
- Weigh (tonnes)
- Tow Speed (m/s)
- Number of vessels to tow and deploy
- Crew needed to deploy and control.
- Total meters available and sections of 250 m. (to containment booms)

This information shall be included in the database of the resource properties. These data are normally available in the equipment's data sheet or can be facilitated by owners.

Regarding the configuration for each response technique, Table 9 shows an overview of the potential configurations of the equipment in each specific case.

Table 9 - Potential configuration of the equipment for each response technique.

Mechanical recovery	Dispersant	In Situ burning
■ Only Booms ■ Booms + Skimmer ■ Booms + Skimmer + Storage ■ Combined equipment: containment booms & skimmer (i.e. [redacted] ■ Combined equipment + Storage ■ Trawl nets: containment & storage ■ Only Storage	■ Dispersant ■ Dispersant application system	■ Fire boom + ignition kit

Pairing stand-alone equipment with vessels

Once defined the aforementioned properties, the stand-alone pairing equipment with adequate VOO can be established taking into account the following aspects:

- Operation Mode of the VOO

During the operations at sea, the vessel adopts a role or mode based on the activity that is carried out (tow mode or deploy mode) and depending on its characteristics.

As previously mentioned, the database of resource properties shall include the different capabilities of each vessel. If this information is not available, based on the rules defined in the RC, mode operation could be approached with the deck space (K). This value can be used to define whether the vessel can tow or tow and deploy equipment. Deck space is calculated with VOO length (L) multiplied by its breadth (B), deck space equation reads as follows:

$$K(m^2) = L(m) \cdot B(m) \quad (9)$$

Table 10 - Tow and deploy capabilities of VOO based on its deck space.

Deck space (K)	Allowed capabilities
K < 200	Tow (only)
K > 200	Tow and deploy

The operation mode of the VOO will define what kind of equipment can be paired with:

- If a VOO just can tow, just equipment for towing can be selected (storage, booms, or fire booms). Based on RC assumptions, when a VOO is in Tow Mode, cannot afford Dispersant response.
- If a VOO can tow and deploy, the selection of equipment is wider (skimmer, fire booms, booms, combined equipment, storage, dispersant, or a dispersant application system).

The selection of the equipment also depends on the deck available area. As established in RC, it has to be into account that from the total dimensions of the vessel, 15% of the deck must be available for storing and operating the equipment. If this 15% is not available, the VOO just is disposed to tow operation without charging equipment.

- Selection of the equipment for the VOO

Two options are proposed for the selection of the equipment:

- Option 1: based on the information previously mentioned. This option provides a more realistic approximation since it is based on the properties of the vessels and the size of the stand-alone equipment. This option requires the elaboration of a complete database of resources and equipment properties with all the information required.
- Option 2: based on the rules of the Response Calculator, which establishes the classification of all the stand-alone equipment as Large or Small. This option requires less information about the properties of the resources.

OPTION 1

A vessel just can deploy one type of response at once, although different types of responses are on board. For proper distribution of the equipment to deploy a complete response, the following general criteria based on the resource properties are proposed:

- For a chosen VOO the system will provide only that equipment that by its size (storage space + operation space needed) can fit with the available deck space, does not exceed the maximum weight, or meet the special needs required (as a crane).
- When a complete response is loaded in a VOO (i.e. boom + skimmer + storage), but there is still available space, another response could be added (i.e. add dispersant + DAS) if possible.
- Some VOO already has some type of built-in response (that should be indicated in the resource properties). To these VOO, new assets can be added, to complete the response already integrated (i.e. a VOO with dispersant application system can be complemented with dispersants) or to create another response. The storage available indicated in the resource properties of these VOO must be the real one, with those assets integrated.

Thus, for each type of response a piece of equipment can be selected until a full response is complete (i.e. if the user selects a boom, the rest of the booms are cancelled so he can complete the response with skimmer + storage). The response is complete when:

- The user determines that the response is complete.
- The maximum weight or the maximum storage space available of VOO is overcome. In this case, a second vessel should be activated to be completed with the remaining necessary equipment.

To conclude, the user has to be able to select the characteristics in a sequence response +vessel + equipment (available) (see Table 11):

- Selection of the response technique (based on the operability assessment and the window of opportunity or other criteria considered by the user).
- Selection of vessels (OSRV or VOO) from each sub-group list (sorted by mobilization time). Vessel > Type > Sorted list of vessels. In the case of dispersant response, aircrafts available too.
- Operation Mode: Tow or Deploy (and tow), according to the information selected in previous steps.
- Specific response equipment from desired response types. Specific response > Type > List of equipment. The system will provide a list of equipment according to the information selected in previous steps, i.e. compatible with the response technique, the location of the selected vessels, the operation mode, and the characteristics of the vessel. As mentioned, the system will provide the list of equipment that can fit with the available deck space, does not exceed the maximum weight, or meet the special needs required (as a crane). Note that the available deck space will be recalculated taking into account the integration of each asset.

Table 11 - Sequence of the selection of the equipment.

Selection sequence	Main category	Type
Response selection	Response types	Mechanical recovery
		Dispersant
		In situ burning
Vessel	Vessels	OSVR
		VOO
	Aircraft (just to Dispersant response)	Aircrafts
Operation Mode of the VOO (based on the capabilities of the VOO)	Operation Mode	Tow (for mechanical recovery and In situ burning)
		Deploy (and Tow) (for Mechanical recovery, In situ burning, and Dispersant)
Specific equipment available based on the vessel characteristics (i.e. required space, available crane,…)	Mechanical recovery equipment	Booms
		Skimmer
		Combined equipment
		Storage
		Trawl nets
	Dispersant application equipment	Dispersant application system (DAS)
		Dispersant
	In situ burning equipment	Fire boom

OPTION 2

Based on the RC the stand-alone equipment is defined as small or large equipment and VOO are classified into small or large VOO in the "size" property of the RC database (the criteria for the definition of small or large VOO are not provided in the RC). Based on vessel classification and equipment size the following rules can be applied directly for large VOO (Table 12) and small VOO (

Table 13).

Table 12 - Large VOO capacity rules.

Deck space	Operation mode	Equipment size	Equipment capacity	Allowed equipment
K < 200	Tow	Small/Large	1 piece of each type	Storage, boom (up to 500 m), fire-boom
K > 200	Tow	Small/Large	1 piece of each type	Storage, boom (up to 500 m), fire-boom
K > 200	Deploy	Small/Large	1 piece of each type	Skimmer, boom (up to 500 m), Hi-speed containment systems storage, fire boom, small dispersant system (DAS and up to 4 m3 of dispersant), or large dispersant system (DAS and up to 20 m3 of dispersant)

Table 13 - Small VOO capacity rules.

Deck space	Operation mode	Equipment size	Equipment capacity	Allowed equipment
K < 200	Tow	Small	1 piece	Storage, boom (up to 250 m), fire-boom
K > 200	Tow	Small	1 piece	Storage, boom (up to 250 m), fire-boom
K > 200	Deploy	Small	1 piece	Skimmer, boom (up to 250 m), sweeping arms, storage, fire boom, small dispersant system (DAS and up to 4 m^3 of dispersant)

This option is less realistic than Option1 as it does not take into account the available deck space of the vessel and the size and needs of the equipment. Moreover, it only allows the selection of the equipment specified in (Table 12) and (

Table 13), regardless of the available deck space left. However, it requires less information about the properties of the resources, which can be an advantage when the availability of information is limited.

Annex 3. Recovery rates and logistics estimations for Response Simulator

*This information was extracted from the document **"EMSATOIL Part1 - Feasibility study for the development of a software tool to support the Member States on oil pollution response operations at sea (Version 3.1)", sections "4.6 – Aspects that influence the efficiency of oil spill response operations", "4.7 – Estimation of the encounter rate", and "4.8 – Technical and logistic aspects associated with the deployment of response assets at sea"** for further information please consult the complete document.*

Aspects that influence the efficiency of oil spill response operations

The objective of this section is to gather information and discuss the different aspects that influence the efficiency of oil response operations at sea that could be integrated into the system (weather conditions and characteristics of the weathered surface oil), as well as to propose technical solutions to incorporate it in the system. These aspects are addressed in step 2 of the proposed methodology.

As stated in the previous section, weather conditions and oil weathering are important properties to determine the feasibility and the window of opportunity of the oil spill response techniques. Besides the operability limits that established the feasibility or not of the response operation, weather conditions and oil weathering also influence its efficiency.

Specifically for mechanical recovery, the reduction of the efficiency due to weather and oil weathering is especially important. As mentioned in Section 0, the Nominal Plate Capacity provided by the manufacturer in the technical documentation of the skimmer is overestimated as is calculated under controlled conditions, which are far from a real response at sea. To pass from idealized pumping performance to real pumping performance, the skimmers are affected by several factors, which have to be applied as reductions to the Nominal Plate Capacity, as shown in Figure 10.

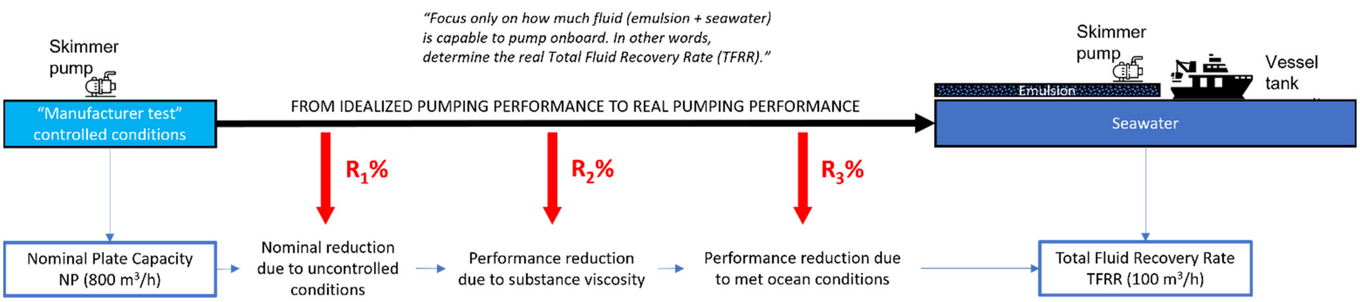
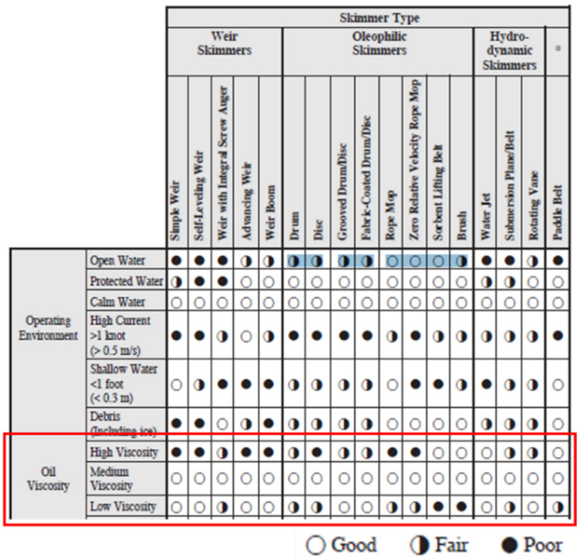


Figure 10 - Diagram of the most relevant reductions in the performance of a skimmer during a mechanical recovery response.

Thus, the following factors are suggested to take into account the nominal plate capacity reduction:

- <u>Uncontrolled conditions (Reduction 1 – R_1)</u>: this term refers to factors different from weather conditions and weathered oil that can reduce the skimmer performance. For example, in a real response, the presence of ice (Fingas et al., 2011), or debris can reduce the performance of the skimmer even producing a failure and the consequent reparation. Moreover, the equipment is never used at full pumping capacity. Thus, this reduction is intended to be applied to simulate possible losses of performance due to these uncontrolled factors. This parameter should be stated based on expert criteria since there is not a clear and sound quantification of these reductions in the state-of-the art.

- <u>Oil viscosity (Reduction 2 – R_2):</u> the viscosity of the oil is a primary limitation on the efficiency of most recovery devices. Oils with high pour points, including some heavy crudes and fuel oils, generally do not flow easily. If the ambient temperature is below the pour point, the oil will become semi-solid and, hence, will be difficult to recover, since it will not readily flow towards the skimmer (ITOPF, 2012). Thus, viscosity is an important factor for skimmer performance. Not all skimmers are efficient for all viscosities. Some guidelines (e.g. ExxonMobil, 2014) defines qualitatively the performance of the different type of skimmers taking into account the oil viscosity as can be observed in Figure 11. This qualitative information can be used in addition to expert criteria to define the reductions associated with oil viscosity.



		Skimmer Type																
		Weir Skimmers					Oleophilic Skimmers								Hydro-dynamic Skimmers			*
		Simple Weir	Self-Leveling Weir	Weir with Integral Screw Auger	Advancing Weir	Weir Boom	Drum	Disc	Grooved Drum/Disc	Fabric-Coated Drum/Disc	Rope Mop	Zero Relative Velocity Rope Mop	Sorbent Lifting Belt	Brush	Water Jet	Submersion Plane/Belt	Rotating Vane	Paddle Belt
Operating Environment	Open Water	●	●	●	◑	◑	◑	◑	◑	◑	○	○	○	◑	●	●	◑	●
	Protected Water	◑	●	●	○	○	○	○	○	○	○	○	○	○	◑	◑	○	○
	Calm Water	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	High Current >1 knot (> 0.5 m/s)	●	●	◑	○	◑	●	●	●	●	◑	●	◑	◑	◑	◑	◑	●
	Shallow Water <1 foot (< 0.3 m)	○	◑	●	●	●	◑	◑	◑	◑	○	●	●	◑	●	◑	◑	○
	Debris (Including ice)	●	●	○	◑	●	◑	◑	◑	◑	○	○	○	○	◑	◑	◑	○
Oil Viscosity	High Viscosity	●	●	◑	●	●	◑	●	◑	◑	●	●	○	○	○	◑	◑	○
	Medium Viscosity	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Low Viscosity	○	○	◑	○	○	◑	◑	○	○	◑	◑	●	●	○	◑	○	◑

○ Good ◑ Fair ● Poor

Figure 11 – Qualitative assessment of several skimmer types based on oil viscosity (ExxonMobil, 2014).

- Met ocean conditions (Reduction 3 - R_3): met ocean conditions also reduce the performance of the skimmers. As previously mentioned, wind-waves are the main factor that can produce a loss in the performance of the skimmer. Since wind is an indicator of sea state, it is often used to define performance reductions. Based on the RC's methodology, the following ranges for wind are proposed to define the met ocean conditions (see Table 14):

Table 14 - Met ocean reductions based on RC.

Wind range	Reduction
0 – 2 m/s	No reduction
2 – 4 m/s	25%
4 – 6 m/s	50%
6 – 8 m/s	75%
8 m/s	90%

After these reductions, the Total Fluid Recovery Rate (TFRR) is calculated. Since the methodology proposed in Section **¡Error! No se encuentra el origen de la referencia.** is based on hourly weather forecasts provided by European Centres (e.g. Copernicus Marine Service), the TFRR can be calculated every hour to obtain hourly time series of TFRR. As was mentioned before, TFRR is the total volume recovered on board, this volume is composed of oil or emulsion and of seawater.

Once the TFRR is estimated, the Recovery Efficiency of the skimmer has to be taken into account. RE is defined as the percentage of emulsion recovered by a skimmer with reference to the total volume of fluids recovered (emulsion + seawater). The quantification of these coefficient is complex because the natural process involves met ocean conditions, the particularities of each skimmer and the viscosity of the emulsion mainly. Therefore, the real quantity of emulsion recovered without consider the seawater pumped aboard is defined as Oil/Emulsion Recovery Rate (ORR).

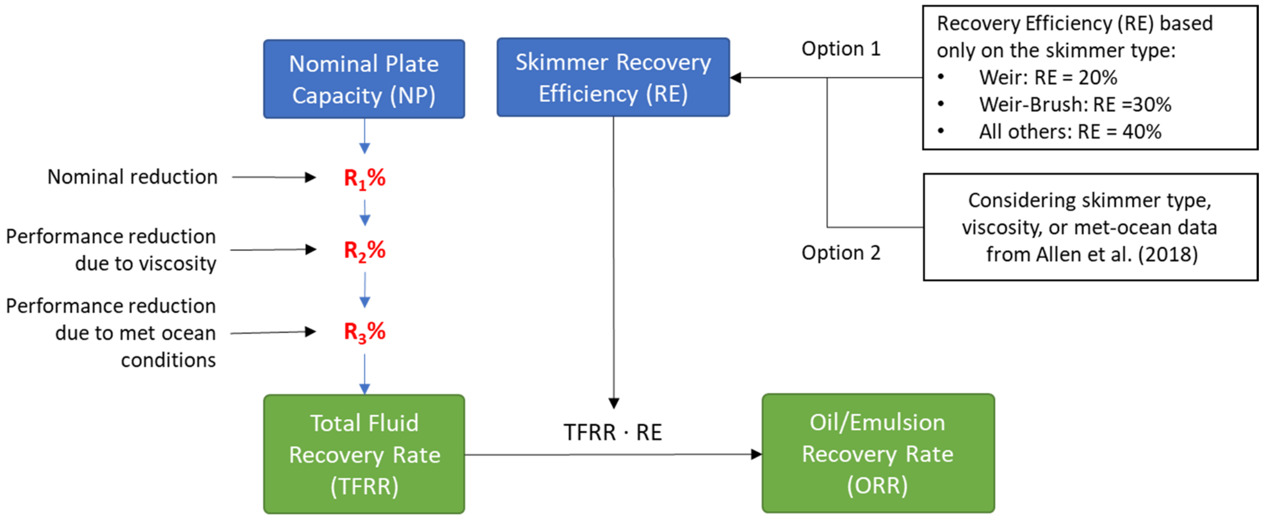


Figure 12 – Conceptual scheme about the implication of the recovery efficiency coefficient

Two potential options are suggested in order to obtain RE percentage:

- Option 1: current RC classification of the Recovery Efficiency based exclusively on the skimmer type (Table 15)

Table 15 - Skimmer's Recovery Efficiency (RE) classification of the Response Calculator.

Skimmer type	Recovery Efficiency (RE)
Weir	20%
Mix type (weir-brush)	30%
Other oleophilic types (brush, disc, belt…)	40%
High-speed systems (current buster)	70%

- Option 2: to adopt the use of the Recovery Efficiency charts provided in ROC (see Figure 13) that takes into account the minimum value obtained by both charts. Figure 13 (left panel) relates the type of skimmer with the met ocean conditions and Figure 13 (right panel) relates the type of the skimmer with the viscosity of the oil/emulsion. As mentioned, to obtain a RE for a skimming system ROC compares RE vs. met ocean conditions and RE vs. viscosity and uses the lower of both values.

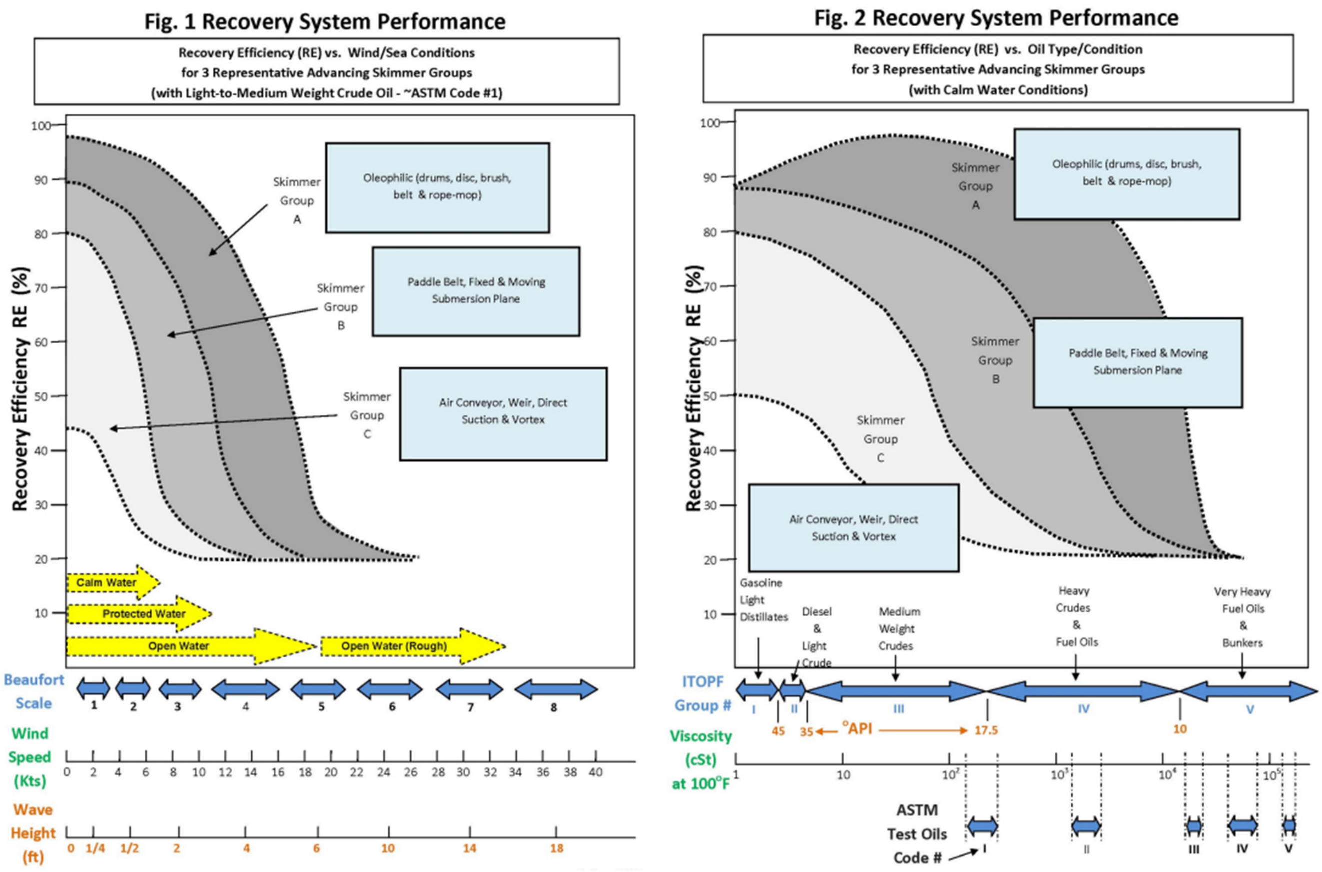


Figure 13 - Recovery Efficiency charts provided by ROC (left-chart: based on skimmer type and met ocean conditions; right-chart: based on skimmer type and oil viscosity).

Estimation of the encounter rate

The objective of this section is to identify, assess, and present one or more technical solutions for capturing the encounter rate of the response asset with the oil slick in the simulator's calculation in a realistic manner. These aspects are addressed in step 2 of the proposed methodology.

The rate at which one can encounter a specific volume of floating oil is one of the most important parameters in the overall assessment of a given response system's ability to access and eliminate spilled oil (Allen et al., 2018). The volume encounter rate will depend upon the system's swath (i.e., the width of its passage through or over oil), its speed while accessing the oil, and the average thickness of the oil encountered.

Thus, the encounter rate (see Figure 14) defines the amount of emulsion encountered by the recovery system per time during the effective skimming period. It is usually defined as a function of the average thickness of the oil slick (*t*), the speed of advance of the response system (*v*), and the swath (*w*) of the response system as defined in Eq. (5). For the purpose of clarity, Equation 5 is presented again below:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s)$$

where *t* is the oil thickness, *w* is the swath length, and *v* is the tow velocity.

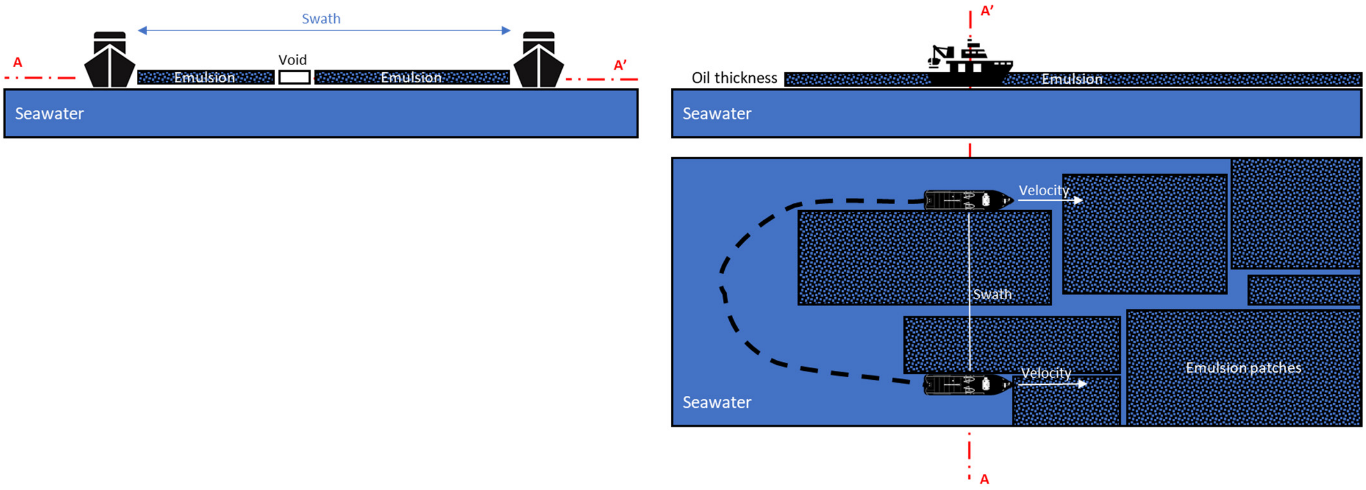


Figure 14 - Diagram of the encounter rate variables.

The estimation of the encounter rate according to Equation 5 is based on the following simplifications: i) the oil thickness is constant in all the areas of the slick, ii) the oil slick is a homogeneous body and the slick always covers all the swath section and iii) there is not any loss of oil from the system. However, in real spill response, the oil is usually fragmented into patches and the boom failures are common due to different causes, such as the excess of the first loss speed while towing and because the effect of the wind-waves mainly that produce the splash over the boom.

To calculate the encounter rate more realistically the aforementioned factors have to be considered in the analysis. Regarding the oil thickness, the oil spill models generally provide an average oil slick thickness, so there is little room for improvement in this issue.

Therefore, to improve the calculation of the encounter rate (Eq. 5) the following aspects can be considered:

- Fragmentation level of the slick: the oil slick is usually encountered disaggregated in several non-homogenous patches of emulsified product as it is represented in Figure 14. The quantity of gaps or discontinuities is defined by some authors as level of fragmentation of an oil slick. This value could be considered as a reduction percentage in Equation 10, as follows:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s) \times (1 - FP) \qquad (10)$$

  where *t*, *w*, and *v* are defined in equation 5 and FP is the fragmentation percentage (0 to 1) of the slick. Since oil spill models do not provide the level of fragmentation of the slick, FP could be defined by the user taking into account, for example, the field observations. Default value will be defined as 0% of fragmentation.

- Boom losses: two options are provided to quantify the boom losses. The first one (Option 1) is to consider a reduction percentage in Equation (11), as follows:

$$EnR\ (m^3/s) = t(m) \times w(m) \times v(m/s) \times (1 - FP) \times (1 - \mathrm{BLP}) \qquad (11)$$

  where *t*, *w*, *v,* and FP are defined in Equation 9 and BLP is the boom loss percentage (0 to 1) due to boom failures, which has to be defined based on expert criteria. Several guidelines and reviews in mechanical recovery define qualitative performance (good/poor, Figure 15) of the booms under specific conditions (Fingas et al., 2011; Exxonmobil, 2014). The reduction percentages can be defined based on the qualitative assessment available in the state-of-the-art and applying expert criteria.

Wind	Waves	Current	Boom Performance
0–10 kts (0-20 km/hr)	Calm, swells	0–0.5 kts (0.25 m/s)	Good
> 20 kts (>40 km/hr)	< 3–4 ft (<1 m)	> 1 kt (>0.5 m/s)	Poor

Figure 15 – Qualitative assessment of the boom performance under wind, waves, and currents (Exxonmobil, 2014).

The second one (Option 2) is based on the work proposed by Kim et al (2019). In this work, the authors state a formulation for the quantification of these loss rates due to boom failures (Kim et al., 2019). The implementation of this formulation can be carried out to better evaluate these losses and subtract this rate directly from the encounter rate at each time step of evaluation.

$$EnR\ (m^3/s) = \big(t(m) \times w(m) \times v(m/s) \times (1 - FP)\big) - BLR(m^3/s) \tag{12}$$

where *t*, *w*, *v,* and FP are defined in equation 2 and BLR is the boom loss rate (m^3/s) due to boom failures.

The implementation of this formulation is based on complex equations that require the following variables: water density, oil density, gravitational acceleration, oil-water surface tension, oil boom draft, oil relative density with the water, wave steepness, buoyancy-weight ratio of the boom. It is worth mentioning that, as far as the authors of this report are aware, there are no applications of this methodology in response simulator systems or software.

Finally, the estimation of the oil recovered by the mechanical recovery system can be calculated by taking into account the Encounter Rate, as well as, the Nominal Capacity Reductions (R1, R2, and R3) and Recovery Efficiency proposed in Section 0. The maximum oil or emulsion recovered by the skimmer and pumped on board will depend on the capacity of the skimmer and the oil encountered (see Figure 16). If there is not enough oil/emulsion encountered, then the maximum ORR rate possible will be equal to the Encounter Rate and the rest of ratios can be derived based on this fact.

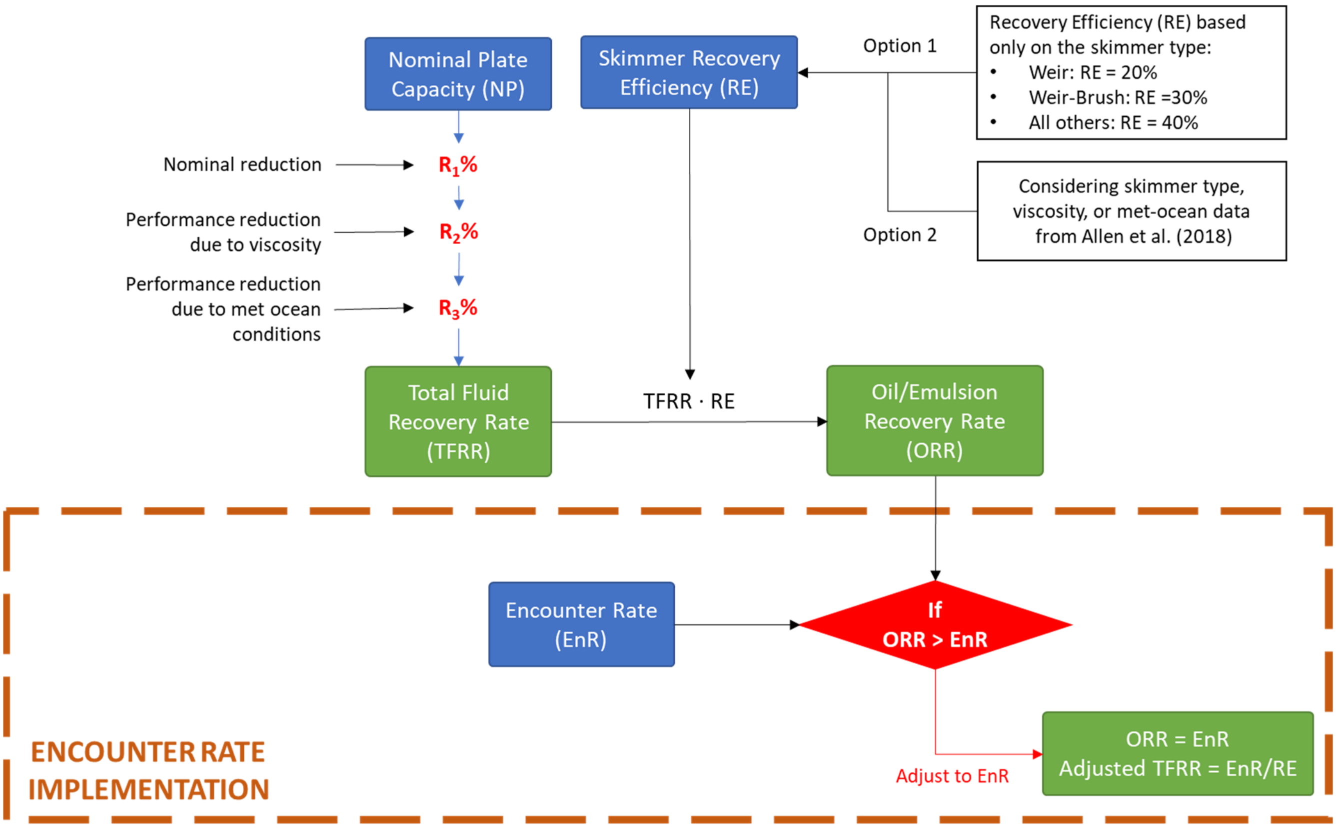


Figure 16 - Conceptual scheme of the complete methodology for calculating recovery rates including the limit imposed by the encounter rate.

Technical and logistic aspects associated with the deployment of response assets at sea

The objective of this section is to identify and assess the technical and logistic aspects associated with the deployment of response assets at sea, as well as to identify the critical issues and propose solutions on how to integrate them into the system. These aspects are addressed in step 3 of the proposed methodology.

Once recovery estimation is calculated, it is possible to define the precise schedule of the recovery operations, usually defined in blocks of transit – recovery – transit – unload (see Figure 17). The working hours are set by default for the entire EU region, but they can also be defined by the user.

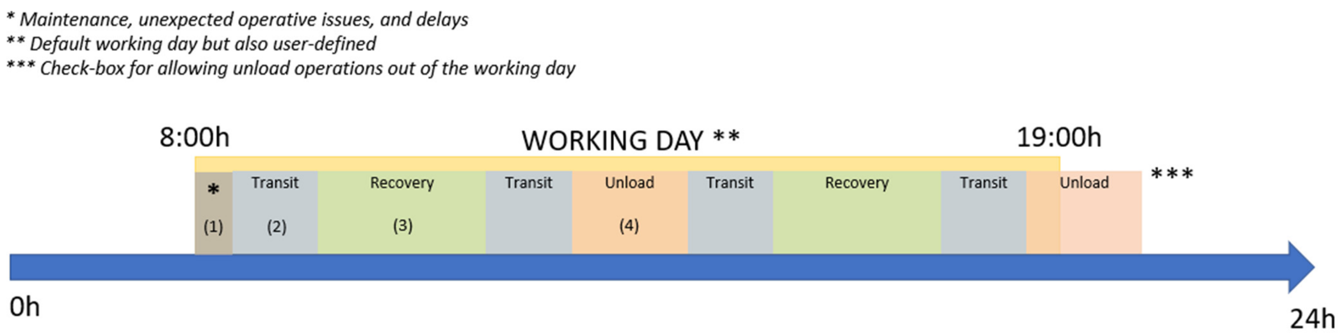


Figure 17 - Schedule of the recovery operations.

A brief review of the main operations shown in Figure 17 is provided below.

- Mobilization Time

This period takes into account the necessary time to activate the resources, prepare equipment, and travel from home base to the emergency base. Therefore, it is suggested the use of pathing algorithms to calculate these transit times. The activation and preparation times are properties of each resource. The resources will not be scheduled at the response until reach the emergency base, once this point will be achieving the schedule for this resource will be calculated for each following day as is shown in Figure 17.

$$MT(h) = VV(m/h) \cdot \mathrm{D}_{\mathrm{home-emergency}}(m) + AT(h) + PT(h) \quad (13)$$

where *MT* stands for Mobilization Time, *VV* stands for vessel velocity, $\mathrm{D}_{\mathrm{base-emergency}}$ is the path to travel from the home base to the emergency base, *AT* stands for the Activation Time and *PT* for the Preparation Time.

- Backup Time (1)

A daily backup time to take into account maintenance of the equipment, delays, and other unpredictable and inefficient times is proposed. By default, the system is suggested to define a small percentage relative to the complete working day to standardize this parametrization. It has to be highlighted that this time will be excluded from the working day even when operations do not require it. Therefore, it is important to not overestimate this value. A value smaller than 5% is suggested (i.e.: 5% of an 8h working day results in 25 min backup time, and for a 10h working day in 30 minutes). However, this backup time (default value) should be defined according to expert criteria and user will be allowed to modify it. Backup-time (*BT*) can be defined as:

$$BT(h) = WD(h) \cdot BTP(\%) \quad (14)$$

where *WD* stands for the hours of the Working Day, and *BTP* for Backup-Time Percentage.

- Transit Time (2)

Transit time is the time needed to navigate to the scene where the oil slick is located, and the recovery operations will be carried out. This navigation can be calculated at the vessel navigational speed and based on pathfinding algorithms. This time will take into account the update of the oil slick location based on the centre of mass evolution provided by oil spill numerical models. Information about the evolution of the centre of mass of the spill is calculated by oil spill models and the estimation of the transit time (when needed) can be performed using modelled location provided by the oil spill model. Transit time (*TT*) will be estimated by means of the vessel velocity (*VV*) and the distance ($D_{port\text{-}spill}$) from the centre of mass of the oil spill and the reference port of the vessel at required time this phase. This phase also will include the deployment or recovery of all the necessary resources (Auxiliary time) like booms and skimmer deployment before starting the skimming operations or its recovery before transit to discharge the vessel tank at the port, as follows:

$$TT(h) = VV(m/h) \cdot \mathrm{D}_{\mathrm{port-spil,t}}(m) + \ Aux\ Time(h) \quad (15)$$

- Recovery period (3)

The recovery period (3) is the effective time during which the skimmer is actively pumping fluid on board. Based on RC rules, the recovery period is limited when: i) the storage is full (90% total capacity); ii) endurance of vessel is over; ii) daily work hours are over or iii) the total oil spill is recovered (whichever occurs first). Thus, the amount of oil recovered can be calculated based on hourly rates for each hour as:

$$Recovered\ Volume\ of\ Oil/Eulsion\ (m^3) = Recovery\ Time\ (h) \times Oil/emulsion\ Recovery\ Rate\ (m^3/h) \quad (16)$$

and the total amount of volume recovered on board can be calculated, also based on hourly rates for each hour as:

$$Total\ Volume\ \mathrm{recovered}\ (m^3) = Recovery\ Time\ (h) \times Total\ Fluid\ Recovery\ Rate\ (m^3/h) \quad (17)$$

When a vessel is deployed conducting mechanical recovery, it will recover oil to fill its on board storage capacity. The storage capacity will determine the maximum working time in which the collection operation can be carried out. Thus, using the total fluid recovered ratios for each hour of work ($TFRR_t$), and the precise recovery time (*RT*) needed during the last hour of recovery to reach the storage capacity ($RT_{t=n}$), the maximum Total Recovery Period (*TRP*) will be reached, as reads the following condition (RT_t = 1 hour and $RT_{t=n}$ < 1 hour):

$$SC(m^3) = \sum_{t=0}^{t=n-1}(TFRR_{\ t} \cdot RT_t) + (TFRR_{\ t=n} \cdot RT_{t=n}) \quad (18)$$

Some vessels are equipped with on board decanting capacity that enhances their capacity to remain longer on the scene. According to RC, only OSRV vessels can perform decanting based on two rules: i) 30 % of the daily total amount of water in the recovered product can be decanted if heating is available and ii) if heating is not available 15% of the total amount of water in the recovered product can be decanted.

Finally, during recovery operations of dedicated vessels a specific break does is not included in Figure 17 can occur and it is called "On scene stand by". This term refers to hours of non-effective work on scene due to night conditions, unexpected weather conditions, or simply taking a break in the middle of continuous deployment or recovery operations.

- Discharge, unload, or reload operations (4)

It refers to the transfer of the recovered oil/emulsion from skimmers to storage platforms. Time is based on the discharge rate of the asset, following RC rules, discharge time is estimated with a 60% performance of the total discharge capacity of the asset:

$$DT(h) = DR(m^3/h) \cdot 60\% \quad (19)$$

where *DT* stands for Discharge time, and *DR* for the asset discharge rate. In the case of the reload operations for other techniques a fixed time will be established to consider the recharge of dispersants and other resources.

Furthermore, it is important to consider the possibility that the response operation may not be completed or may need to be modified due to:

- Breaks and failures of the equipment (normally associated with skimmer/pumps/booms due to high currents, presence of debris, maintenance failures, bad practices…)
- Improvement of the met ocean forecast to obtain reliable forecasts
- Add new relevant information collected during the first stages of the response as aerial/satellite imagery, oil properties measurements…

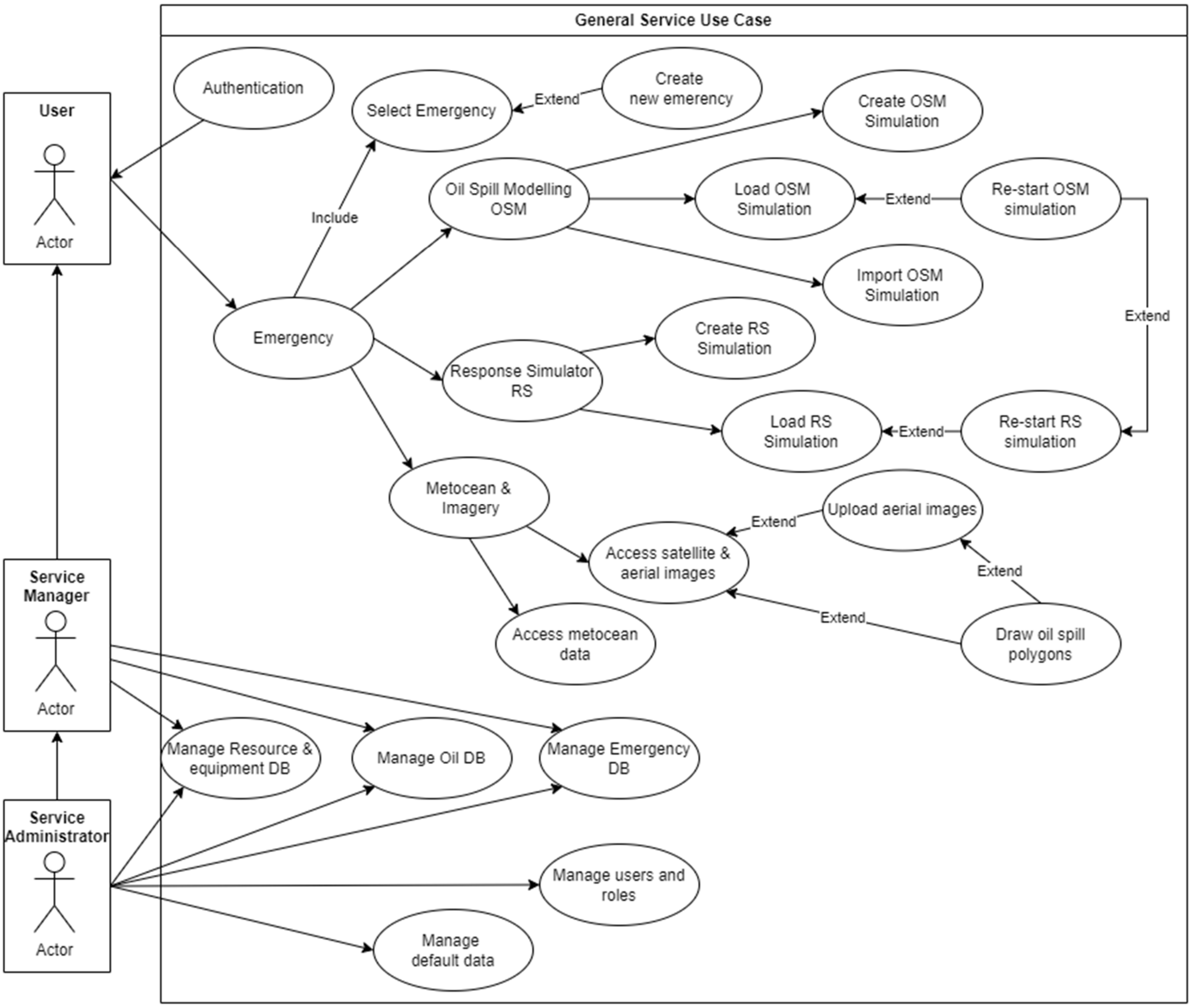
These problems make it necessary to re-evaluate the chosen alternatives, make changes to the selected equipment, activate new assets... All these situations are considered to be allowed by a re-initialization functionality of the simulations as described in Section **¡Error! No se encuentra el origen de la referencia.**.

Annex 4. Use cases

In this annex, it is included the total of Use cases defined in the framework of this project. Each Use case includes a Use case diagram following UML conventions and a table that explains the use case and its main point in text form.

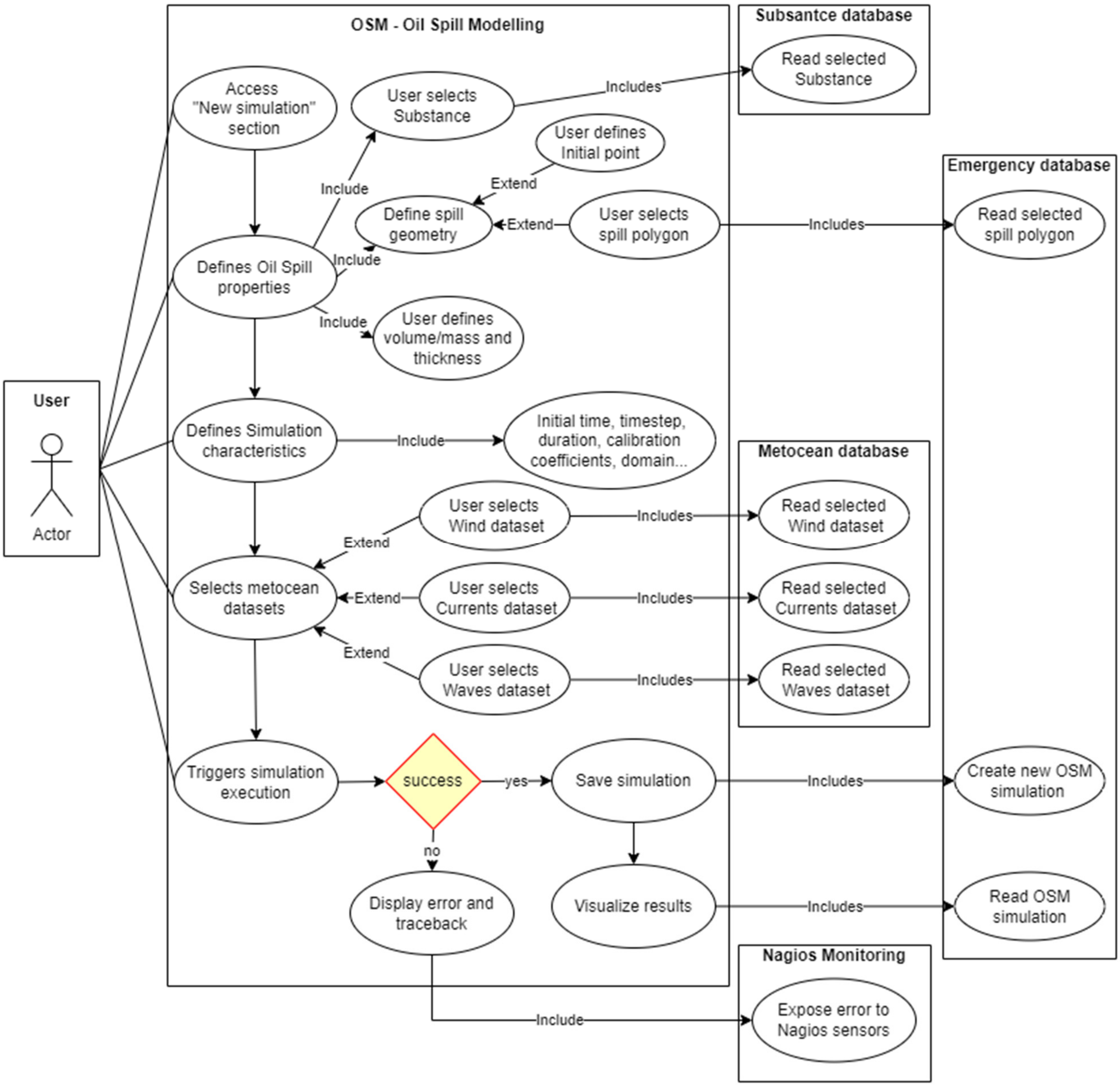
Use case No. 1 – USER ROLES AND MAIN FUNCTIONALITIES OF THE SERVICE

Purpose	Define the main functionalities depending on each user's role
Associated Requirements:	1, 2, 3, 4, 5, 6, 9, 13, 16, 21, 22, 33, 34, 38, 40, 42
Actors:	User, Service Manager, and Service Administrator
Preconditions:	1. The user is logged into the system.
Main Flow:	**Service User.** 1. The user selects an existent emergency but also is allowed to create a new one and select this emergency to access the main functionalities of the system. 2. The user will be able to access the section "Oil Spill Modelling" where he is allowed to perform three main actions: 2.1. Create a OSM simulation 2.2. Load an existent OSM simulation and visualize its results. During the visualization of the results, the user will be able to trigger the process of restart a simulation from an specific timestep. 2.3. Import a third-party OSM simulation and visualize its results. 3. The user will be able to access the section "Response simulator" where he is allowed to perform two main actions: 3.1. Create a RS simulation 3.2. Load an existent RS simulation and visualize its results. During the visualization of the results, the user will be able to trigger the process of restart a simulation from an specific timestep. 4. The user will be able to access the section "Metocean & Imagery" to perform two main actions: 4.1. Access and visualize metocean data. 4.2. Access and visualize Satellite and aerial imagery. In this section the user will be allowed to import imagery from files and external services as CleanSeaNet. Also, the user will be able to digitalize oil slicks during the visualization of the images (based on GIS functionalities). **Service Manager.** Service managers will be allowed to perform extra capabilities. 1. Manage all databases with exception of the defaults registers. 2. Manage operability limits used for the assessment of the window of opportunity in the Response Simulator module. 3. **Service Administrator.** This role will be allowed to perform the complete set of capabilities of the system. Which includes: 1. Manage the mapping of users and roles 2. Manage users 3. Manage default registers and information


General Service Use Case
User
Actor
Service Manager
Actor
Service Administrator
Actor
Authentication
Select Emergency
Extend
Create new emerency
Create OSM Simulation
Include
Oil Spill Modelling OSM
Load OSM Simulation
Extend
Re-start OSM simulation
Import OSM Simulation
Extend
Emergency
Create RS Simulation
Response Simulator RS
Load RS Simulation
Extend
Re-start RS simulation
Metocean & Imagery
Upload aerial images
Extend
Access satellite & aerial images
Extend
Extend
Access metocean data
Draw oil spill polygons
Manage Resource & equipment DB
Manage Oil DB
Manage Emergency DB
Manage users and roles
Manage default data

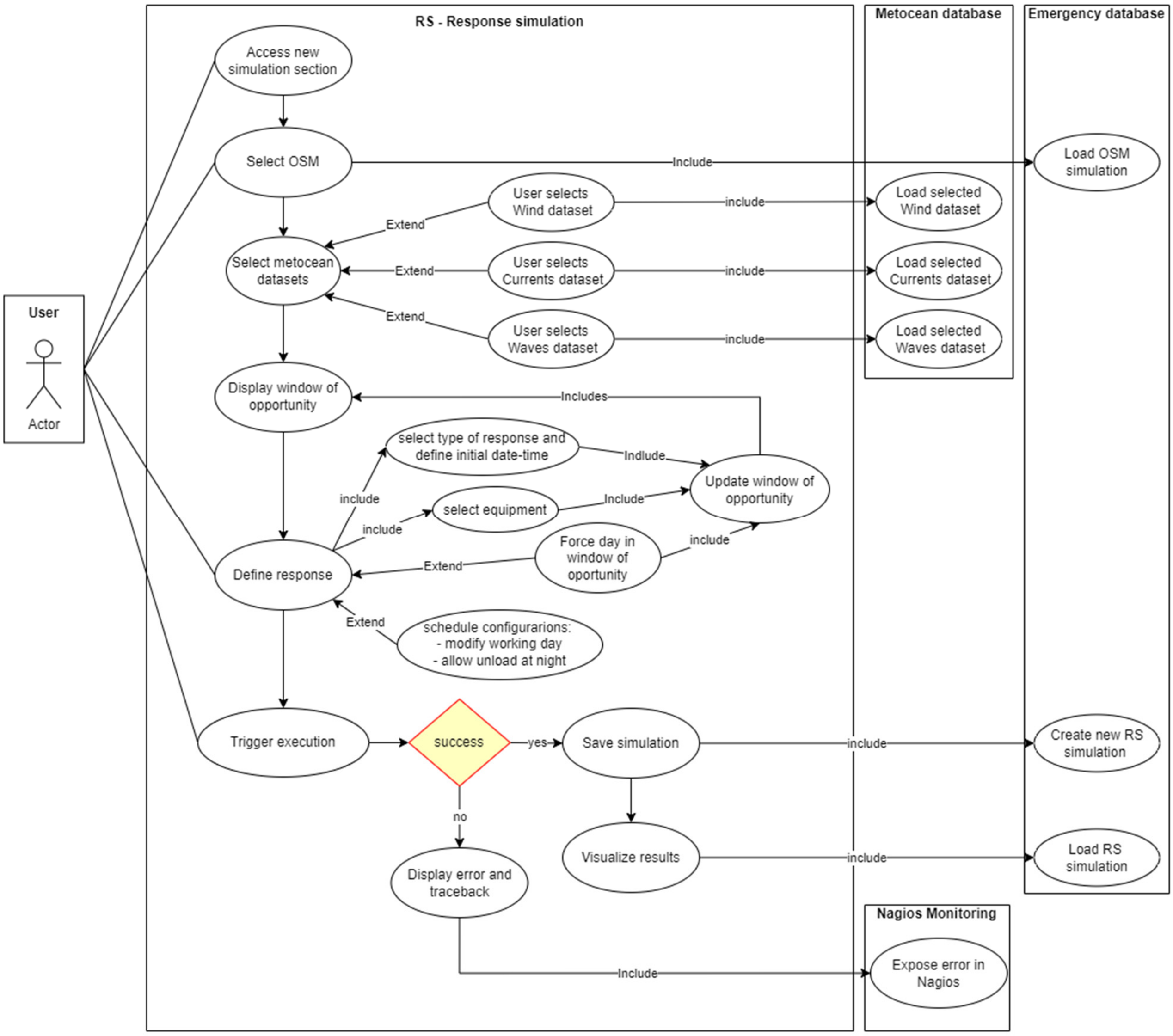
Use case No. 2 - PERFORM A NEW SIMULATION WITH THE OIL SPILL MODELLING (OSM) MODULE

Purpose	Define the user workflow to perform a new oil spill simulation to forecast the evolution of the trajectories and weathering of an oil spill.
Associated Requirements:	16, 17, 20, 38, 39, 40, 41, 44
Actors:	The user.
Preconditions:	1. The user is logged into the system. 2. The emergency is already created in the system and the user has already selected it.
Main Flow:	1. The user accesses the section "New simulation" of the OSM module. 2. The user defines the oil spill properties (substance, volume/mass spilled, initial geometry: point or polygon, the thickness of the spill…) 3. The user defines the properties of the simulation (Simulation domain, initial time, calibration coefficients…) 4. The user selects the provider and dataset to use for each forcing desired in the simulation (currents, winds, and/or waves). 5. Finally, the user triggers the execution of the implemented oil spill model, which automatically saves the simulation in the database or if the process fails, exposes errors on the web and to the Nagios sensors of the system to be monitored.
Alternative flow 1:	If there is an error during the simulation. The error will be displayed and exposed through Nagios sensors to be monitored and logged.
Post Conditions:	1. A OSM simulation must be created in the Emergency database, or an error message must be displayed and logged in Nagios.
Notes:	


OSM - Oil Spill Modelling
Subsantce database
Read selected Substance
Access "New simulation" section
User selects Substance
Includes
User defines Initial point
Extend
Include
Define spill geometry
Extend
User selects spill polygon
Emergency database
Includes
Read selected spill polygon
Defines Oil Spill properties
Include
Include
User defines volume/mass and thickness
User
Actor
Defines Simulation characteristics
Include
Initial time, timestep, duration, calibration coefficients, domain...
Metocean database
User selects Wind dataset
Includes
Read selected Wind dataset
Extend
Selects metocean datasets
Extend
User selects Currents dataset
Includes
Read selected Currents dataset
Extend
User selects Waves dataset
Includes
Read selected Waves dataset
Triggers simulation execution
success
yes
Save simulation
Includes
Create new OSM simulation
no
Display error and traceback
Visualize results
Includes
Read OSM simulation
Nagios Monitoring
Include
Expose error to Nagios sensors

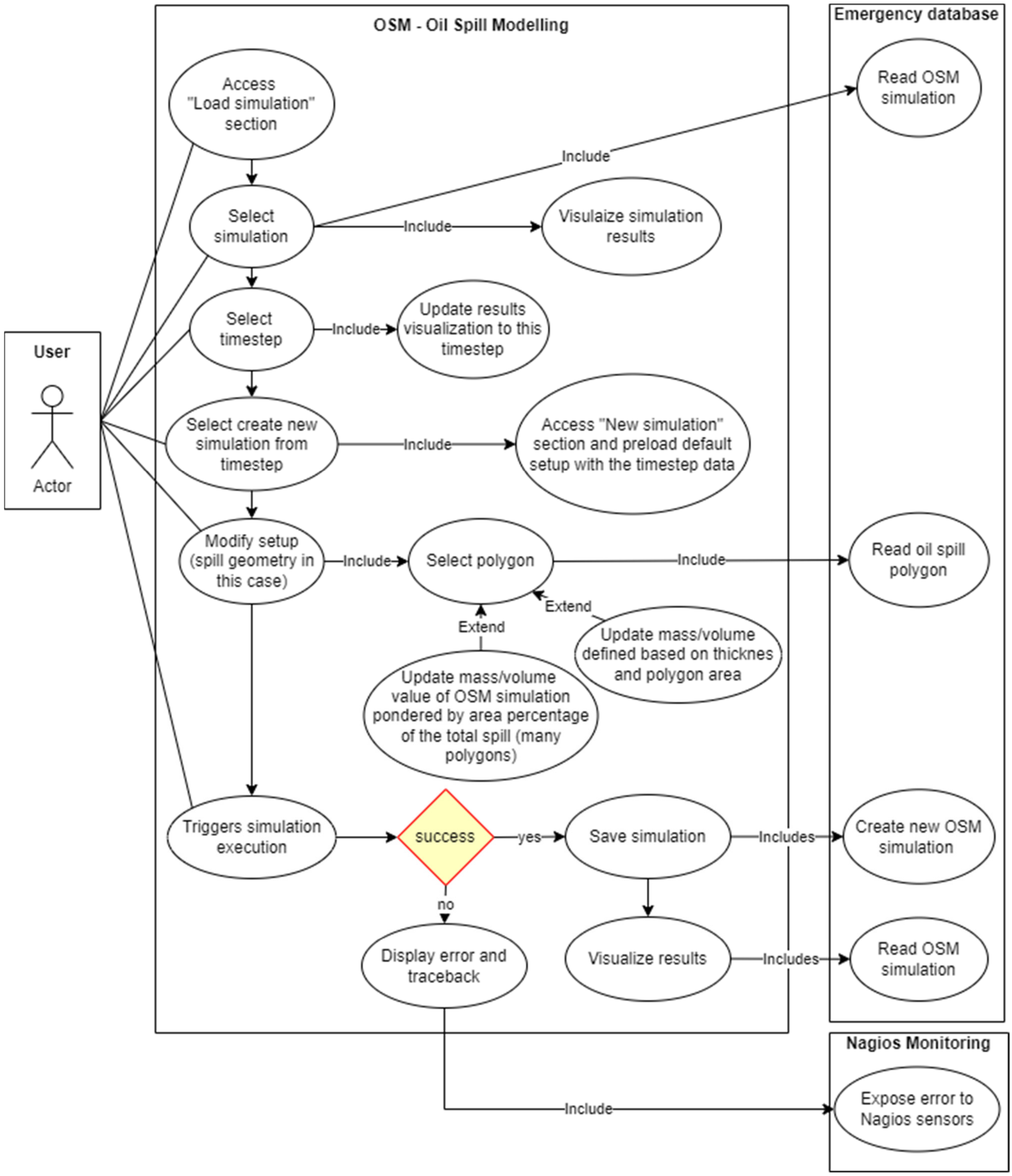
Use case No. 3 - PERFORM A NEW SIMULATION WITH THE RESPONSE SIMULATOR (RS) MODULE

Purpose	Define the user workflow to perform a new RS.
Associated Requirements:	22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 34, 38, 39, 40, 41, 42, 43, 44
Actors:	The user.
Preconditions:	1. The user is logged into the system. 2. The emergency is already created in the system and the user has already selected it. 3. A previous OSM simulation has been performed.
Main Flow:	1. The user accesses the section "New simulation" of the RS module. 2. The user loads an OSM simulation from the Emergency database (precondition 3). 3. The user is able to define which metocean datasets to use in the simulation range if the OSM simulation was imported from a third-party OSM simulation (In that case, metocean data used in this OSM simulation should be unknown). 4. Window of opportunity will be calculated based on the current information provided and the system will automatically show the access to the different sites to define the response. 5. The user will define the response (window of opportunity will be visible and updated dynamically during the definition): 5.1. The user will select the type of response. 5.2. The user will select the equipment and resources 5.3. The user will be able to force any day, even though the operational rules will recommend not to work. 5.4. The user will be able to modify key parameters to configure how the schedule of the operations will be done by the system. 6. Finally, the user will trigger the execution of the methodology by pressing a button and accepting all the previous response definitions. After the computation and saved in the database the system will show the results.
Alternative flow 1:	If there is no previous simulation, the user will not have the option to load any simulation.
Alternative flow 2:	If there is an error during the simulation. The error will be displayed and exposed through Nagios sensors to be monitored and logged.
Post Conditions:	1. A new RS simulation must be created in the Emergency database, or an error message has to be displayed and logged in Nagios.
Notes:	


RS - Response simulation
Metocean database
Emergency database
User
Actor
Access new simulation section
Select OSM
Include
Load OSM simulation
User selects Wind dataset
include
Load selected Wind dataset
Extend
Select metocean datasets
User selects Currents dataset
Load selected Currents dataset
User selects Waves dataset
Load selected Waves dataset
Display window of opportunity
Includes
select type of response and define initial date-time
Indlude
Update window of opportunity
select equipment
Force day in window of oportunity
Define response
schedule configurarions:
- modify working day
- allow unload at night
Trigger execution
success
yes
no
Save simulation
Create new RS simulation
Visualize results
Load RS simulation
Display error and traceback
Nagios Monitoring
Expose error in Nagios

Use case No. 4 - RESTART SIMULATION TO IMPLEMENT NEW OIL SPILL POLYGON FROM SATELLITE IMAGERY

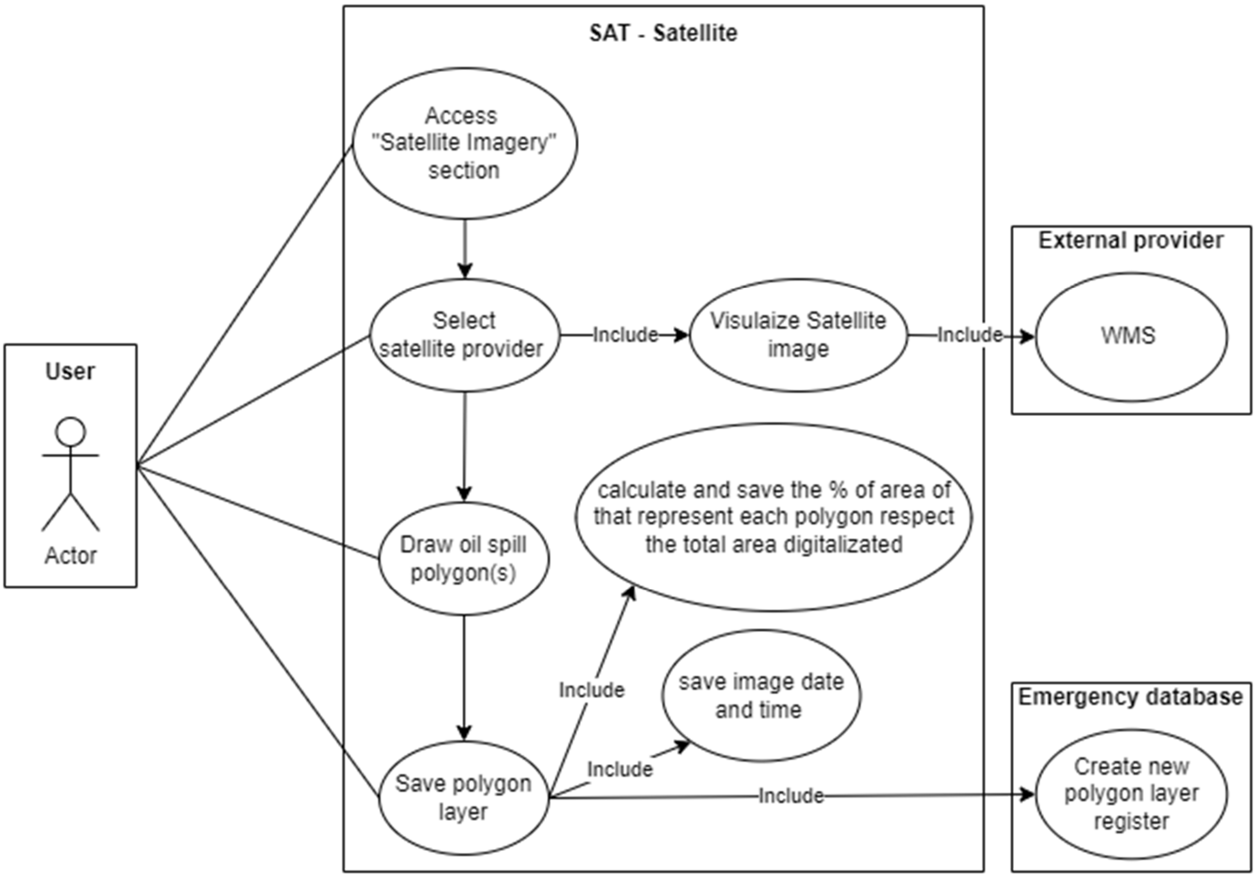
Purpose	Define the user workflow to create a new simulation from the results of a previous one updating inputs with a new oil slick shape extracted from satellite imagery.
Associated Requirements:	16, 20, 21, 38, 39, 40, 41, 44
Actors:	The user.
Preconditions:	1. The user is logged into the system. 2. The emergency is already created in the system and the user has already selected it. 3. A previous OSM simulation has been performed. 4. Oil spill polygons have been created in the emergency database see Use case n.3.
Main Flow:	1. The user accesses the section “Load simulation” of the OSM module. 2. The user selects the simulation to be loaded (precondition 3) 3. The user selects the timestep of the simulation closest to the date and time of the satellite image used in precondition 4. 4. The user clicks over a button to access the “New simulation” section. A default setup configuration will be loaded from the results of the timestep (see point 3 above). 5. The user modifies the spill location and geometry by selecting one or several polygons created in precondition 4. 6. (Optional - Extend) the user can select to update the initial mass/volume of the new simulation, via two alternatives: 6.1. The system calculates the percentage of area each polygon associated with the satellite image (the sum of the percentage area of all polygons should be 100 %). 6.2. The user manually assigns a thickness to each polygon. 7. The user triggers the execution of the simulation from the time selected in point 3 above by pressing a button.
Alternative flow 1:	If there is no previous simulation, the user will not have the option to load any simulation.
Alternative flow 2:	If there is no polygon saved in the emergency database, the user will not have the option to load any polygon.
Alternative flow 3:	If there is an error during the simulation. The error will be displayed and exposed through Nagios sensors to be monitored and logged.
Post Conditions:	1. A new OSM simulation is created in the Emergency database, or an error message is displayed and logged in Nagios.
Notes:	



OSM - Oil Spill Modelling
Emergency database
User
Actor
Access "Load simulation" section
Select simulation
Include
Visulaize simulation results
Read OSM simulation
Select timestep
Include
Update results visualization to this timestep
Select create new simulation from timestep
Include
Access "New simulation" section and preload default setup with the timestep data
Modify setup (spill geometry in this case)
Include
Select polygon
Include
Read oil spill polygon
Extend
Update mass/volume defined based on thicknes and polygon area
Extend
Update mass/volume value of OSM simulation pondered by area percentage of the total spill (many polygons)
Triggers simulation execution
success
yes
Save simulation
Includes
Create new OSM simulation
no
Display error and traceback
Visualize results
Includes
Read OSM simulation
Nagios Monitoring
Include
Expose error to Nagios sensors

USE CASE n.5 - DIGITALIZE OIL SPILL POLYGON(S) FROM SATELLITE IMAGERY PROVIDER

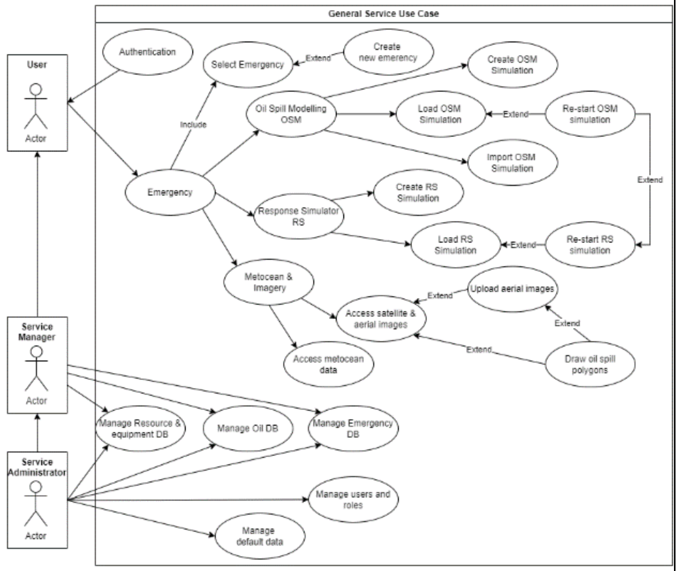
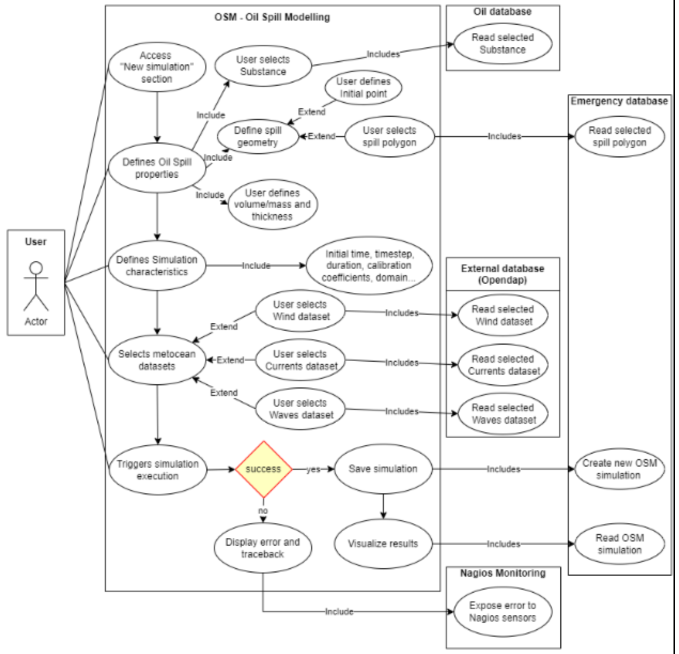
Purpose	Define the user workflow to digitalize the oil slicks (oil polygons) with the help of a satellite image and the implemented GIS capabilities included in the Web app.
Associated Requirements:	8, 9, 11, 38, 39
Actors:	The user.
Preconditions:	1. The user is logged into the system. 2. The emergency is already created in the system and the user has already selected it. 3. The system has access to satellite images via WMS protocol.
Main Flow:	1. The user accesses the section "Satellite Imagery" of the "Satellite" module. The system will display the images available according to the criteria defined by the user i.e., time and area of the simulation. 2. The user selects a satellite image containing the oil slick (precondition 3) 3. The user digitalizes the slick(s) creating polygons by means of the GIS capabilities included in the Web app. Note if oil slicks are detected in a CSN image, the system shall use the polygon(s) created by CSN for this oil slick(s). 4. The user saves the polygon by fulfilling a name, and description (optional) and clicking a button. 4.1. The system calculates the percentage of area that represents each polygon in the total area of the spill. This information is defined as an attribute of each polygon. 4.2. The system saves the specific date and time of the satellite image.
Alternative flow 1:	If there is no access to satellite images, the user will not have the option to load any image.
Post Conditions:	1. A new polygon layer register must be created in the Emergency database – Oil spill polygons section.
Notes:	

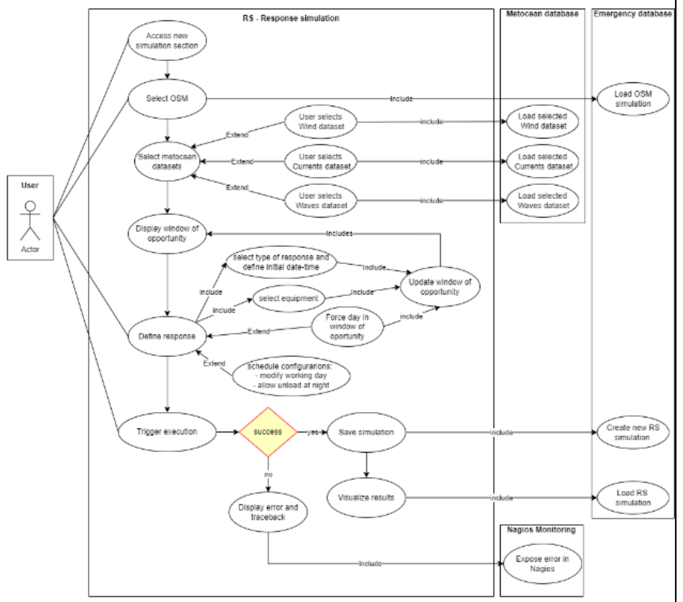
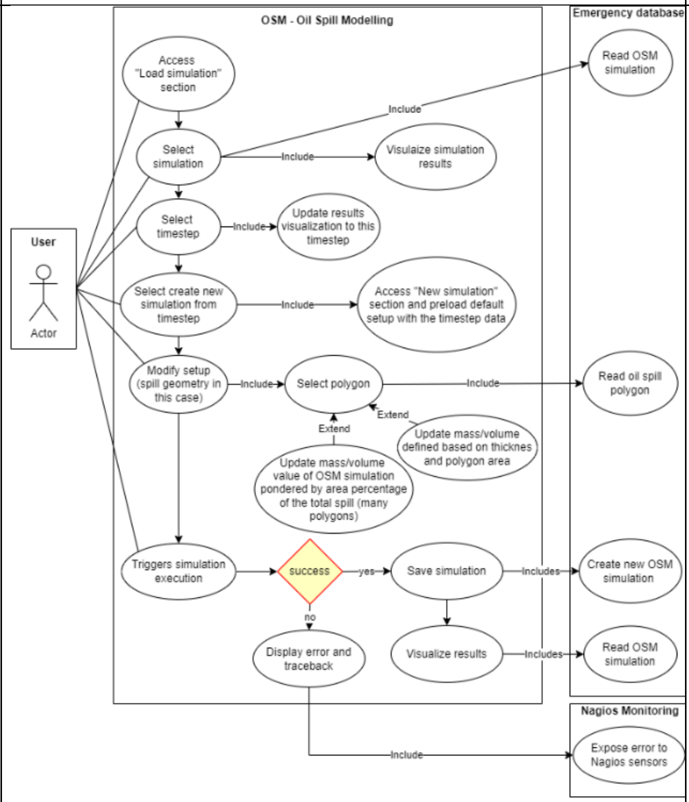

SAT - Satellite
User
Actor
Access "Satellite Imagery" section
Select satellite provider
Include
Visulaize Satellite image
Include
External provider
WMS
calculate and save the % of area of that represent each polygon respect the total area digitalizated
Draw oil spill polygon(s)
Include
save image date and time
Include
Save polygon layer
Include
Emergency database
Create new polygon layer register

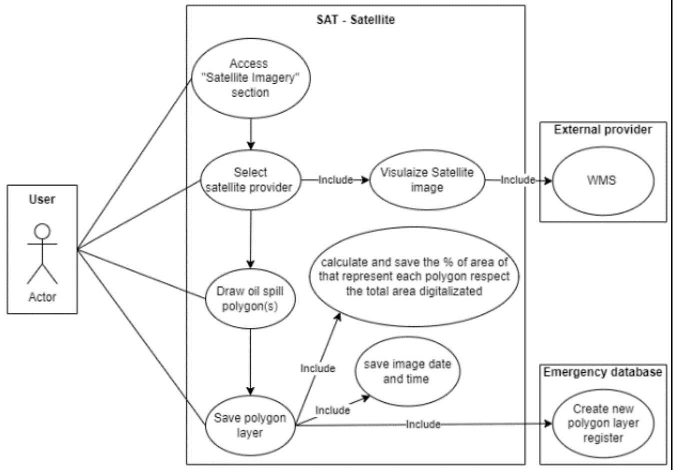
Annex 5. Mapping between actions and roles

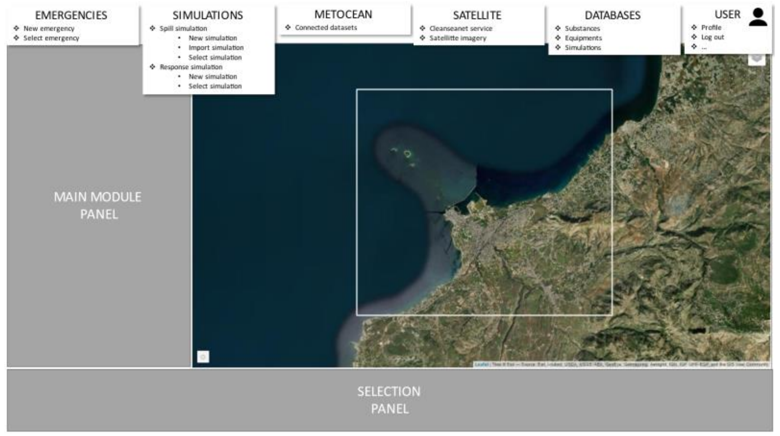
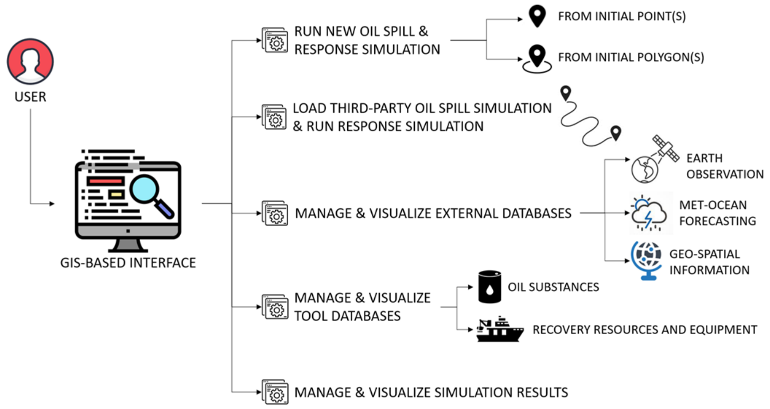
In this annex, the mapping between different actions and roles are defined in a matrix allowing to visualize if each role is allowed to perform each action.

ACTION	ROL		
	user	manager	administrator
Emergency database (emergencies, simulations, and oil spill polygons)			
View emergencies created by himself	✓	✓	✓
View emergencies by other users of the same nation	✓	✓	✓
View emergencies created by other users of different nation	✗	✗	✓
View default emergencies	✓	✓	✓
Manage emergencies created by himself	✓	✓	✓
Manage emergencies created by other users of the same nation	✗	✓	✓
Manage emergencies created by other users of different nation	✗	✗	✓
Manage default emergencies	✗	✗	✓
Create his own emergencies	✓	✓	✓
Create default emergencies	✗	✗	✓
Oil database			
View oil substances created by himself	✓	✓	✓
View oil substances by other users of the same nation	✓	✓	✓
View oil substances created by other users of different nation	✗	✗	✓
View default oil substances	✓	✓	✓
Manage oil substances created by himself	✗	✓	✓
Manage oil substances created by other users of the same nation	✗	✗	✓
Manage oil substances created by other users of different nation	✗	✗	✓
Manage default oil substances	✗	✗	✓
Create his own oil substances	✗	✓	✓
Create default oil substances	✗	✗	✓
Oil pollution resources and response equipment database			
View resources and equipment created by himself	✓	✓	✓
View resources and equipment by other users of the same nation	✓	✓	✓
View resources and equipment created by other users of different nation	✗	✗	✓
View default resources and equipment	✓	✓	✓
Manage resources and equipment created by himself	✗	✓	✓
Manage resources and equipment created by other users of the same nation	✗	✗	✓
Manage resources and equipment created by other users of different nation	✗	✗	✓
Manage default resources and equipment	✗	✗	✓
Create his own resources and equipment	✗	✓	✓
Create default resources and equipment	✗	✗	✓

Nº	Title	Requirement Type	Priority	Description	Acceptance Criteria
USE CASES					
UC. 1	Use case: User roles and main functionalities of the service	FUN - Functional	Should have	 See the complete use case in annex 4	- All the functionalities are included in the system - Roles allow users to perform specific functionalities as defined in the use case diagram.
UC. 2	Use case: Perform OSM simulation	FUN - Functional	Must have	 See the complete use case in annex 4	- Use case functionalities are included in the system

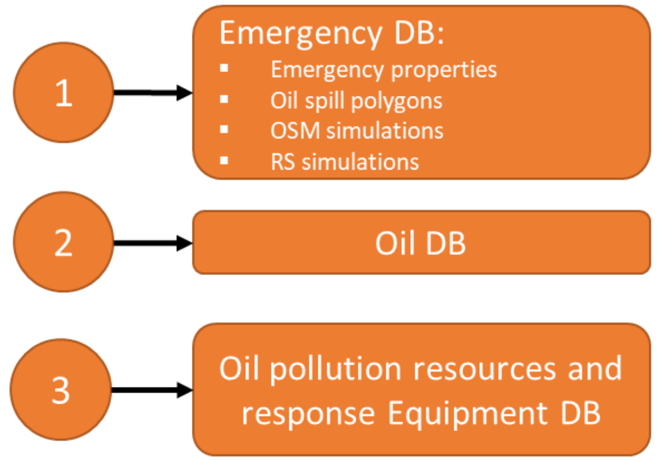
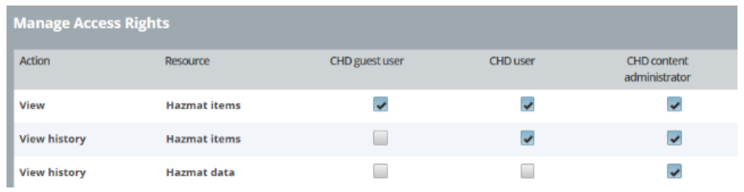
UC. 3	Use case: Perform RS Simulation	FUN - Functional	Must have	 See the complete use case in annex 4	- Use case functionalities are included in the system
UC. 4	Use case: perform simulation re-start	FUN - Functional	Must have	 See the complete use case in annex 4	- Use case functionalities are included in the system

UC. 5	Use case: digitalize oil spill polygons	FUN - Functional	Must have	 See the complete use case in annex 4	- Use case functionalities are included in the system

<table>
<tr><th>Nº</th><th>Title</th><th>Requirement Type</th><th>Priority</th><th>Description</th><th>Acceptance Criteria</th></tr>
<tr><th colspan="6">OVERVIEW OF THE SYSTEM</th></tr>
<tr><td>1</td><td>General view, modules, and sections</td><td>INF - Informative</td><td>Should have</td><td>The app should have the following modules:
- Emergency module
- Simulations module
o Oil Spil Modelling
o Response simulator
- Meteocean module
- Satellite module
- Databases module
- User module

</td><td></td></tr>
<tr><td>2</td><td>Main functionalities of the system</td><td>INF - Informative</td><td>Should have</td><td>Main functionalities of the system:

</td><td></td></tr>
<tr><td>3</td><td>General structure of the databases</td><td>FUN - Functional</td><td>Must have</td><td>Three databases will be developed to contain data required or created by the system, following the structure:
1. Emergency database
1.1. Emergency properties
1.2. Oil spill polygons
1.3. OSM simulations
1.4. RS simulations
2. Oil database
3. Oil pollution resources and response equipment database</td><td>- The three databases (Emergency, Oil, and Oil pollution resources and response equipment are implemented and accessible to the users of the system.

- The subsections of the Emergency database are implemented in the emergency databases as specific tables.

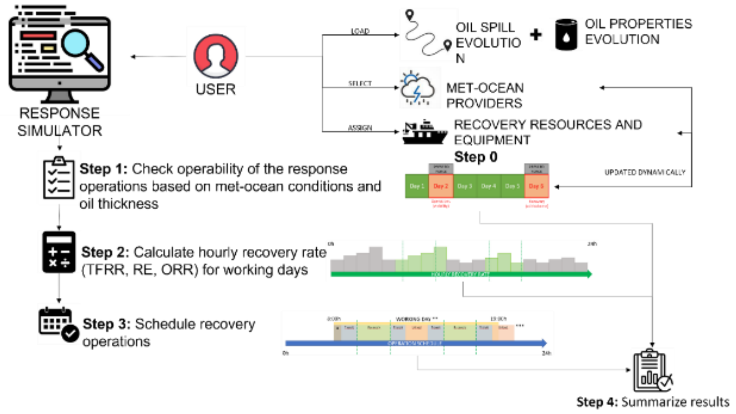
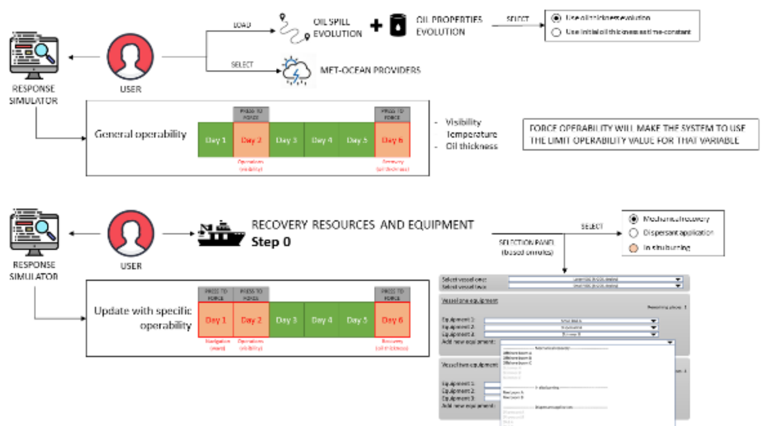
- Database privileges are managed based on the mapping of roles and actions that can be defined using the functionality of req.6 (“Mapping between roles and actions”).</td></tr>
</table>

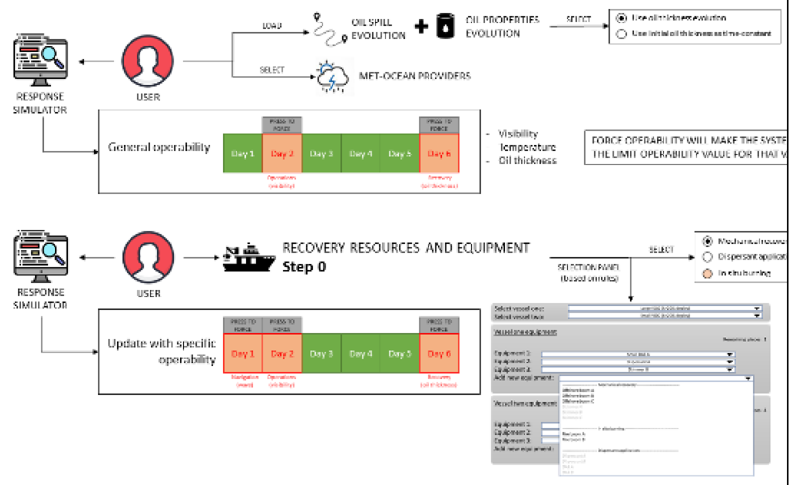
				 Minimum auditing info should be included, at least: the creator, the last update of each item, and the corresponding timestamps	- At least the minimum auditing info of the records will be saved in the databases.
AUTHENTICATION AND AUTHORISATION					
4	Login, authentication, and authorization of users	FUN – Functional	Must have	Only authenticated users will access the Web app. The service will use EMSA's Identity Provider Oauth2/OpenID connect system to authenticate and authorize user access. Further details will be provided during the project execution.	- Users are able to authenticate as required and log into the system.
5	User roles	FUN - Functional	Must have	The Service will consider the following user roles: - The role "Service administrator" will allow access to all functionalities of the system. - The role "Service manager" will allow access to the following functionalities: Update of the databases (emergencies, oil spill, resources & equipment created by himself or by other users of the same country) and operability rules. - The role "Service user" will allow access to the modelling capabilities (oil spill and response simulator)	- The service has a method to create, modify and delete user roles. - login with each of the roles (service administrator, service manager, service user) and allow access to their corresponding functionalities (and not more). - Specific actions or functionalities of each role are defined in req.6. - "service manager" will be able to modify the default operativity thresholds regarding each kind of equipment as defined in the operativity rules defined in annex 2.
6	Mapping between roles and actions	FUN - Functional	Must have	The web app will include a section for mapping and managing the privileges of each role for each action of the system. The mapping of actions and roles are defined in Annex 5 as a matrix in which are included the default set of privileges. Graphical example: 	- The user is capable to visualize the mapping of privileges between roles and actions. -The user, with the required privileges, is capable to modify the privileges of each role for each action.
WEB APP AND GIS CAPABILITIES					

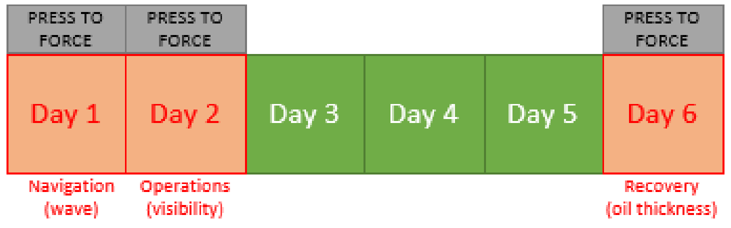
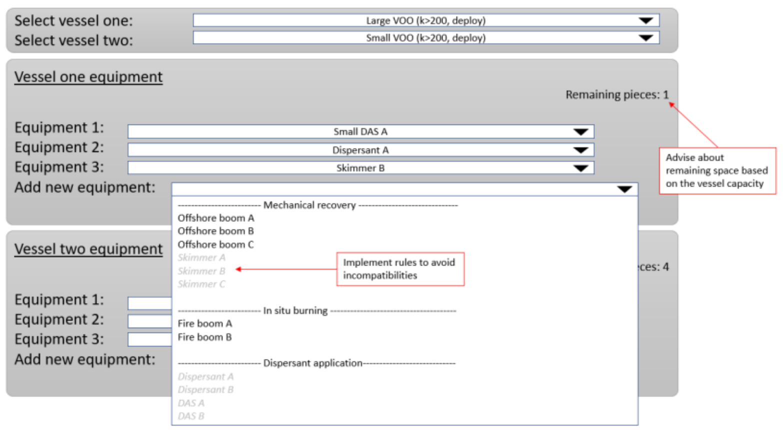
7	Visualize geospatial information	FUN - Functional	Must have	The Web app will be able to visualize on the map spatial data from data providers via interoperability protocols (OGC Services) such as the Central Geographical Database (CGD), Electronic Nautical Charts (ENC), EMODNet, among others.	- Vector data is visualized (e.g. coastlines, vector data from CGD) - Raster data is visualized (e.g. bathymetries from EMODNet, raster data from CGD)
8	Web map and geospatial functionalities	FUN - Functional	Must have	The Web app will include a web map and geospatial functionalities to visualize GIS data (e.g. zoom, pan, and identify) through any standard Web browser (e.g. Chrome)	- The Web app provides standard geospatial functionalities (e.g. zoom, pan, identify)
9	Drawing Oil spill polygon	FUN - Functional	Must have	End users will be able to draw the geospatial location of the oil spill on the web map. The Web app will provide mapping tools to obtain the oil spill geometry (e.g. end users could draw the geometry over an aerial image uploaded by them).	- The Web app provides a section to draw the oil spill geometry. - Oil spill polygons will be saved in the emergency database
10	Uploading Oil spill polygon	FUN - Functional	Must have	The oil spill geometry provided by data services such as CleanSeaNet will be able to be uploaded and used by the System. Samples of the files and format will be provided. Moreover, OGC standard formats will be also considered.	- The Web app provides a section that allows uploading oil spill geometries. - The geometries are visualized correctly (georeferenced) on the Web map. - The status messages (success, failure, etc.) are shown.
11	Visualize Metocean, satellite, and aerial images	FUN - Functional	Should have	The listed Metocean data will be visualized thanks to the interoperability protocols (WMS, WCS, etc.) from metocean data or the metocean service from ETLs. The system will allow to: - Visualize the metocean products selected on the Web map. - Visualize real-time (e.g buoys, HF Radar) and metocean conditions (metocean modelling products) on the Web map. - Visualize satellite and aerial images provided by the Earth Observation Data Centre (EODC) or Remotely Piloted Aircraft Systems Data Centre (RPAS DC) via interoperability protocols (OGC Services).	- The selected metocean, satellite, and aerial products can be visualized on the web map. - Selected metocean, satellite, and aerial products can be activated and deactivated for visualization on the Web map.
12	Upload aerial images	FUN - Functional	Should have	The system will be able to upload aerial images in GeoTIFF and GMLJP2 format (e.g. images provided by drones) The system will provide information messages when uploading aerial images, e.g. success, failure, and error messages.	- The Web app provides a section that allows uploading aerial images. - The uploaded images are visualized correctly (georeferenced) on the Web map. - Status messages (success, failure, etc.) are shown.
			EMERGENCY		
13	Emergency section	FUN – Functional	Should have	A section for the selection (by name, owner, country, ID…) or creation of an emergency will be provided. This will be the first step for the user after logging into the system (e.g., pop-up window). Emergencies will be registered in the “Emergencies database” and for a creation of a new emergency, at least the following information will be requested from the user: 1) Name	- A section to create or select an existent emergency is the first step in the system after the user is logged in. - The user can create an emergency. - The user can access an existent emergency.

				2) Domain of the Emergency (req.14) 3) Initial point/area of the emergency 4) Initial date/time of the emergency	- The user is capable to search emergency at least by the following fields: name, owner, country, and ID.
14	Define emergency domain	FUN - Functional	Should have	A section for the creation of the emergency domain and searching metocean and satellite products for an area of interest will be provided. In this section, end users will be able to select the domain of the emergency by drawing a box on the Web map (a maximum area will be defined by default, X km^2).	- The user is capable to define the domain of the emergency by selecting a box or providing box coordinates. - The user can not define a box with an area bigger than X km^2.
15	Search for metocean and satellite data	FUN - Functional	Should have	Based on the domain defined in req.14, the list of data products (e.g. wind, waves, currents, satellite) & data providers (e.g. Copernicus, ECMWF, NOAA, EMODnet) and the status of the interoperability protocols available will be shown. The user will be able to activate the operational downloading and put into service the WMS and WCS protocols nonactive natively by the provider.	- A Web searching tool (based on an area of search) provides a list of available metocean products and satellite data for a given emergency domain. - The status of the interoperability protocols (Opendap, WMS, WCS…) of metocean and satellite data of external providers is shown. -The user is able to trigger (or not) the process to activate WMS/WCS protocols if it is not provided by the provider (req.35 and req.36)
OIL SPILL MODELLING (OSM)					
16	OSM Module	FUN – Functional	Must have	The system contains a specific module for OSM which is divided into the following sections at least: 1) Create new OSM simulation: setup, perform and save an OSM simulation with the oil spill model integrated into the system (please see the specific use case in annex 4). 2) Load OSM simulation: load and visualize the results of an existing OSM simulation performed within the system. 3) Import third-party OSM simulation: import results files of a third-party oil spill model, transform data to system structure by using a specific ETL, and save the simulation into the system database.	Through this module the user will be able to: - Create a new OSM simulation. Includes the setup and execution of the numerical model and automatically saves the setup and results in the Emergency database. - Load an OSM simulation performed by the system. Includes the load from the Emergency database and visualizations of the results. - Upload third-party OMS simulation result files (req.18) and perform ETL process (req.19) to standardize information to the system structure. Finally, the results will be saved in the Emergency database.
17	Oil spill modelling functionality	FUN - Functional	Must have	The Web application will allow to setup and run the selected oil spill model to predict the trajectory, dispersion, and weathering of oil spills at sea considering the metocean conditions at the spill site (area of work). All parameters necessary for the OSM to run will be provided and be fed into the system through the “Create new OSM simulation section”. The main parameters to be defined are: 1) Initial time of the release 2) Initial geometry of the release (point or polygon and thickness of the initial slick)	- The Web app provides a section to run oil spill simulations. - The Web app section includes the functionality to provide all parameters necessary for the OSM to run. - The status messages of the simulation (success, failure, etc.) are shown. - The model can run one or several oil spills.

				3) Substance released (selected from the oil database integrated into the system) 4) Definition of general simulation parameters (duration of the simulation, processes to be simulated, calibration parameters) 5) Selection of the forcing datasets (winds, currents, and waves) The model should also be able to run several independent spills to take into account the division of the oil spill into several slicks. This process is achieved by means of the manual restart of an existing simulation (see use case 4).	
18	Third-party OSM outputs upload functionality	FUN - Functional	Must have	The Oil Spill Modelling (OSM) outputs upload functionality will allow to: - uploading data files containing geometries from the outputs of oil spill modelling results (shp, csv, xml, gml, or other required formats for the selected models that the app is intended to be compatible with). - uploading data files containing coverages from the outputs of oil spill modelling results (raster, netCDF, or other required formats for the selected models that the app is intended to be compatible with). This functionality is the first step of the OSM module – section 3 (Import third-party OSM simulation).	- The Web app provides a section that allows uploading the results from oil spill numerical models.
19	ETLs for third-party OSM outputs	FUN - Functional	Must have	The Oil Spill Modelling (OSM) output uploaded is extracted, transformed to the system's data structure, and loaded in memory to be managed in the emergency database. This step is the second part of the importation of third-party model results. Has to be mentioned that each model required to be compatible will need a specific ETL due to the lack of homogeneity in the results structure (formats, variable names, units…) The system will provide processing messages when processing the uploaded data file, e.g. success, failure, and error messages. This ETL also triggers the saving of the simulation in the system's Emergency database.	- The geometries or coverages are visualized on the Web map and their visualization can be activated or deactivated. - Status messages (success, failure, etc.) are shown. - The minimum variables required from an OSM to feed Response Simulator (RS) and detailed in annex 1 can be loaded and visualized. - The ETL triggers the storing of this information and creates a simulation register in the OSM database.
20	Metocean data access for OSM	FUN - Functional	Must have	The Oil Spill Modelling will access the required data from the metocean data providers (Copernicus, ECMWF, NOAA, EMODnet, etc.) making use of interoperability protocols (such as OpenDAP)	- Metocean data are not downloaded. The OSM uses direct access to data through interoperability protocols
21	Restart from existing OSM simulation	FUN – Functional	Must have	The system will allow the user to restart an OSM simulation, which means, using the setup data and a specific timestep results data of an existent simulation to feed the setup of a new simulation. Restart information will feed the default setup values of the new simulation and the user will be able to modify any of them. This functionality will be accessed through a button at the visualization of the results of an OSM simulation.	- The user is capable to perform an OSM simulation from an existing one. - The user is capable of modifying any setup value before running the new OSM simulation. - The user can access this functionality from the visualization of OSM simulation results.
RESPONSE SIMULATOR (RS)					

22	RS module	FUN – Functional	Must have	The system contains a specific module for RS which is divided into the following sections at least: 1) Create new RS simulation: setup, perform and save an RS simulation (please see the specific use case in annex 4). 2) Load RS simulation: load and visualize the results of an existing RS simulation performed from the system database.	Through this module the user will be able to: - Create a new RS simulation. Includes the setup and execution of the Response simulator methodology and automatically saves the setup and results in the Emergency database. - Load an RS simulation. Includes the load from the Emergency database and visualizations of the results.
23	RS methodology	INF - Informative	Should have	The response simulator will be based on 4 steps. 	
24	RS - Window opportunity and response equipment workflow	INF - Informative	Should have	Window opportunity and response equipment workflow 	
25	RS – Window Opportunity	FUN - Functional	Must have	The system will provide the window of opportunity for the response operation. For this purpose, it will use specific metocean relevant variables (visibility, air temperature, wind, currents, and wave fields) and oil thickness to ensure that response and each specific equipment will be used under its required conditions.	- The Web app provides the window opportunity for OSM simulation and metocean datasets. - The window of opportunity will be automatically updated (based on the process defined in requirements 28.a) during the selection of “type of response” and “equipment selected”. - The window of opportunity will present the option to force a working day declared not feasible and to revert this change using buttons. (See requirement 28.b)

<table>
<tr><td></td><td></td><td></td><td></td><td>The window of opportunity will be informative; the user may disregard the window of opportunity.



</td><td></td></tr>
<tr><td>26</td><td>RS – Assignment of resources</td><td>FUN - Functional</td><td>Must have</td><td>The system will automatically provide the assignment of resources. When an oil spill simulation is loaded in the RS the following process must be automatically triggered. Based on the initial point of the center of mass of the spill and the window of opportunity, a sorted list for each recovery equipment must be visualized on the Web map to support the user in the selection of the resources. This list will be sorted by considering different options: 1) the minimum mobilization time required for each piece of equipment, 2) distance to the oil spill, 3) oil spill recovery capacity, 4) rate, 5) name,6) code.
In the case of the skimmers, the viscosity of the oil will be also considered to sort this kind of equipment.

</td><td>- The Web app allows the oil spill simulation to be uploaded.

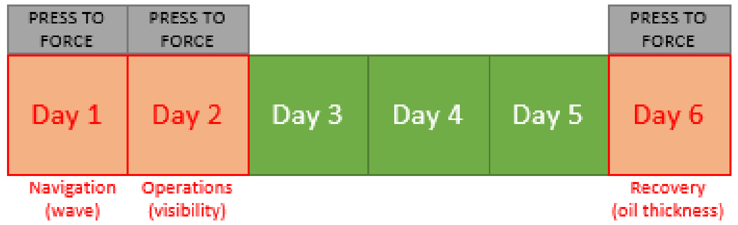
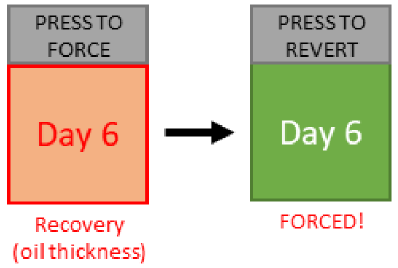
- Once uploaded, the Web app provides a sorted list for each recovery equipment.

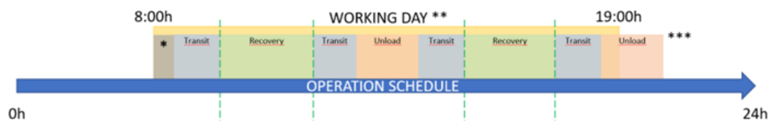
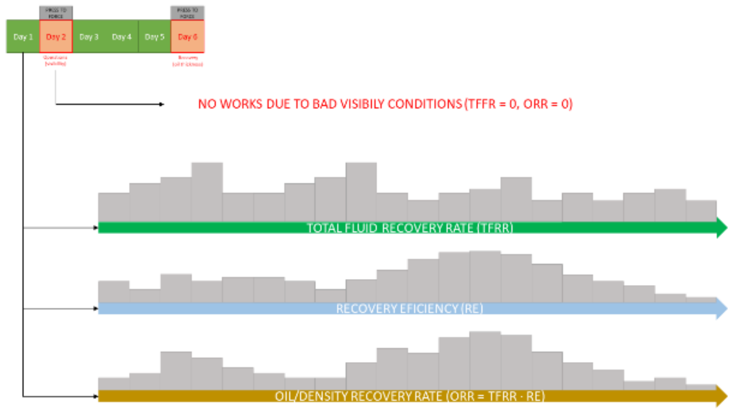
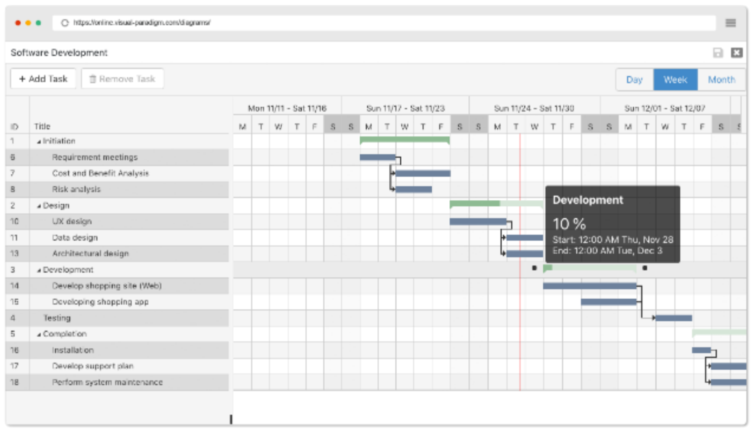
- Sorting can be done by the options described.

- The system automatically updates the window of opportunity based on the equipment selected.

- The system automatically neglects the selection of incompatible types of equipment or response types due to operability rules (annex 2).

- Controls the stock of resources, also when multiple oil slicks are under response</td></tr>
</table>

27	RS – Check feasibility	FUN - Functional	Must have	The system will check if recovery operations are feasible on the specific working day of the simulation with the complete equipment selected in requirement 26. The result of this process is the window of opportunity shown in requirement 26.  	The Web app automatically provides the window of opportunity for the selections stated by checking if recovery operations are feasible. - The web shows a message about what criteria are failing to declare that day as a feasible day.
28	RS – Force working in not feasible days	FUN - Functional	Must have	If the operation is not feasible for a working day, the user will have the opportunity to force the working day despite the recommendation regarding the window of opportunity based on the equipment and response operativity thresholds. If the user forces a workday, the system will use the limit values of the threshold of the variable(s) that are not passing the criteria stated. And the system will update the working days.  	- The web allows to force any day not feasible for response by pressing a button for that specific working day. - The web shows the message “forced!” when the user forces a working day. - The interface has the option to revert a forced day to the original state before the user clicks the button to force.
29	RS – Schedule configuration and trigger calculation	FUN - Functional	Must have	The user will be able to configure the time of start and end of the working day, and if unload operations are allowed out of the working day days (the web app will provide default values). After modifying or not these options, the user will be able to trigger the calculations of the schedule (29), rates (30), and summary of the response (31).  	- The user can modify the initial and end times of the working day. - The user can modify if unload operations are allowed outside of working hours. - The web allows accepting working days by pressing the button “Start response simulation”. - This action triggers the calculations of the response simulator defined in requirements 29, 30, and 31.
30	RS – Schedule recovery operations	FUN - Functional	Must have	The Web app will automatically schedule the recovery operations for the working days. Once hourly recovery rates (requirement 30) are calculated, the web app will define the schedule of the recovery operations by blocks of transit – recovery – transit – unload. A daily time backup will be added to consider possible maintenance of the equipment, delays, and other unpredictable and inefficient periods.	- The user can modify the start and end times of working days. -The user can allow unloading operations outside the working day period. - The Web app automatically schedules recovery operations based on transit times and time loading oil and time unloading oil at the port.

				The user will have the possibility to accept the unloading of the recovery product outside the working day (optionally) and to modify the start and end times of the working day.  	- Show interactive Gant's diagram of the response operations
31	RS – Recovery rates	FUN - Functional	Must have	The Web app will allow calculating hourly recovery rates for that specific working day: Total Fluid Recovery Rate (TFRR) and the Oil/Emulsion Recovery Rate (ORR) will be calculated for mechanical recovery response, considering the encountered rate as the maximum oil volume possible to be recovered per hour.  	- The Web app calculates recovery rates according to the stated methodology in annex 3.
32	RS – Summary	FUN - Functional	Must have	The Web app will provide a summary of the simulation time horizon. The results provided by the RS will be: (1) the amount of oil removed/dispersed/burned, (2) the operation schedule, and (3) the cost summary of the operations. The visualization of the results will be presented employing pie charts, bar charts, stacked bar diagrams, line diagrams, area charts, and/or Gant's diagrams. Interactive charts are recommended to improve user experience. Option to export results to standard formats as pdf, csv, and excel spreadsheet must be provided.  	- The Web app provides a summary of the response simulator results. - The Web app provides visualization of the results in pie charts, bar charts, or other kinds of representation. - The results can be exported to pdf, csv, and xlsx formats.

					
33	Restart from RS simulation	FUN – Functional	Must have	The system will allow the user to restart an OSM and RS simulation, which means, using the setup data and a specific timestep results data of an existing OSM and RS simulation to feed the setup of an RS and OSM new simulation. Restart information will feed the default setup values of the new simulation and the user will be able to modify any of them. This functionality will be accessed by employing a button at the visualization of the results of an RS simulation and the user will be able to run only a new RS simulation skipping the setup and execution of an OSM simulation	- The user is capable to perform an RS and OSM simulation from an existing one. - The user is capable of modifying any setup value before running the new OSM or RS simulation. - The user can access this functionality from the visualization of RS simulation results. -The user can select to set up and execute only the RS simulation, using the existing OSM simulation.
			METOCEAN & IMAGERY		
34	List of metocean and satellite data	FUN - Functional	Should have	The list of metocean and satellite products available for the area of interest will be provided. The list will include the characteristics of the products according to their availability, e.g., products that can be accessed through OGC interoperability protocols are available for immediate viewing, while products that are not will require selection for an ETL process.	- The list includes real-time, forecasting, and satellite products. - Products that require an ETL process can be selected and launched.
35	ETLs metocean data	FUN – Functional (mix)	Should have	Metocean products that cannot be consumed through OGC interoperability protocols (WMS, WCS) will be Extracted Transformed, and Loaded (ETL). Metocean data, real-time (buoys and HF Radar), and forecasts from different data providers (e.g. Copernicus, ECMWF, NOAA, EMODnet) are extracted, transformed, and loaded into the system.	- Sensors about the ETL process are exposed and can be consumed by EMSA's NAGIOS
36	Metocean Service from ETLs products	TEC - Technical	Should have	The system will provide standard interoperability protocols (OGC compliant: WMS, WMS) to access metocean data products Extracted Transformed, and Loaded.	- Interoperability protocols for accessing ETL products are exposed and accessible
37	Time for metocean data download	PER - Performance (Non-Functional)	Must have	The area of work must be limited according to the performance required. The maximum time to download the metocean data will be 3 hours.	- Product download does not exceed 3 hours
			PROPRIETARY DATABASES		
38	Emergency database section	FUN - Functional	Must have	The Web app will provide a section dedicated to emergency data management. The emergency data section will provide the roles/privileges defined in req.6.	- The Web app provides a section to manage the oil spill database according to user privileges.
39	Emergency database service	TEC - Technical	Must have	Through interoperability protocols (e.g. API) this requirement allows users to manage:	- The Emergency properties can be managed via interoperability protocols (e.g. API) according to user privileges.

				1. Emergency general properties (name, domain, initial date and time, initial point/area…) 2. GIS vectorial layers of the oil spill polygon(s) defining the geometry of the oil slick(s) and its properties. 3. OSM simulations (setup and results). 4. RS simulations (setup and results).	- The Oil spill polygon(s) layers can be managed via interoperability protocols (e.g. API) according to user privileges. - The OSM simulations can be managed via interoperability protocols (e.g. API) according to user privileges. - The RS simulations can be managed via interoperability protocols (e.g. API) according to user privileges. - All protocols are able to restrict access based on user privileges (CRUD) defined by the user role.
40	Oil database section	FUN - Functional	Must have	The Web app will provide a section dedicated to oil database management. The oil spill data section will provide the roles/privileges defined in req.6.	- The Web app provides a section to manage the oil spill database according to user privileges.
41	Oil database service	TEC - Technical	Must have	The Oil spill data service will facilitate the data management via interoperability protocols (e.g. via API). The services will be accessible to both human and system users.	- The oil spill database can be managed via interoperability protocols (e.g. API) according to user privileges (human and system). - Minimum variables needed to be stored are defined in Annex 1.
42	Resource & equipment database section	FUN – Functional	Must have	The Web app will provide a section dedicated to resource & equipment data management. The resource & equipment data section will provide the roles/privileges defined in req.6.	- The Web app provides a section to manage the resource & equipment database according to user privileges.
43	Resource & equipment database service	TEC - Technical	Must have	The Resources & equipment data service will facilitate the data management via interoperability protocols (e.g., via API). The services will be accessible to both human and system users.	- The resource & equipment database can be managed via interoperability protocols (e.g., API) according to user privileges (human and system).
			ACCESIBILITY AND MONITORING		
44	Monitor	TEC - Technical	Must have	System processes will expose sensors (e.g., system metrics, service state, process state, file system usage, etc.) for the EMSA's monitor system. The sensors must be compliant with Nagios interoperability agent or cloud equivalent tools.	- Nagios can access and integrate the exposed sensors.
45	Progressive Web app	TEC - Technical	Should have	The Web app will be compliant with mobile devices. The Web app should be an all-in-one solution for a site/app to be delivered across all devices without the hassle of app-store distribution.	- The Web app is a Progressive Web App (PWA) that can be used on mobile devices
46	Mobile device functionalities	FUN - Functional	Should have	The Application should reduce the functionalities available when detecting a mobile device using the system. The application will provide access only for reading and simulating.	- In a mobile device the System provides lighter functionalities (read and simulate) - The App interface is responsive and adapts to mobile devices

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