The SAFE-PORT Project:

An approach to port surveillance and protection

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Abstract — **SAFE-PORT is a recently started project addressing the complex issue of determining the best configurations of resources for harbour and port surveillance and protection. More specifically, the main goal is to find, for any given scenario, an adequate set of configuration solutions — i.e., number and type of sensors and equipments, their locations and operating modes, the corresponding personnel and other support resources — that maximize protection over a specific area.**

The project includes research and development of sensors models, novel algorithms for optimization and decision support, and a computer-based decision support system (DSS) to assist decision makers in that task. It includes also the development of a simulation environment for modelling relevant aspects of the scenario (including sensors used for surveillance, platforms, threats and the environment), capable to incorporate data from field-trials, used to test and validate solutions proposed by the DSS. Test cases will consider the use of intelligent agents to model the behaviour of threats and of NATO forces in a realistic way, following experts' definitions and parameters.

Keywords- Maritime Surveillance, Harbour and Port Protection, Decision Support Systems, Simulation.

I. INTRODUCTION

Considering the highly dynamic nature of NATO missions and assets (e.g., change in coalition and/or availability of resources), the SAFE-PORT Project aims at improving the quality of planning as well as reducing the planning cycle, proposing a more efficient use of available resources and, at the same time, increasing overall effectiveness — that is, *to do more with less*.

The SAFE-PORT project addresses the issue of selecting the best configurations of surveillance systems for purposes of harbour and force protection which can be deployed in any given scenario. The main purpose consists of determining an adequate set of configuration solutions that should maximize the number of threats detected (or minimize certain risks), considering available assets, user and environment's conditions and restrictions. A configuration solution comprises the number and type of sensors and equipments (fixed or mobile), their locations and operating modes, as well as the corresponding personnel and other support resources. The problem is rather complex and multifaceted and, to tackle it, it requires combining multiple scientific disciplines and technical know-how, including sensors modelling, mathematical optimization algorithms, simulation and validation.

The main result of SAFE-PORT will be a fully functional computer-based DSS, together with online resources with an expandable knowledge base of scenarios, solutions and simulations, as well as definitions and parameters to be used in the simulation of intelligent agents, which will be made available and accessible to NATO partners. The SAFE-PORT relevance, in fact, is well aligned with NATO's DAT PoW Item 2: Protection of Harbours & Ports [1].

During development, we intend to join ongoing research activities and groups dealing with port and maritime protection or computer optimization (operational research) areas, with the purpose of learning and sharing know-how relevant to SAFE-PORT and to disseminate some of the project's main achievements to the community.

The development will go through the following activities:

- Analysis of operational scenarios and conditions in which harbour protection (and shore-surveillance in general) is required, so that the problem is understood in detail and system requirements are derived.
- Development of realistic and accurate models, covering all relevant aspects of the scenario, including surveillance sensors, platforms, threats and the environment. A high-degree of accuracy is required in models so that optimization

algorithms may generate valid configurations for real-world environments, as well as for simulation environments.

- Development of optimization algorithms to determine a set of candidate configuration solutions for a given scenario and according to established criteria.
- Perform simulations and build extensive datasets so that robust statistical analysis may be conducted, allowing determining the best configuration solutions from the set (according to a pre-defined set of Measures of Merit and Measures of Effectiveness).
- Evaluate the system validity by conducting field-trials — at different times of the year, in different locations and under a variety of conditions — and comparing the collected data against results from optimization and simulations.

II. SYSTEM COMPONENTS

The envisaged system includes three main components, as depicted in Figure 1.

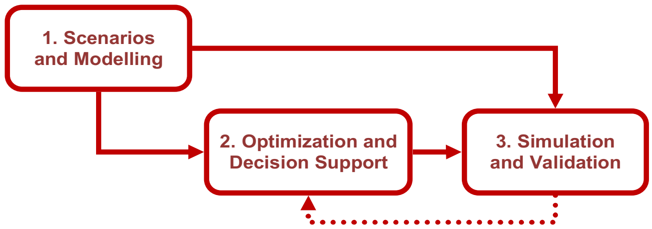

Figure 1. Main components of SAFE-PORT.

We derive the SAFE-PORT main requirements by analyzing a set of operational scenarios and conditions in which harbour protection is required. Realistic and accurate models covering all relevant aspects of the scenario, relevant to determine the best configuration of equipment and personnel to maximize protection will be developed. The scenarios and models will then feed the DSS optimization algorithms which will determine a set of candidate configuration solutions, that is, the combination of equipment and personnel used for detection purposes and their location. This equipment may comprise radar sensors, EO/IR sensors, satellite observation, sonar, unmanned platforms and ships, among others.

Given the high complexity of the problem, and as in similar previous projects (e.g., [2]), there will be an extensive use of simulation to assess performance of each of the configuration solutions. Previously used configurations or template configurations that were used in similar scenarios, can be used as initial configurations to accelerate the optimization process. Subsequently, configuration solutions are ranked based on the assessment results and according to cost-effectiveness criteria, enabling identification of *the best solution under constraints,* or *the best trade-off solution*.

Finally, validation activities will be conducted to confirm models' correctness and accuracy towards the real-world systems they represent, as well as the applicability of optimization algorithms in real-life scenarios. For that, real data from sea trials will be collected and compared against simulations.

These components are next described in detail.

A. *Scenarios and Modelling*

Scenario analysis allows establishing problem scope and understanding the user's requirements, from which the DSS and its models can be built. A broad set of realistic and credible models is required prior to determine DSS solutions so that its outputs are valid for simulated environments and, especially, for real-world environments. The following models, by category, will be built: (1) **Sensors**, (2) **Platforms**, (3) **Threats** and (4) **Environment**.

1) *Modeling Sensors*

Sensors are the means that allow the detection of objects in a specific area of interest. Sensor models are required both by the optimization algorithms — to know a sensor's coverage area and detection probability — as well as by the simulation environment — to estimate the system's actual effectiveness.

It is essential to model different types of sensors to reflect their actual application in the military domain or, in general, in critical systems. Since the performance of sensors heavily depends on external conditions, such as climate (e.g., IR visibility is reduced with temperature increased, EO range is degraded with fog), system effectiveness, over a wide range of conditions, can only be ensured with a combined and complementary use of sensors located at the right places. Therefore, facing the constraints of a given scenario, the DSS will present a set of solutions that maximize overall effectiveness rate using an adequate diversity of sensors over a wide range of conditions, including both fixed sensors and mobile sensors (e.g., sensor in a patrol-boat).

The main **types of sensors** to be modelled in SAFE-PORT are described next. In each case, they may be either fixed or mobile, i.e., attached to mobile platforms (such as ships, or UAVs/UUVs).

Radar

Radar sensors are reliable tools for surveillance and detection purposes given their ability to accurately detect an object's position (2D and 3D) and speed under conditions where other emissions would fail, such as sound or visible light. Amongst other, the following radar characteristics will be modelled: gain/loss factors (including transmitter power, waveform and antenna size), clutter, noise, system parameters, radar cross section and antenna type.

EO/IR

Electro Optic and Infrared technologies are key elements of every surveillance system to be used in an infrastructure dealing with the detection of asymmetric threats. Visible, near-, mid- and far infrared (IR) sensors can be used individually or in combination to perform specific security applications.

The nature of these types of sensors and the technology involved contribute to very high visit times, thus allowing very wide spatial coverage with high probabilities of detection, even for very fast moving objects approaching the surveilled AoI.

Although the weather penetration capability and maximum detection ranges are poorer with regard to other sensor technologies, the specificity of the mission of harbour protection, where limited operating ranges are required and complex backgrounds produce spurious reflections (degrading, for example, the performance of radars and sonars) is a strong argument to consider EO/IR technology in SAFE-PORT.

EO/IR sensors models will be developed incorporating both active and passive equipments — e.g., laser radars and Imaging VIS/IR, respectively — in order to guarantee a larger set of conditions to be covered under the best possible conditions.

Factors that may reduce the effectiveness of EO/IR sensors in the contect of harbour protection include:

- The environmental factors affecting the atmospheric channel: The target detection probabilities and, conversely, the range at which targets can be detected are affected adversely by the atmosphere and environmental conditions (e.g. sun position).
- The type of backgrounds: The capability of discriminating possible alarms in complex backgrounds and therefore influencing directly the probability of detection deeply depends on spatial resolution and intensity contrast of the image produced by a sensor system.
- The type of targets: The capacity of an EO/IR system to discriminate the target, and to be able to extract some information from its spatial spectra content, depends strongly on the target characteristics. Shape or form factor, reflectivity and its dynamic characteristics are critical parameters affecting the detection capability. For thermal sensors, this list is augmented with factors like body temperature and emissivity. The mobility of the sensors shall also be taken into account since EO/IR sensors can operate on mobile platforms.

Sonar

There are a number of cases, mainly triggered by weather and sea conditions, in which remote sensing from space, air and sea surface may be difficult or even impossible. Moreover, there has long been a requirement to protect naval facilities and naval assets from underwater attacks. Sonars can also be deployed from a ship to provide security in high risk locations, such as foreign ports, and can be integrated with other sensors to provide a common operational picture of a designated area.

Although other classes of active sonars would be eligible for the type of scenarios covered in SAFE-PORT, only multibeam sonars will be modelled.

Coverage of the Sonar is a key consideration for any surveillance system, which is mainly determined by four parameters: transmit power, receiver sensitivity, beamwidth, and target strength.

Moreover, the following environmental factors, which may affect a sonar's effectiveness, will be considered: *Water Column Aeration* (propeller wash from vessel traffic in the area of acoustic coverage can obscure small mid-water targets); *Water Column Refraction* (thermal layers in the water column affect the propagation of an acoustic pulse by causing them to "bend" away from the warmer water to the colder layers – most often below); *Surface and Ambient Noise* (as wave height increases, there will be higher levels of acoustic backscatter from the undersides of the waves which may mask a target of interest). The deployment of the sonar sensors will also be considered [3][1].

2) Modeling Platforms

Platforms, especially unmanned ones, are important assets to consider in SAFE-PORT. Platforms with onboard sensors operate as mobile detection platforms (e.g., sensor on ship, human-eye detection) and allow extending surveillance areas especially on locations where fixed sensors cannot be installed.

A number of platforms, typically used for defence and surveillance purposes, will be modelled: *maritime surface platforms* (e.g., frigates, patrol-boats, small and large vessels and ships, USVs); *subsurface platforms* (e.g., submarines and UUVs); *aerial platforms* (e.g., UAVs); *man* (e.g., swimmers)

We will consider modular models that can be parameterized so to account for several categories of vehicles. This is achieved by separating the structure of the model from its parameters, which are loaded from a vehicle database for each specific platform category. Each platform category will comprise:

- Dynamic models with specific degrees of freedom (for example, a UUV has six) [4]–[6], with a high degree of fidelity (effects of disturbances, motors, hydrodynamics, aerodynamics, etc.);
- Model simplifications [7] which allow for fast simulations (at the expense of accuracy).

3) Modeling Threats

Threats will be defined and modelled in order to operate on the computer simulation environment. Threats may comprise, among others, fast-boats, vessels and divers. These objects will be used to test a configuration solution effectiveness rate under a specific scenario.

As with vehicle models, threat models will be handled at different levels of detail in a modular fashion. We consider isolated threats and coordinated threats.

Isolated threats range from divers, to human-operated vehicles and/or unmanned vehicles (ocean, air and ground vehicles). As physical entities, they are characterized by motion and a number of physical features (e.g., size and reflectivity index). In addition, they can be classified according to the level of "intelligence" — this can range from open-loop mission plans (scripts) to sensor-based algorithms for decision-making as well as optimal path planning under uncertainty [8], [9]. Coordinated threats involve multiple physical entities running distributed algorithms in a cooperative manner [10] – [15].

Attackers are to be modelled as intelligent agents, and their expected proactive and reactive behaviours have to be anticipated in simulations. For that purpose, and given the lack of enough real data about incidents, an extensive set of interviews are to be conducted with defence and security experts. This knowledge elicitation process will enable the identification of possible attack profiles and attacker behaviours, as well as the definition of vulnerability maps from the defence point-of-view.

4) Modeling the Environment

The environment characterizes the conditions under which material and personnel resources operate. The environment may have a direct impact on the performance of sensors, may condition their coverage area and operation, such as obstacles, may constrain areas where they can be installed, such as energy spots, and may severely constrain operations. It is therefore crucial to develop exact and detailed models of the most relevant environment characteristics that may have an impact on the envisaged solution.

Next, we describe the main environment aspects that will be modeled.

2D and 3D modeling of the surface and subsurface topography

2D and 3D modeling of the geographical AoI, including surface and subsurface topography is essential, in particular, to calculate sensors coverage range (e.g., a land obstacle results in a non-coverage area by a radar or optical sensor).

The level of detail will be conditioned by the availability of data. Terrain information will be imported from widely used formats, such as ENC/S-57 digital charts.

Climate and Sea Conditions

Climate and sea conditions affect sensors performance, such as their coverage and detection rate. Climate conditions to model include temperature, humidity, wind, liquid and solid precipitation, fog, dew, frost and near surface downward short-wave radiative flux. Sea conditions to model include temperature, salinity, ice and maritime currents.

A climate characterization of the region will be produced, based on large scale weather forecast models reanalysis from NCEP (National Centers for Environmental Prediction, USA) or from ECMWF (European Centre for Medium-Range Weather Forecast). This characterization will focus on adverse and extreme weather conditions and will be used to reproduce monthly typical and extreme weather conditions.

Climate and sea conditions will be obtained and modeled in a realistic way using state of art mesoscale non-hydrostatic models. Real cases of severe weather conditions will be simulated in this way.

Maritime Traffic

Maritime Traffic will be modelled and developed to emulate real vessel activity and distribution in a pre-defined region (the AoI and its circumventing area). Vessel distribution will be derived from historical data and adhere to actual shipping lanes, expected velocities, etc. The traffic distribution shall be able to process the ICOADS dataset (ICOADS is the most comprehensive and robust to cover worldwide scenarios) and also region historical data sets (if available), in order to assure the statistical elements of the real-world/regional traffic occurrences.

The most significant stage of the vessel activity simulation is the spatial distribution of vessels according to the real density areas. Each vessel will be characterised by its position and velocity, which means that vessel density will change in time. Therefore the distribution of the vessels in a region, as a whole, follows certain patterns in accordance to their intended course and existing shipping lanes. Thus it is possible to define a region with a probability of vessel existence.

Besides close to real representation of maritime traffic, further manipulations are allowed for simulation purposes, such as increasing traffic density by 20% or more.

B. Optimization and Decision Support

The SAFE-PORT system is designed to support planning decisions related to the definition, for any given scenario, of an adequate — optimal, in some sense — set of configuration solutions that should maximize system effectiveness. A configuration solution is mainly defined by the number and type of sensors and other equipments (fixed or mobile), their locations and operating modes, as well as the corresponding personnel and other support resources.

The problem of configuration optimization is rather complex, namely taking into account the goal of having a DSS adaptable to any scenario or set of equipments and the need to integrate sensors of quite a different nature and capabilities, and the potential combination of fixed as well as mobile, permanent as well as non-permanent resources. To tackle such complexity, the problem is approached in an hierarchical way.

At the most basic level, one needs to estimate the collective detection performance of a set of sensors, at given locations, and under given environmental conditions. For optimization purposes, a number of measures will be used to assess the configuration solution: the detection performance will be primarily defined by the *estimated probability of detection.* In simulation, this probability is estimated by the *detection ratio*. In validation tasks, through field trials, one may be able to identify the objects and compute other key metrics, such as the *sensitivity* (true positives proportion) and the *false positive rate*, as well as a *detection effectiveness ratio*.

The following levels in the hierarchical approach deal with different optimization problems. Firstly, for any given set of sensors, one has to *determine their best location and operating modes*. Following that, the system seeks to *find the best configuration*, possibly under given constraints on some criteria — this means finding the appropriate number and location of each type of sensor. Finally, one needs to *determine appropriate complements to the configuration solution*, including the definition of the necessary operating personnel, and other support resources, mobile sensors and patrols, etc.

1) Global optimization

The optimization modules of the DSS require a reliable estimation of the performance of the sensors, both separately and in conjunction. Multisensor integration may require large quantities of data recorded under realistic conditions. However, field trials and field campaigns can be both expensive and time consuming and it is impossible to test all possible sensor configurations, or all operating and environmental conditions. On the other hand, supervised neural networks can be very useful as predictive models, able to incrementally learn from observed examples, and to produce appropriate generalization responses for yet unobserved cases. If properly designed, they can filter measurement errors, and, in most cases, generalization amounts to multidimensional nonlinear interpolation from the observed examples, as well from supplementary examples generated from the individual sensor models. Therefore, one aims to achieve better estimates of multisensor performance, to feed the configuration and location optimization algorithms, even when a relatively limited, but reasonably varied set of experimental records is available.

Supervised neural networks may also be considered to produce a reasonable initial solution for the configuration optimization problem, to reduce the subsequent search computational effort. Namely, a neural model may be used to associate the main features of archetypical scenarios to the corresponding predefined configuration solutions. Moreover, through nonlinear regression models, it will be possible to synthesize functions able to estimate cost-performance trade-offs in allocating a group of mobile sensors, given the area to cover, as described further below.

Also, neural models, such as radial basis function networks, can help in the application of metaheuristic search methods, which are especially able to tackle global optimization problems, and are often used in computational intelligence applications.

In the last decades, there is a growing interest in the application of evolutionary algorithms to multiobjective problems [16]. The existence of a population of solutions motivates, immediately, the idea of simultaneously approximating several non-dominated solutions. We consider solving the location optimization problem through *multiobjective interactive memetic algorithms*, which integrate genetic procedures and local search heuristics [17]. The decision-maker can force the algorithm to look for solutions that are placed within a region of interest. This possible interaction will be based on a reference points approach, which is capable of finding more and better solutions in less iterations than the alternative approach of establishing bounds to the objective functions.

The configuration optimization module will require a very large number of calls to the location optimization module. Therefore, it is necessary to speed up the evaluation of configuration solutions by resorting to an efficient global optimization approach, namely using radial basis interpolation models [18][19][20].

2) Mobile platform operation optimization

Mobile platforms carrying different types of sensors can be used to provide complete coverage of a surveillance area for a given threat over time, thereby reducing the number of necessary sensors or making possible the surveillance of areas where the deployment of fixed sensors is not feasible or not cost-effective. A central problem is designing motion planning and control for networks of sensor-equipped, autonomous vehicles that yield efficient collection of information-rich data [21], [22].

The surveillance area may have a given threat profile, as well as climate and environmental factors. In planning the movement of the platforms these factors (including sensor degradation performance due environmental conditions) have to be taken into account. The negative effects, due to interferences, of multiple heterogeneous platforms (unmanned underwater vehicles, unmanned surface vehicles and unmanned aerial vehicles) and multiple types of sensors, under both independent and coordinated operation, also have to be considered [23], [24].

Trying to optimize configuration solutions that include both fixed and mobile sensors poses a very demanding load in the location and configuration optimization algorithms, as the coverage that can be guaranteed by (a group of) mobile sensors depends on the geometry of the zone to cover, within the AoI. Due to the complex signal propagation environment, especially when dealing with underwater systems, the objective function has in general a complicated nonlinear behaviour, and suitable nonlinear optimization techniques are likely to need methods for global optimization, i.e. methods with a capability to escape from local minima [25] [26]. The sensors can be stationary moored sensors or acoustic arrays attached to buoys, as well as mobile sensors mounted on AUVs and surface vessels. The mobile sensors can furthermore be used to adapt the coverage in response to environmental changes, e.g. temperature.

We propose a sensor coverage algorithm for mobile sensors, based on previous approaches recently proposed in the literature [27] – [29], that will determine a set of best possible solutions given a scenario (geographical, climatic and environmental characteristics) and a set of deployable assets (number, characteristics of vehicles and corresponding sensors, their initial location and the location of support infra-structures). In planning the movement of sensors, areas that are deemed of higher risk should receive proportionately higher coverage. Starting from a given threat profile, scenario, assets collection and deployment configuration the algorithm will determine several performance measures (MoM and MoE) that will be used to assess the proposed solution. The zone to be covered by mobile sensors may, in some cases, be specified *a priori*, and the DSS should help determining if and where they should be used: their type, number, and optimal paths.

The approach we propose — to the best of our knowledge, an innovative one — should make the problem more tractable. Firstly, when searching for the best configuration solution or solutions, we intend to use evaluation functions — to be developed — with typical, approximated values relating cost (including number of mobile units needed) and detection performance (assuming near-optimal coordination), more or less independent of the geometry of the zone to cover. In the end, the solution perceived to be best — or the most promising solutions, in a multicriteria sense — would be further refined, taking into account a more precise definition and performance estimation of the set of mobile sensors to be used.

3) *Solution Assessment and Prioritization*

Configuration solutions will be evaluated according to selected performance measures (MoM and MoE), as well as to other criteria, such as operating and installation costs. As a result, the DSS will allow the decision-maker to choose between 3 support modes:

- the identification of the *best possible solution*, for a chosen weighting of the different criteria;
- the identification of the *best solution under given constraints* — for instance, in terms of best detection performance given budget or other resource limitations;
- the identification of a set of interesting — i.e., non-dominated, Pareto optimal solutions — that offer good trade-offs among the criteria.

Possibly, the most common support requirement will correspond to the maximization of detection effectiveness, given real or simulated ("what-if") resource constraints. Or, converserly, the cost minimization for a desired security level, i.e., finding the minimum number of sensors and equipment for a given detection effectiveness rate [30]. Moreover, as mentioned before, we will also allow the decision-maker — may he wish — to explore a set of non-dominated solutions, leaving to him the commitment of choosing one, from the analysis of the trade-offs between them, but without imposing the assignment of weights to the evaluation criteria.

Therefore, the methods used in the optimization algorithms component will generate a set of candidate configuration solutions (i.e., best *perceived* solutions by algorithms), not a single solution. The performance of any of these configuration solutions can be evaluated by testing them in a simulated environment. Under simulation, the environment will be generated, including objects to detect (consisting of maritime traffic, own-platforms and threats). The decision-maker will be allowed to visualize any of the candidate configuration solutions recommended by the DSS, and assess it by visualizing a simulation demonstration. Moreover, he will be able to assess the solution from the results of a Monte Carlo analysis — namely, experimental measures of merit (e.g., percentage of false positives) and measures of effectiveness (e.g., percentage of detections).

Finally, we note that, if required, the optimization algorithms may be applied according to any of the following assumptions: *(i)* considering the sensors performance only under typical environmental conditions (mode/average/median values); *(ii)* considering the weighted average sensor performance, according to the frequencies (probabilities) of different classes of environmental conditions; *(iii)* considering several cases: typical sensor performance; average sensor performance; sensor performance under critical environmental conditions.

4) *Knowledge Base*

To help in the preparation of input data for the DSS and to support its regular usage, we plan to organize a knowledge base, including a collection of descriptions of scenarios, resources, experiments and solutions. This should be incrementally expanded, from the early stages of development, and is designed to accommodate the results from future usage of the DSS.

Among other instrumental types of knowledge that may be worth considering, we intend to include a repository of knowledge about judgmental solutions proposed by defence experts for achetypical scenarios, either real or conceptual ones. Such expert knowledge would be taken into account in automatically recognizing special cases (scenarios), such as those where the usage of mobile sensors would be most recommendable. The main features of a scenario can be encoded into a record, and this can be correlated to a second record encoding the main features describing a "best protection configuration" solution. Eventually, a KB with enough such records would enable, through analogy — in fact, through generalization from a supervised learning model —, the quick generation of reasonable solutions for new scenarios.

The knowledge base will not preclude the existence of auxiliary data bases, with basic input information, that might possibly differ in format and extent from one end-user to another. However, the KB should be a corpus of elaborated and higher-level information, easy to consult and use, in support of the optimization and simulation modules of the system. For instance, from the basic input data available, we need to create appropriate "decision support maps", namely to be used by the optimization algorithms.

High-level attributes to be evaluated, both judgmentally and from hard data, include: *feasibility* (degree of feasibility of installing some type of equipment); and *risk*. There will be two types of risk maps. Firstly, *prior risk maps* will help in guiding the optimization search procedures, and combine 3 indexes: *(i)* of *threat likelihood* (namely, given the reachability and the traffic density); *(ii)* of *criticality* (the danger associated to a threat issued from a point or, at least, the importance given beforehand to that point); and, *(iii)* of *prior vulnerability* (i.e., the lack of adequate original coverage). Afterwards, the results from the simulation of a configuration solution will enable the reassessment of the vulnerability, and the *revised risk maps* may be used to improve upon the optimization of the configuration.

C. *Simulation and validation*

Simulation will be used extensively for the purposes of assessing, testing and validating the DSS algorithms and models. It will also allow end-users to visualize and validate custom solutions. The simulation framework is targeted at preliminary integration and testing, rapid prototyping and faster than real-time experiments. It comprises a simulation environment allowing to run scenarios and configuration solutions, either using simulated data (i.e., output of sensors, platform and other models) or real field-data (i.e., sensors data collected from field-trials).

1) *Simulation environment*

For modeling and simulation purposes, SAFE-PORT will use a COTS simulation environment that allows analyzing and visualizing physical and operational aspects of military surveillance systems, including modeling of surface/subsurface terrain, threats, radars and platforms, simulating detection grids, calculating sensors coverage areas, generating time dynamics and generating reports for validation purposes.

A specific functionality that will be exploited in the simulation environment will be line-of-sight visibility, with the possibility to add constraints like body masking, terrain or communication parameters, so that it can be determined when objects can see each other. This is especially important when dealing with coverage and detection rates (e.g., *considering modelled terrain and environment, what is the probability that a radar sensor will detect that ship object?*). Subsequently, measures of effectiveness for a given configuration solution can be calculated and the simulation data exported and statistically analyzed by external modules.

This functionality allows assessment of a configuration solution against a set of cases and its performance calculated with a high-degree of confidence. Cases may involve testing a given configuration under a variety of different environmental conditions and/or threats number and types.

2) Validation

Validation will be conducted to demonstrate the correctness, accuracy and applicability of SAFE-PORT developed models, and the DSS proposed solutions. Essentially, it should demonstrate that models behave, with sufficient accuracy, according to the real world system they represent, and that the solutions recommended include the configurations that maximize detection rate subject to the constraints set by the user.

Validation will undergo two stages:

- Validation under a fully simulated environment

At this stage, the scenario is fully synthesized, including environment conditions, platforms, sensors and threats. All conditions are parameterized with realistic values (considering AoI geographical area and date-and-time of the year, maritime traffic, etc.), allowing further manipulations (e.g., increase maritime traffic by 20% and introduce heavy fog).

The Monte Carlo method will be used, through repeated simulation of a large number of trials, trying to reproduce the probability distributions of all relevant parameters, including sensors parameters, weather parameters, communication parameters, traffic distribution initial conditions, threats behaviour, etc. Among the most useful statistical indicators will be the extreme probability quantiles — say, .01 or .99 quantiles — revealing the system best-case/worst-case performance.

Repeated intensive simulation is also quite useful for design purposes and not only to test the behaviour of the system upon uncertainties in the modelling and to conduct a robust statistical analysis. Parametric analysis will also allow a sensitivity analysis to test robustness of a dominant-configuration solution over other candidates. By changing a value of a parameter, within a predefined range, one is able to assess its effect upon performance metrics, allowing in this way to refine the configuration solutions.

- Validation under a simulated environment using data collected in sea-trials

At this stage, models are replaced by real-equipment, conditioned to their availability, and data related to environment conditions, platforms, sensors and threats collected from sea-trials. This data will allow validating the developed models, as well as validating the SAFE-PORT system itself. Therefore, sea-trials have an important role in the Project. Since they require an enormous set of resources and coordination effort, we expect to carry out these tasks with the key participation of the Portuguese Navy, and in close collaboration with other national entities.

III. Outcomes and Deliverables

The main SAFE-PORT delivery will be a fully working Decision Support System for purposes of port and harbour protection. It includes SAFE-PORT software (including databases and simulation platform), hardware (hosting the software and with appropriate system requirements) and an online knowledge base platform to be made accessible to NATO nations and partners at no cost.

Additionally, the following deliverables are planned:

- Realistic and accurate models, covering all relevant aspects related with scenarios and subsystems;
- DSS optimization algorithms developed to determine a set of candidate configuration solutions for a given scenario and according to established criteria ;
- Extensive datasets resulting from simulations and field-trials;
- The project development documentation, including requirements specification, software design, software source code, test documents, test results, binaries and executables;
- End-user documentation: user manual, installation manual, maintenance manual and training manual;
- A website where authorized users can have access to the main resources, including the knowledge base platform;
- Experts' definitions and parameters to be used for the intelligent agents to model behaviour of threats and NATO forces in a realistic way. This information may be subject to classification and will be handled accordingly;
- A number of papers reporting the main scientific contributions of the Project.

IV. Development Plan

SAFE-PORT was planned as a five years project, developed in two phases comprising in total a three step iterative spiral process, as follows:

PHASE 1 / Iteration 1 - An early prototype will be developed for proof-of-concept, comprising a basic set of components and functionalities (e.g., sonar sensor and DSS algorithms for stationary sensors). This iteration will allow consolidating systems requirements and assessing areas with associated high-impact development risks, such as those related with the optimization algorithms.

PHASE 1 / Iteration 2 - SAFE-PORT version 1 will comply to the final system requirements and remove uncertainties in critical subsystems models and functionalities. It is envisioned to include validation results from a system field-trial with sonar sensors.

PHASE 2 / Iteration 3 - SAFE-PORT version 2 will include the development of further added-value subsystems models (e.g., satellite, satellite AIS, additional radar models), fine-tuning of system parameters and algorithms, system validation (incl. improvement and assessment of the subsystems models and optimization algorithms). At this stage, it is envisioned to include validation results from several field-trials with real sensors of different types.

V. THE CONSORTIUM

The consortium structure was chosen to fulfil all the intensive research, development and modelling activities that have to be conducted in SAFE-PORT. A private company, EDISOFT, was chosen to lead and manage the consortium due to its goal-oriented nature and consolidated competences in management and coordination of large scale and complex projects with strict calendars. The Portuguese Navy will act as end-user, mainly contributing to the specification of scenarios and system requirements, as well as system validation, field-trials coordination and system acceptance.

The Portuguese Navy function relies in three pillars: Military defence and support to foreign policy; Security, safety and state authority; Economic, scientific and cultural development. In some countries these functions are carried out by several distinct organizations: Blue Water Navies, focused on military defence and support to foreign policy; Coast Guards, committed to security, safety and state authority; and other agencies dedicated to specific tasks, such as maritime Search and Rescue, scientific investigation or maritime culture.

In other countries, such as Portugal, the Navy ensures the functions typically performed by a Blue Water Navy as well as the functions typically attributed to a Coast Guard, allowing efficient use of national resources. Such a Navy makes possible an economy of effort and develops important synergies, by sharing knowledge, resources and capabilities.

The operational performance of this dual-role Navy makes its capabilities available to carry out projects in partnership with national enterprises like the various IT and engineering projects carried out with EDISOFT. In particular, for this project the Portuguese Navy will be integrated in the consortium through a group of officers from several sectors, aggregating the knowledge required to establish the requirements needed for the final user. This effort will include the definition of the scenarios based on the lessons learned and available NATO doctrine and procedures compliance, and trends of HP. The Portuguese navy will support all trial and validations required to provide NATO with a high quality deliverable.

EDISOFT, a private company, is the leader of the SAFE-PORT consortium. EDISOFT has experience in managing and developing medium and large-scale Defence and Security projects, including participating and coordinating national and European collaborative R&D projects with a strong emphasis in innovation and technology, with well-defined objectives and outputs. EDISOFT expertise will also be used for the development of the software components related with human interface, IT infrastructures (databases and data models), space segment and simulation environment.

The research centres will mainly participate in areas where modelling, research and experimentation activities are more intense and require specific scientific background.

The Faculty of Sciences of the University of Lisbon (FCUL) participates through two research centres. FCUL-LOLS (Laboratory of Optics, Lasers and Systems) will deal with the modelling of Electro-Optical and Infrared sensors, given its high competences in conducting R&D activities related to sensor systems, laser and materials processing, and signal and image processing.

FCUL-CIO (Operations Research Center) will deal with the development of optimization algorithms that determine a set of configuration solutions compliant with the established criteria. It has competences in the field of O.R., including the relevant areas of combinatorial/discrete optimization; multicriteria decision analysis and decision support systems; neural computation, forecasting, and risk analysis. This Center will be responsible for the scientific coordination of the project, since it deals with the decision support functions, which are seen as the most critical component in SAFE-PORT.

The Underwater Systems and Technologies Laboratory (LSTS), of the Faculty of Engineering at Porto University (FEUP), will deal with aspects related with underwater sensors (sonars) and autonomous vehicles, comprising both surface and subsurface autonomous vehicles. FEUP-LSTS has extensive R&D and field experience with these types of systems, having their own fleet of surface and subsurface vehicles. These assets will be available for SAFE-PORT field-trials.

The Geophysics Centre of Évora (CGE), within the University of Évora, will deal with climate and sea modelling, given its strong know-how in the areas of Sciences of the Earth, Climate and Environment.

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