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datAcron

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EXECUTIVE SUMMARY

This document describes the experimental evaluation of the datAcron system prototype for the maritime domain, pertaining to the fishing use case and scenarios defined in the datAcron Deliverable D5.1. The datAcron maritime prototype set-up (cf. Deliverable D5.4) and system evaluation (cf. Deliverable D5.5) will follow the methodology and the experimental plan specified in this document.

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ABBREVIATIONS

Acronym	Term
AIS	Automatic Identification System
MSI	Maritime Situational Indicator
WPI	World Port Index
METOC	Meteorology and Oceonography
RMSE	Root Mean Square Error
SSE	Sum of Square Errors
AEE	Average Euclidean Error
GAE	Geometric Average Error
IUU	Illegal, Unreported and Unregulated (fishing)
PMF	Probability Mass Function

1 Introduction

This document describes the evaluation methodology to design the experimental plan for assessing the datAcron functionalities and for validating the datAcron approach in the maritime domain. The datAcron maritime prototype set-up, which will be presented in Deliverable D5.4, and its evaluation, which will be reported in Deliverable D5.5, will rely on the methodology and the experimental plan specified in this document. The assessment and the evaluation design discussed in this document rely on the fishing use case and scenarios defined in the datAcron Deliverable D5.1.

The document refines the preliminary assessment plan specified in Deliverable D5.1 [2] (cf. Sec 3.6), detailing the adopted methodology for testing and validation. In particular, assessment will be an integral step in the development and integration cycle of the datAcron prototype, with datAcron components developed to satisfy project and use case requirements tailored to the maritime domain, and evaluated according to formalised performance criteria. Additional assessment steps are foreseen for all integration phases, up to the evaluation of the datAcron prototype in maritime scenario settings. The assessment will be therefore performed at different stages and levels of the integrated prototype development, depending on the project and the use case objectives.

The goal of the assessment and validation is to evaluate whether and how the integrated datAcron prototype supports the scenarios defined in Deliverable D5.1 for the maritime use case. The six scenarios, which are summarised Figure 1, describe events related to secure and sustainable fishing and maritime security. They will serve as a framework for the experimental set-up of the datAcron prototype. Figure 1 lists the scenarios together with maritime operational objectives and the desired actions for each corresponding scenario.

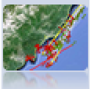
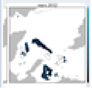
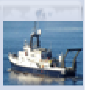
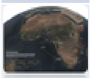
Scenarios			Objective	Actions
Secure Fishing		Collision prevention	Protect fishing vessels from collision with big vessels (cargos, tankers, ferries)	Warn fishing vessels at risk, warn vessels heading to fishing areas
		Vessel in distress / MOB (SAR)	Provide early assistance to a vessel in distress	Warn the closest vessels for early assistance, provide precise location of the vessel for the SAR team
Sustainable development		Protection of ecological areas	Protect specific areas from illegal fishing activities	Send control patrol boat to suspicious vessels location
		Fishing pressure	Estimate and predict fishing pressure, identify areas at risk	No direct action, but could modify the fishing policies on the mid-term
Maritime security		Migrants and human tracking	Detect possible human tracking involving fishing vessels (or the like)	Communicate to security boarder control authorities, provide possible assistance
		Illicit activities	Detect suspicious activities involving fishing vessels	Send control boats for further checking

Figure 1: Scenarios for datAcron Fishing Use Case

The objective of the experimental plan design presented in the document is twofold:

1. *Assessment of datAcron maritime prototype*: on one hand, the maritime experiments aim at assessing whether the maritime set up of the integrated datAcron prototype helps the maritime security operator accomplish the tasks described in the fishing scenarios. The

assessment must test the different functionalities offered by the datAcron prototype, as required by the maritime use case. Project requirements, reminded in Table 1, identify the necessary functionalities of the datAcron system to allow the user accomplishing the missions specified in the fishing scenarios. The functionalities developed within the different work packages and provide the queried information.

2. *Assessment of project requirements and associated functions*: on the other hand, because the maritime use case has been developed to illustrate the project requirements in an operational maritime context, the maritime experiments may also be used to assess project requirements shown in Table 2, where the fishing scenarios map extensively the project requirements, hence evaluation of scenarios is an indirect way to assess project requirements.

   The *Maritime Situational Indicators (MSIs)* defined in Deliverable 5.1 are the semantic bridge between project requirements, work packages, maritime functionalities and scenarios implementation (thus the user). Indeed on the one hand, the project requirements are derived into several functionalities which are connected and get meaning through MSIs. On the other hand, the MSIs express operational needs and are meaningful to the users. For this reason, the maritime experimental plan focuses mainly on MSIs evaluation. Underlying prototype functionalities (under-MSI) are evaluated in the measure they support MSIs.

Table 1: Project requirements

Requirement	Description
R1.1	Real-time integration/interlinking of spatial and/or spatio-temporal entities
R1.2	Interplay of in-situ and stream processing components
R1.3	Integration/interlinking of trajectories and events over stored data
R1.4	Spatio-temporal RDF querying of integrated data
R1.5	Retrieval of spatio-temporally constrained subsets of integrated data
R2.1	Computation of trajectory similarity and clustering
R2.2	Pattern discovery
R2.3	Prediction of trajectories and locations
R2.4	Computation of surveillance data synopses, reconstruction of trajectories by data synopses
R3.1	Event detection and forecasting in the maritime domain
R4.1	Visual Analytics Requirements for the integrated datAcron system

Table 2: How fishing scenarios match project requirements

Scenario	R1.1	R1.2	R1.3	R1.4	R1.5	R2.1	R2.2	R2.3	R2.4	R3.1	R4.1
SC11 Collision avoidance	X	X	X	X	X		X	X	X	X	X
SC12 Vessel in distress, Man overboard	X	X	X	X	X	X	X	X	X	X	X
SC21 Protection of ecological areas	X	X	X	X	X		X	X	X	X	X
SC22 Fishing pressure	X	X	X	X	X	X	X	X	X	X	X
SC31 Migrants/refugees and human trafficking	X	X	X	X	X	X	X	X	X	X	X
SC32 Illicit activities	X	X	X	X	X	X	X	X	X	X	X

The document is organised as follows: The experimental plan design presented in Section 2 relies on the project requirements as formalised in Deliverable D1.1 to define a first layer of testing hypotheses, and more specifically the basic functionalities to be provided by the integrated datAcron prototype. First, a collaborative approach to the maritime prototype assessment much inline with the work package structure of the project is proposed. Second, the assessment of the datAcron functionalities is described. The harmonised set of performance criteria that will be applied for evaluation is defined in Section 2.4.

Section 3 is dedicated to the description of the data to be used for the evaluation. We propose a multi-scale assessment (Brest area versus Europe with focus on the Mediterranean sea) for different foci in big data dimensions. The Brest dataset being representative of a strict controlled fishing area provides some reference information that can then be degraded to challenge the algorithms. This section also details the big-data dimensions and sub-dimensions to be made varying in the different experiments in order to stress how the datAcron prototype answers the big data challenges. Finally, an approach for generating pseudo-synthetic events for assessment is introduced. These events would be then injected into real datasets for testing the efficiency of the datAcron prototype, providing some ground truth when real events are not available.

Finally, Section 4 presents examples of experiments to assess the datAcron system in the maritime domain at different semantic levels of evaluation, depending they are developed and validated within each work package in isolation, or contextualised to the maritime use case to satisfy the operational needs of the six scenarios. Examples of experiments presented in Section 4 include functions to test, input and output data, performance criteria, data and algorithm parameter variations.

The experiments presented in this documents refer mainly to assessment of functionalities necessary to evaluate the datAcron prototype in the fishing scenarios that will be demonstrated at the project review at M18, specifically: *SC11 Collision avoidance*, *SC21 Protection of areas from fishing*, and *SC22 Fishing pressure on areas*. Novel experiments will be introduced along the project, according to the methodology described in this document. The final evaluation of the datAcron prototype and approach for the maritime domain will be presented in Deliverable 5.5 - Maritime final validation report.

2 Design methodology for the experimental plan

In this section we describe the experimental evaluation methodology for assessing the datAcron prototype in the maritime domain. We propose an holistic approach to assessment, integrating validation steps in the design and development of each software component and in components integration. To facilitate the collaborative development, keeping some autonomy for the different teams in datAcron while ensuring the efficient integration of the datAcron prototype to meet the operational objectives, we propose to develop the experimental plan along the following centrepieces, as illustrated in Figure 2:

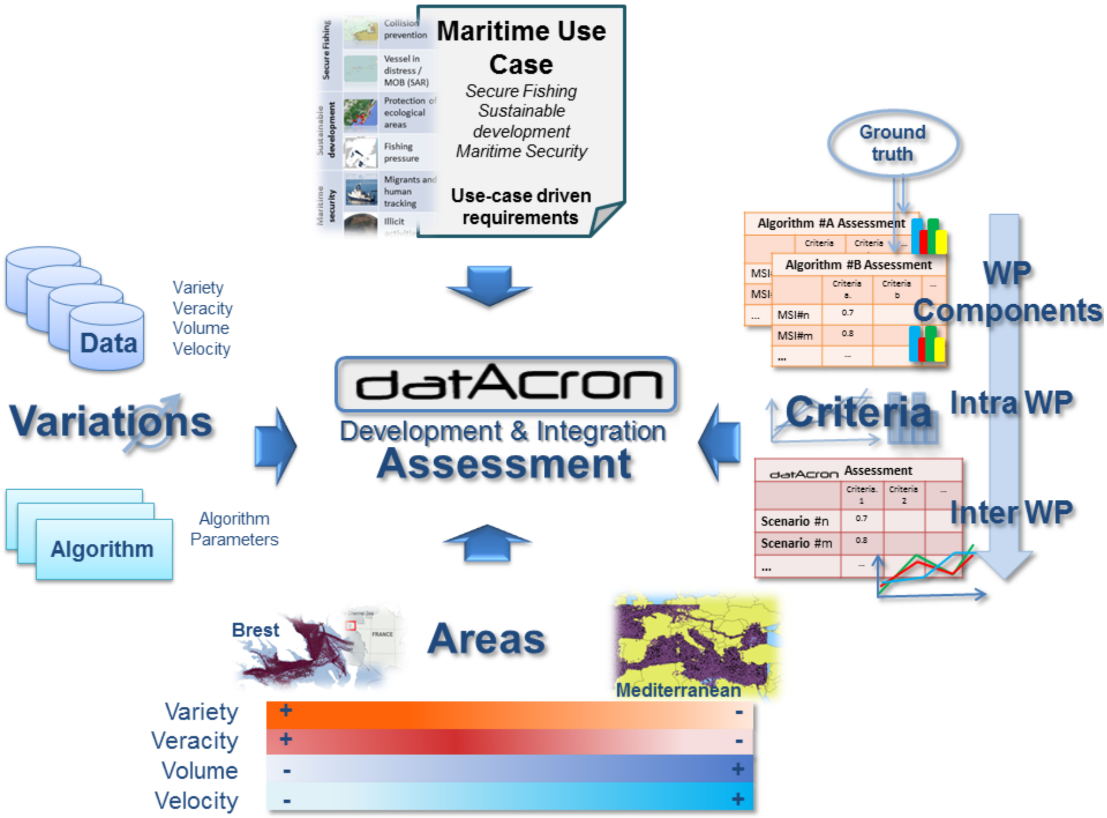


Figure 2: Maritime datAcron prototype assessment

1. A scenario-driven evaluation, to ensure that the maritime domain benefits from the datAcron outcomes;
2. Three interconnected stages for collaborative development, integration and assessment, to facilitate the inter-team cooperation;
3. Three functional semantic levels for assessment, enabling an incremental integration of the application context;
4. A data-driven approach emphasised by two spatial contexts, to address different big data dimensions foci.

The soundness of the datAcron system prototype will be evaluated within the scope of the fishing use case described in Deliverable D5.1. This scenario-based experimental methodology emphasises the role of operators and analysts. The approach to user evaluation is presented in Section 2.1. Moreover, as introduced in Deliverable D5.1, the functionalities of the maritime prototype will be evaluated against operator driven quality criteria, including the performance criteria derived for the evaluation of the *recognised maritime picture* (i.e., *completeness, accuracy, clarity, timeliness, continuity*). Additional technical criteria assessing the performance gain in the use of resources are also included. In particular, we integrated in this maritime experimental plan the performance criteria defined in Deliverable D1.1 [1], where project requirements and corresponding functionalities are defined. Moreover, prototype functionalities will be evaluated also in terms of *usability* [6] and human factor criteria. The harmonised criteria that will be used for maritime experiments are presented in Section 2.4.

Assessment should be an integral part of development, in a continuous cycle validating each development and integration stage. In order to enable the collaborative development of the datAcron prototype, in Section 2.2, we propose a multi-stage assessment approach, distinguishing assessment of independent developments inside each Work Package, of intra-Work-Package integration components and of inter-Work Package integrations.

Moreover, the assessment of the datAcron functionalities for the maritime use case will be at multiple semantic levels. Three semantic levels are proposed in Section 2.3, starting from prototype functionalities, which give the first basic level of functions to evaluate. The results of the evaluation of these functionalities will be discussed and reported in the deliverables of the Work Packages where such functionalities will be developed. The experiments for their evaluation in the maritime domain will adopt the approach specified in the experimentation plan described in this document. Functionalities for scenarios implementation, expressed by MSIs as introduced in Deliverable D5.1, represent the second level of evaluation. Finally, closer to the user, we have scenario settings, where the prototype needs to be evaluated for its ability to support the user in accomplishing secure fishing, environmental monitoring and maritime security missions.

The robustness of the big-data algorithms at the core of the datAcron approach will be assessed for for their ability to cope with the big-data dimensions of *volume*, *velocity*, *variety*, and *veracity*, by introducing controlled degradation schemes of the input datasets, applied at all levels of assessment together with variations of the algorithm parameters. Data preparation for assessment is presented in Section 3, where possible approaches for the development of synthetic events to be used for assessment are also discussed. Being the scope and the interest of the datAcron project the processing and the analysis of big-volume and high-speed datasets, the automatic creation of synthetic data set for datAcron evaluation is not feasible. However, as we will discuss in the section, a *limited* number of pseudo-synthetic events may be created for compensating the lack of ground truth in specific areas and periods of interest. Each development team in datAcron will be responsible of the creation of synthetic data for the evaluation of their algorithms, and the guidelines and the approach presented in Section 3.3 given in this document may be applied.

Finally, the section concludes with a proposal of schedule for assessment, to be revised by the consortium at the M12 datAcron meeting.

2.1 User evaluation

The assessment of datAcron in the maritime domain will be user-centred, and different types of user evaluations are considered in for the evaluation of the prototype. Formative testing should be run involving the users in the development cycle in order to identify and fix issues at an earlier stage, making the developers aware of insight of user evaluation. Furthermore, summative testing will be run to validate whether the prototype satisfies the maritime use case and the project requirements, validating the final development.

Usability testing is required at the scenario level and it will include experts review of the prototype design and development. A focus group evaluation in a simulated operational setting reproducing the situations described in the scenarios will be tentatively organised, in order to assess qualitatively the experience of the user in typical working situations. Domain experts, including maritime surveillance operators and specialists with experience in the maritime use case scenarios will be tentatively involved in the experimental evaluation. Questionnaires and semi-structured interviews in a game structure might be organised to collect the data necessary to usability testing and evaluation. Similar data collection tools could be used for evaluating operational criteria. Additional data for quantitative performance criteria (such as processing time) will be collected automatically. The results of the evaluation will be disseminated in Deliverable D5.5.

User evaluation will be used uniquely for focusing the project development and for project assessment, and the outcomes of the evaluation will be included in project dissemination according to the datAcron dissemination plan. In particular, user evaluation will be shared with the scientific community to maximise the impact of the project results. No issues regarding confidentiality of evaluation or on user personal information are foreseen at the moment. In case ethical issues arise, they will be discussed in detail in the Ethics Management Plan that will be presented in Deliverable D8.5.

2.2 Development, integration and assessment stages

The development and assessment of the datAcron prototype are organised in three interconnected stages that will occur in parallel for most of the project, realising a continuous development, integration and assessment cycle as graphically represented in Figure 3. This development, integration and assessment cycle will continue until the final setting and delivery of the maritime datAcron prototype.

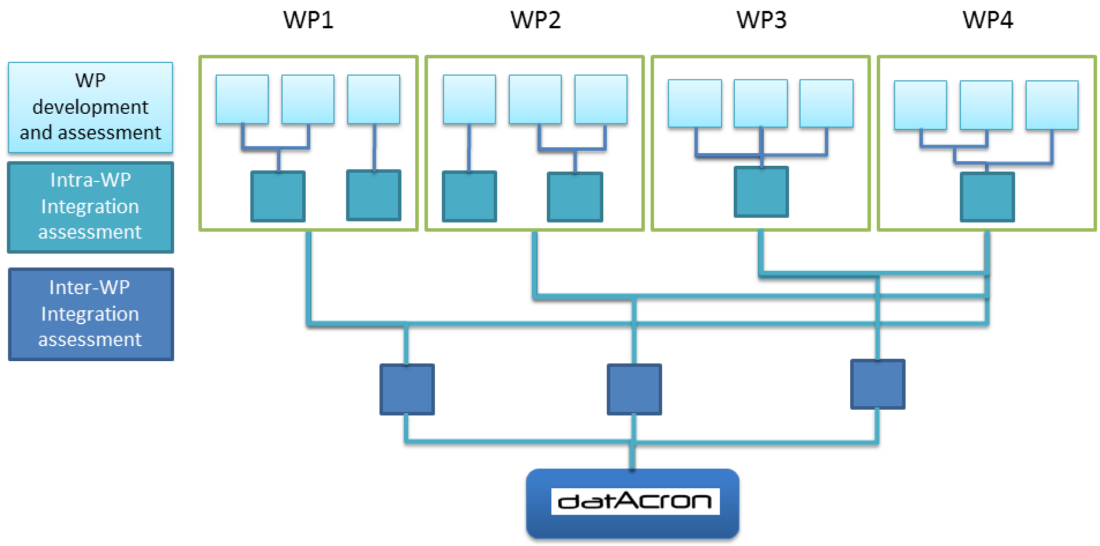


Figure 3: Development, integration and assessment stages of datAcron prototype implementation

2.2.1 Work Package development and assessment

At this stage, elementary algorithms and functionalities are developed. The development of these software components has been initiated inside each Work Package (WP) since the early stages of the project. Their formative assessment will take place during the whole development of the project, with the intention to improve their effectiveness for the maritime use case.

2.2.2 Intra-WP integration and assessment

In order to realise an integrated prototype, integration steps at the WP level (intra-WP) and inter-WP are required. Such integration will be incremental, where each step needs to be assessed against scenario and user requirements. In particular, the WP component once assessed, is to be integrated at the WP level, after which the integration itself is assessed to verify whether the requirements are satisfied and whether the user-driven functionalities necessary to accomplish the missions defined in the scenarios (typically, MSI detection and forecast) are also implemented. Integration at WP-level will be complemented with visualisation and interaction functionalities supporting the analyst in algorithm tuning.

2.2.3 Inter-WP integration and assessment

WP-level integrated components will be combined with other functionalities developed in other WPs. Specific summative assessment is required to evaluate the final integration.

2.3 Semantic levels of functionalities

The maritime datAcron experiments will evaluate the datAcron prototype according to the performance criteria described in Section 2.4 attaining multiple, refined, assessment levels, or scopes.

2.3.1 Assessment of under-MSI functionalities

A first level of experiments addresses the basic functionalities of the prototype derived directly from project requirements when these are specified in the maritime domain context, i.e., when functions are applied to maritime datasets. These functionalities cannot be mapped directly to events of interest for the maritime surveillance operators, i.e., MSI, but are necessary building blocks for the discovery of those events. These *under-MSI* functionalities include for instance data management functionalities, such as the search of and access to stored maritime data, the creation of vessel trajectory synopses, and the generation of vessel routes.

Technical criteria are mainly of interest for the evaluation of *under-MSI* functionalities. For instance, the time necessary to answer a semantic query and the compression rate of a trajectory synopsis may be used to measure the *efficiency* of the corresponding algorithms and tools. However, also quality criteria may be used for these functionalities. For instance, the precision of the generated routes for a given area in a specified season may be used to evaluate the *quality* of the route extraction algorithm. Figures 4 illustrates this *under-MSI* level of assessment.

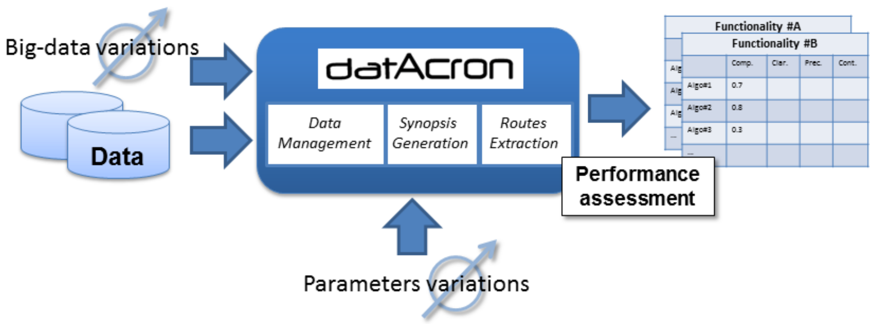


Figure 4: Assessment of under-MSI functionalities

2.3.2 Assessment of MSIs

The second level of assessment corresponds to the evaluation of the algorithms and the tools implementing the detection and the prediction of MSIs. These may include higher level data management functions as well as event detection and prediction algorithms developed in WP2 and WP3. At this *MSI-level* of assessment, technical and operator-driven quality criteria may be used to evaluate and choose the best algorithm among those implementing the same MSI, as illustrated in Figure 5. At this level, usability may be considered among the assessment criteria in particular if the corresponding functionality is interactive or visualisation is involved. Otherwise, the effectiveness and the efficiency of the algorithms may be assessed by technical and quality criteria.

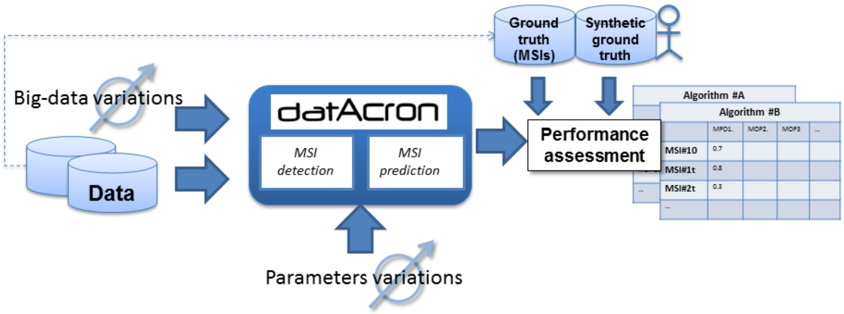


Figure 5: MSI-level assessment

2.3.3 Assessment of fishing scenarios

At the last level of assessment the system is used by the operator to accomplish a mission as described in one of the scenario. The *scenario-level* assessment aims to identify the best mission solving configuration (Figure 6). In particular, at this level usability must be assessed together with technical and quality criteria.

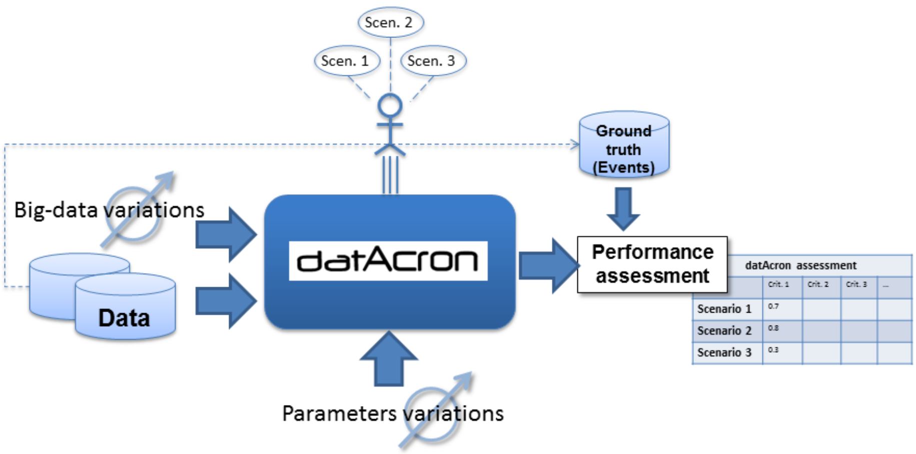


Figure 6: Scenario-level Assessment

2.4 Performance criteria for evaluation

Several performance criteria must be considered when assessing and validating the effectiveness of the datAcron approach in the maritime use case.

A preliminary set of performance criteria was defined in Deliverable D5.1 for MSI assessment, refining the fusion and tracking criteria for the quality evaluation of the maritime picture. Here, we extend that preliminary list including all the performance criteria and measures defined in Deliverable D1.1 for project requirements evaluation. The resulting list was further refined by each WP independently, and enriched with criteria for usability evaluation.

The list of performance criteria presented herein includes quantitative and qualitative criteria. We further distinguish the criteria in three different categories:

1) technical criteria, assessing quantitatively the efficiency of algorithms in terms of resource consumption (time, space, etc);

2) quality criteria, to assess the quality of the algorithms, that may include quantitative and qualitative measures depending on the scope of the assessment; and

3) usability evaluation criteria, to evaluate the usability of the prototype.

Some of the criteria in these categories may have overlapping or closely related definition. In particular, quality criteria may be expressed in terms of technical criteria or combination of them to assess the quality of use case related functionalities and scenarios. Similarly, usability criteria may sometime be expressed in terms of quality or technical criteria when evaluating a scenario or the usability of a domain driven functionality. Some criteria may also be evaluated with different measures, depending on the assessment stage and level of the experiment. For instance quality criteria may be "instantiated" differently when used to evaluate MSI detection algorithms or when applied in scenario assessment. Also, some criteria can be assessed in co-relation. For instance, the prediction accuracy may be relaxed to improve the compression ratio of synopses generation algorithm. Moreover, the quality of the data exploited may affect the effectiveness of the patterns learnt by the pattern detection algorithms. The different categories of performance criteria are defined in the rest of the section, including also examples of measures for their evaluation.

2.4.1 Technical criteria

Technical criteria, listed in Table 3, quantitatively assess the efficiency of algorithms and prototype functionalities, expressed in terms of resource consumption. Technical criteria are used for example to evaluate data management functionalities and synopsis generation. Moreover, they can be used also to evaluate use-case driven functionalities, in combination with other performance criteria.

For *Latency*, we refer to the target scale defined in Deliverable D1.1 where three levels of latency are devised: Operational (in milliseconds), Tactical (in few seconds) and Strategic (tens of seconds or minutes).

2.4.2 Quality criteria

Performance criteria for evaluating the quality of an algorithm are introduced in Table 4. Other names used internally to datAcron WPs (as per Deliverable D1.1) are included in the table (column Other names in D1.1). For each criteria the last column, includes examples of measures considering the case of an MSI detection algorithm.

The same criteria may be applied to assess the quality of the prototype when it is used by the operator to accomplish a mission defined for the fishing scenarios. Tailored definitions of the performance criteria defined in Table 4 and examples of measures for scenario evaluation are reported in Table 5.

Table 3: Technical criteria for performance evaluation of datAcron functionalities

Criterion	Definition	Measure
Processing time	Execution time	Time (in seconds, milliseconds) to execute a function
Latency	Response time	Time (in seconds, milliseconds) to output the result of a function
Output (Input) Data Size	Volume of the output (input) data	Size of the output (input) data (in Gigabyte, GB) of a function
Output (Input) Stream Size	Volume of the output (input) stream	Size of the output (input) stream (in Gigabyte per seconds, GB/s) of a function
Output (Input) Data Rate	Size of the output (input) data with respect to the input (output) data	Rate of the output (input) data of a function / the input (output) data
Output (Input) Stream Rate	Size of the output (input) stream with respect to the input (output) stream	Rate of the output (input) stream of a function / the input (output) stream
Efficiency of an RDF query	Percentage of accessed data over the total amount of data in the distributed RDF store	Accessed data / total data in the RDF store
Compression ratio	Reduction in data representation	Percentage of positions dropped from raw trajectories to obtain the approximate trajectory synopsis
Scalability	Capability of a system, network, or process to handle a growing amount of work, or its potential to be enlarged in order to accommodate that growth	Growth/decrease of the response time, while increasing the volume or the speed of data in input / increasing the number of physical processing nodes
(Approximation) Quality	Information of approximated representation	Average and Maximum Root Mean Square error among the original representation of a trajectory and its approximation (synopsis)

2.4.3 Usability and Visualization criteria

In Table 6, criteria to assess the usability of an interactive functionality or the full software prototype are presented. As in [6], usability is defined in terms of *effectiveness*, *efficiency* and *user satisfaction*, as defined in the table. According to this definition, effectiveness is closely related to *accuracy* quality criterion defined in Section 2.4.2. Satisfaction is measured qualitatively, with focused questions to the users with scaled answers. For instance, for the assessment of the *user satisfaction* of the integrated prototype:

- Is the user greatly satisfied / moderately satisfied / indifferent / not satisfied by the answers? (Alternative formulation: Evaluate satisfaction while using the system, from 5 to 1 where 5 is greatly satisfied and 1 is unsatisfied)
- Does the system greatly improve / moderately improve / not improve / worsen user productivity?
- Is the system straightforward to use / moderately difficult to use / very difficult to use / impossible to use?
- Would the user greatly recommend / moderately recommend / not recommend / discourage the use of the system to colleagues?

Usability criteria may be used to evaluate also the quality of the visualization and the interactive capabilities of the systems. In particular, *Effectiveness* evaluates if the visualisation shows correctly the information the user needs. In addition, *Expressiveness* of visualization evaluates if the relevant information is shown to the user.

Table 4: Quality criteria for algorithm assessment

Criterion	Definition	Other names in D1.1	Example of Measure	Example of Measure for MSI detection
Completeness	Degree to which data are processed by an algorithm	Coverage	(Size of) processed data over the input data	Number of contacts (or number of trajectories or synopses) processed to detect an MSI
Accuracy	Degree to which the algorithm output agrees with ground truth (Needs ground truth)	Correctness, Coverage, Completeness, Approximation quality (cf.)	True positive rate (alt., False positive rate). F1 Score (F-score, F-measure). Root Mean Square Error (RMSE). Sum of Square Errors (SSE). Average Euclidean Error (AEE). Geometric Average Error (GAE). Empirical Error Probability Mass Function. Error histogram. Intra-cluster and Inter-cluster similarity	True positive rate of the MSI against the corresponding true value
Clarity	Degree of confidence to which the algorithm output is provided		Probability value before the execution of the algorithm	
Continuity	Degree to which the algorithm output is maintained in time	Latency, Scalability	Function of latency of output with respect to (real-time) data input	Latency over time, Ratio of processed data over time
Timeliness	Time to provide the algorithm output	Time, Response time, Latency	cf. Latency	Time to provide the detection result for an MSI

Table 5: Quality criteria for scenario assessment

Criterion	Definition	Example of measure
Completeness	Degree to which data necessary to accomplish the mission are processed	Number of processed contacts (alt., trajectories, synopses) over the ones crossing the area under surveillance
Accuracy	Degree to which the system captures the relevant MSIs for the mission	True positive rate (alt. False positive rate) of the detected (forecasted) MSIs in the area under surveillance
Clarity	Degree of confidence on the support the system provides to the operator for the mission	Probability value before decision, on the detected or forecasted MSIs
Continuity	Degree to which the system supports the operator over time during a mission	Function of latency of detected (forecasted) MSIs in the area under surveillance
Timeliness	Degree to which MSIs detection and forecasting is provided to the user, over the user requirements	Latency of detected (forecasted) MSIs in the area under surveillance

Table 6: Usability Criteria for the evaluation of functions and scenarios

Criterion	Definition	Examples of measure
Effectiveness	Degree to which a user is able to fulfill the task and achieve the goals	Number of tasks completed successfully (e.g., number of detected events in a scenario, number of missions accomplished) / Number of users able to complete the task)/ Number of errors made while doing the task (e.g., missed events in a scenario / False rate)
Efficiency	Degree to which a user needs to invest effort on the system to accomplish the task	Time spent to learn how to use the application / Difference in the time spent to perform the task with and without the system
Expressiveness	Degree to which the user see the relevant information for accomplishing the task	Relevant information / complete information (e.g., relevant alerts / alerts)
Satisfaction	Degree to which the user is satisfied by working with the system	Number of users satisfied (e.g., greatly satisfied/moderately satisfied/not satisfied) by the system/answers (more/less than alternative methods)

2.5 Sketch of schedule for experimental evaluation

Figure 7 is a proposal for the schedule to be followed for the experimental plan, implementing the three considerations introduced above and as they align with the project schedule, drawing the path to the demonstration at M18, to be validated by the consortium members at the M12 meeting.

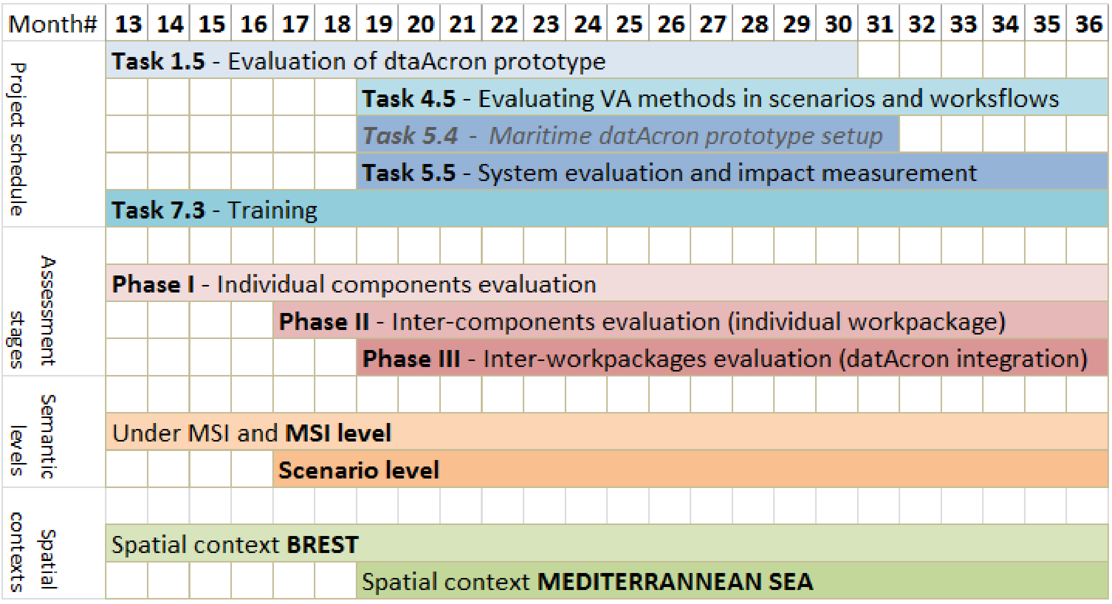


Figure 7: Proposed schedule for the datAcron experimental plan

The next 4 months (from M13 to M16) will focus on processing data from Brest area and assessing individually developed components. Interactions between components will be experimented, and some interaction between the different work packages will be implemented. Three scenarios will be considered for the integration, specifically the ones that will be demonstrated at M18 project review: *SC11 Collision avoidance*, *SC21 Protection of areas from fishing*, and *SC22 Fishing pressure on areas*.

3 Data preparation

In Deliverable D5.1 and further in Deliverable D5.2 [3], a potential list of datasets supporting the fishing use case and scenarios have been identified. Sources examples are provided as well, but both lists are not exhaustive, and not all datasets are mandatory for the assessment of the prototype.

All scenarios need at least one source of surveillance data, for which vessel positions may be extrapolated. AIS data have been selected as the main data source for generating the maritime moving objects trajectories (synopses) that will be analysed by the algorithms developed by WP2, WP3 and WP4. These surveillance data will be based on both AIS terrestrial and satellite messages. Experimentation can be carried out on two internal sources from project partners: a training dataset with historic data on a limited but well-known area and a stream dataset at the European scale.

Other type of data, such as port information, nautical charts, navigation rules, protected areas, are useful to identify vessel behaviour of interest, such as deviation from pre-defined scheme of navigation, but in lack of ground truth, such information may be inferred from historical data analysis, such as *Patterns-of-Life* analysis [8]. Other information sources such as vessel register, lists of black listed vessels, may be useful as well. When available, fishing and vessel facts may provide a source of ground truth for event detection algorithms. Similarly, environmental data on ocean and weather conditions may complement observations from data. Ocean and weather forecasts may be a valuable source of information for vessel trajectory prediction.

The data used by datAcron for the development and the validation of the maritime prototype will be incrementally acquired along the course of the project and stored in the datAcron data management infrastructure. In the early stages of development and testing, data may be partially available, or be available at a coarser resolution. To overcome this problem, the training dataset is created, as discussed in Section 3.1.

3.1 Multiple spatial contexts for multi-scale assessment

To support the integrated approach of development, integration and testing described above, beside the project dataset covering the area of the whole Mediterranean and part of the Atlantic and the north of Europe seas, datAcron will make use of a dataset prepared for a smaller *training* area, that will be used especially for testing and validation. A training area is a region where datAcron can have a more accurate knowledge of ships' movement and ground truth support. It should contain an active fishing area. Additional contextual information (cartography, regulated areas, known fishing fleet...) has to be available. Knowledge on local fisheries and connections with operational entities (e.g., control centre, local committee of fishery, port authorities, navy) are also necessary to establish ground truth. This is essential for initial experimentations and validation of algorithms before application at a European scale where such information are more difficult, possibly impossible to obtain.

Figure 8 illustrates this methodology of experiments based on two datasets having different characteristics, in particular with respect to the different big-data dimensions.

The western part of France, around Brest city has been identified as a good training area that fulfils most of the aforementioned constraints. Moreover, the Brest bay itself has local regulations which enforce fishing vessels to use AIS permanently. Moreover multiple information sources among the ones mentioned above are more easily available, aligned in space and time and with the resolution required for the analysis.

At a larger scale, European seas have been retained with a specific interest for the Mediterranean, which is large and semi-closed with clear entrance / exit zones (Gibraltar, Bosphoru

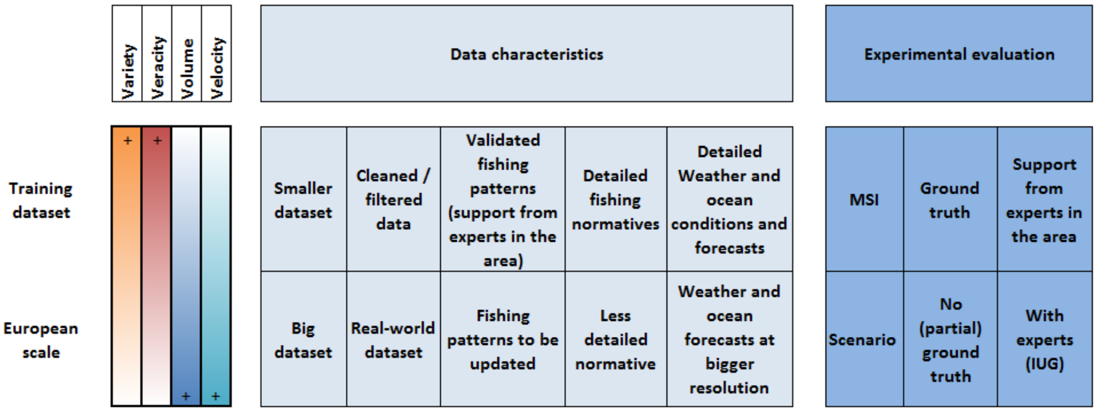


Figure 8: Multi-scale assessment: comparing the training and European datasets

/ Dardanelles, Suez) that can provides meaningful information especially for maritime security scenarios. It also contains well-known fishing activities all around coasts and fishing restriction areas. Many fishing areas, typically in the South of Sicily Island (Figure 9), intersect maritime routes.

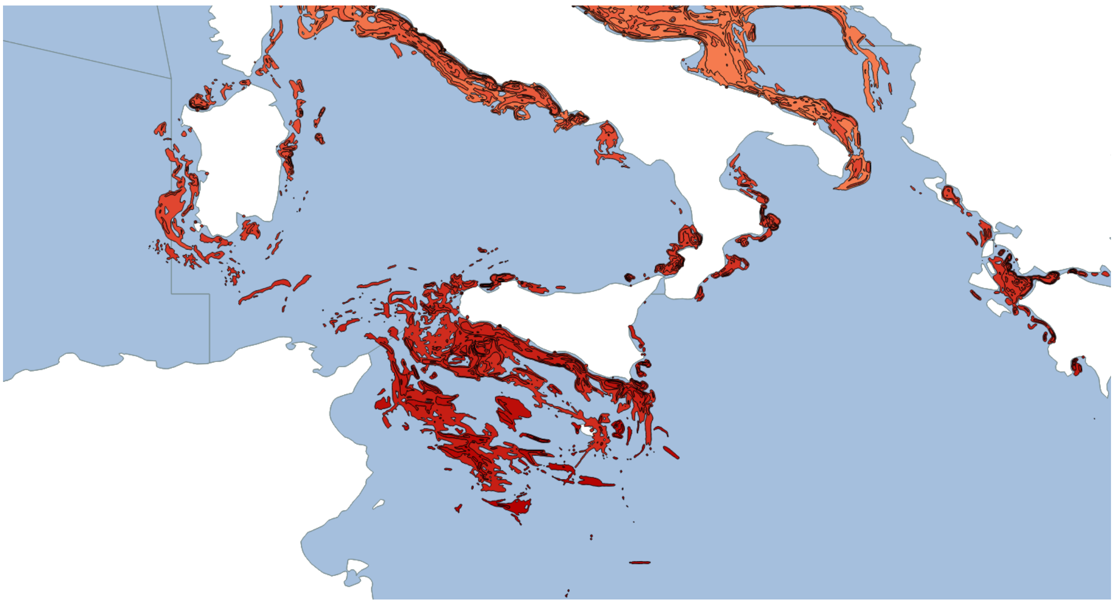


Figure 9: Fishing intensity in the South of Sicily

Zooming the tests from the Brest area to the European seas will enable to evaluate the scalability of the datAcron algorithms, in particular in terms of the *volume* of data, both for historical data analysis and for real-time analysis (i.e., data-at-rest and data-in-motion, respectively). The larger dataset may be controlled to evaluate the prototype performance and robustness to *volume* and *velocity* of data, by varying the size of the dataset and the speed of the data flow in input to the prototype, and observing the impact on the timeliness and the continuity of the algorithms. Specifically, possible variations of data *volume*, both in the real-time and data-at-rest case, are variations of:

- the number of contacts in input;
- the number of trajectories or trajectory synopses in input;

- the temporal span of the analysis (of data-at-rest);
- the temporal resolution of the input datasets;
- the area of interest of for the surveillance task;
- the spatial resolution of the input datasets.

Keeping the pace of the *velocity* of the data stream is important in particular for real-time analysis. Possible variations consider:

- the time stamps of the contacts, which is equivalent to reducing the number of contacts;
- the spatial and temporal resolution of the data;
- the spatio-temporal scope of the analysis.

The *variety* of the data may be controlled by modifying the information sources selected to feed the algorithms, for instance:

- Use of different sources for surveillance data, integrating collaborative and non-collaborative sources or using different providers of collaborative sources;
- Use different types of information sources (surveillance, contextual, environmental).

3.2 Data variations

The Brest (training) and the European datasets will be controlled and diversified with respect to *veracity*, *variety*, *volume* and *velocity* dimensions, in order to study the impact of such dimensions on the algorithms outputs and on the prototype performance.

About variety The initial training dataset is intended to be delivered with this current report. It first relies on a set of data files mainly prepared in csv and ESRI Shapefiles. The training dataset includes in particular surveillance data from AIS messages in the area of Brest and beyond (see Figure 10). It includes partial redundancy (one full month out of six) from two different sources.

Contextual information contains few fishing and vessels facts and blacklist, that will be used as ground truth information for event detection algorithms; detailed navigation and fishing rules for the area; fishing intensity, weather condition, seasonal fishing regulations. It also includes many geographical features such as detailed ports localisation, traffic separation schemes, coastline, regulated areas. Contextual data are considered at different geographical scale; from very local (Brest bay) to European scale. The training dataset will be enriched all along the project.

The European dataset will rely on a continuous stream of AIS data. The stream will use JSON formatting for AIS messages. Each AIS message is tagged with a flag field that can be used to determine the accuracy of the data being used for further processing (data format is detailed in Deliverable 5.2). Contextual information will be partly shared with the ones provided for the training dataset as some data have been obtained at the European, worldwide level.

About veracity AIS data have an intrinsic uncertainty. Sources themselves lack quality. For instance, a terrestrial receiver may not cover uniformly an area under surveillance, depending on its geographical position; they may be unreliable, incomplete, intentionally manipulated, imprecise, uncertain, etc., this resulting in providing information that suffers from equivalent drawbacks. The errors, mostly unintentional, sometimes spoofed, can be caused by transponder deficiency, a wrong input of manual data, an input of manual data of poor quality, erroneous

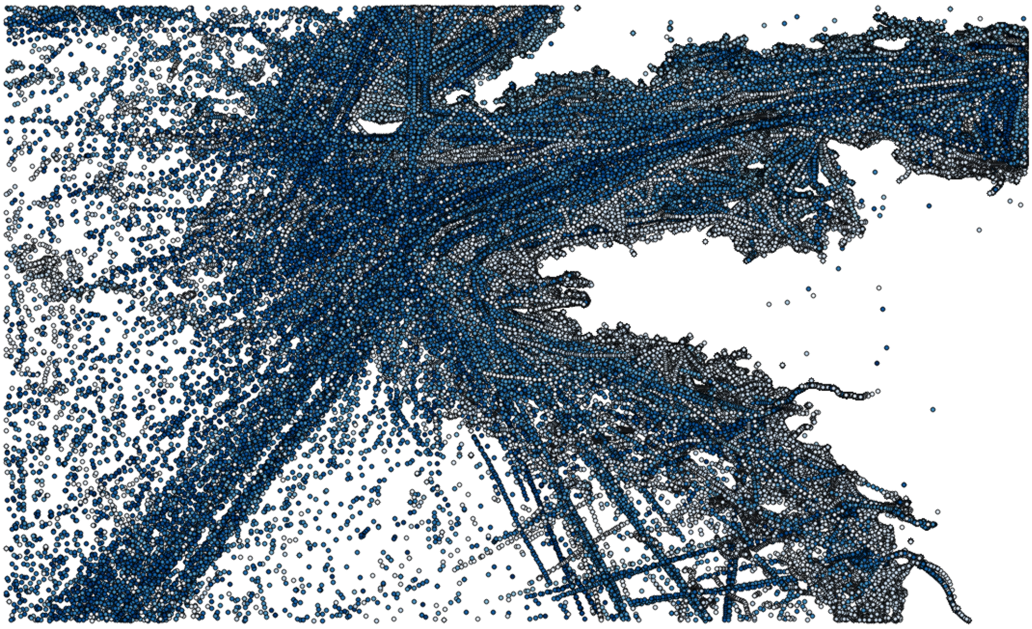


Figure 10: AIS coverage and containt of the training dataset

pieces of information that come from external sensors, and can have an impact on the name of the vessel, its physical characteristics, the position or the destination for instance. Figure 11 illustrates intermittent reporting of positions while fishing. Those pieces of information can then be false, incomplete, impossible according to the norm or impossible according to the physics. According to [9], circa 50% of the messages contain erroneous data. For instance, in our dataset 44.3% of ships provide no heading value. AIS messages (kinematic and static information) will be provided as received. Only unparsed messages are discarded. For the training dataset, this represents 1.36% of the overall received messages.

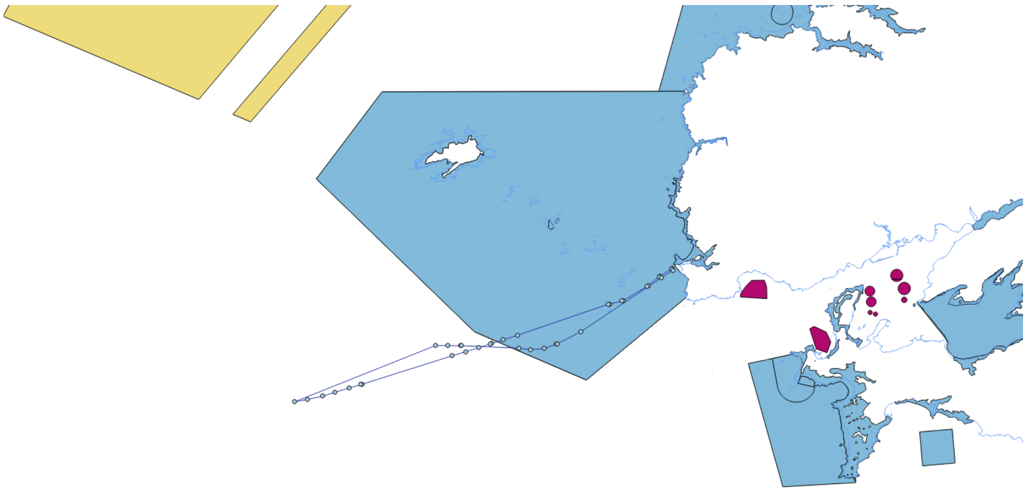


Figure 11: Intermittent position reports of a fishing vessel crossing a Natura 2000 area (http://www.eea.europa.eu/data-and-maps/data/natura-7), in blue background

For the Brest area ground truth information is available thanks to larger variety of data but also thanks to local organisations (control centre, local committee of fishery, port authorities, navy) that collect and share accurate and complete information also on vessel facts. Therefore this dataset will be controlled along the project in particular to assess the robustness of event detection and prediction algorithms to data *veracity*, and validate the robustness of algorithms in terms of accuracy. At a larger level, historical surveillance data from the European coast may be used as ground truth information for the validation of trajectory prediction algorithms.

Geographical features (e.g., world seas, traffic separation schemes, regulated areas, ...) of the datasets are provided by official partners (e.g., IHO[1], SHOM[2], Aires Marines[3], ...) and verified in order to confirm an intrinsic resolution compliant with datAcron objectives.

About volume and velocity Terrestrial and satellite AIS data provided define the core datAcron dataset and thus the main matter on which volume and velocity applies. Automatic Identification System communicates 27 different messages (kinematic and static information, aid to navigation, safety, timing, control). The datAcron datasets focus on a specific subset of all messages.

Localisation messages emitted from moving objects which are sent on a regular basis are all considered: ITU 1-2-3 (class A shipborne mobile equipment), ITU 9 (airborne stations), ITU 18-19 (standard position report for Class B shipborne), ITU 21 (position and status report for aids-to-navigation). These messages represent the largest part of AIS data and typically account for circa 90% of the total message number. Kinematic messages includes information on position (latitude and longitude), speed over ground (SOG), heading, course over ground (COG), Rate of Turn (ROT).

Secondly, static messages providing ship meta-information are selected: ITU 5 and ITU 24. They provide meaningful information such as ship identifiers (MMSI and IMO number), name, type, and dimension of vessel, and the voyage-related information, such as destination (port of call), danger, Estimated Time of Arrival (ETA), draught. In the training dataset, these messages account for 4.6% of the total message number received.

Two sources of AIS data are considered for the project. A first one provided by NARI is dedicated to the training dataset within a limited time period (six month). A second one provided by IMISG covers main European coasts. A one-month data sample of training area is used for redundancy and extended coverage (mix several sources[4]). Figure 12 illustrates the relation between these areas and the overall coverage of data sources (bounding boxes are [-10,45], [0,51] vs [-12,30], [37,52]).

The AIS data provided by IMISG for the datAcron project has been sourced from a range of terrestrial and satellite AIS sources. While terrestrial data arrives in an almost continuous stream, the satellite AIS data arrives in bursts as the satellite downloads the data to a ground station. This can somewhat lead to fluctuating velocity. The AIS data provided by NARI has been sourced from one terrestrial receiver located in front of the Brest bay entrance. The velocity in this dataset is more affected by the number of ships in coverage each day (ranging from 12 to 266, with an average of 53 distinct ships per day over a six months period). Figure 13 summarizes the main characteristics of the training dataset.

At the European scale, the main data source will be the IMISG data stream. As mentioned in Deliverable D5.2, additional public data sources could be used in order to provide redundancy or complementary information. The data sample contains messages (ITU123, ITU5, ITU9, ITU18, ITU19, ITU21, ITU24) received for larger bounding box in Figure 12 during the month of January 2016. It contains 81,722,110 records including duplicates. This represents an average volume of 1830 messages per minute for 118 003 distinct vessels.

[1] www.iho.int
[2] www.shom.fr
[3] www.aires-marines.fr
[4] Let us note that these multiple sources provide similar messages, duplicates have been removed from IMISG data. This represents 18.4% of the overall amount of received messages

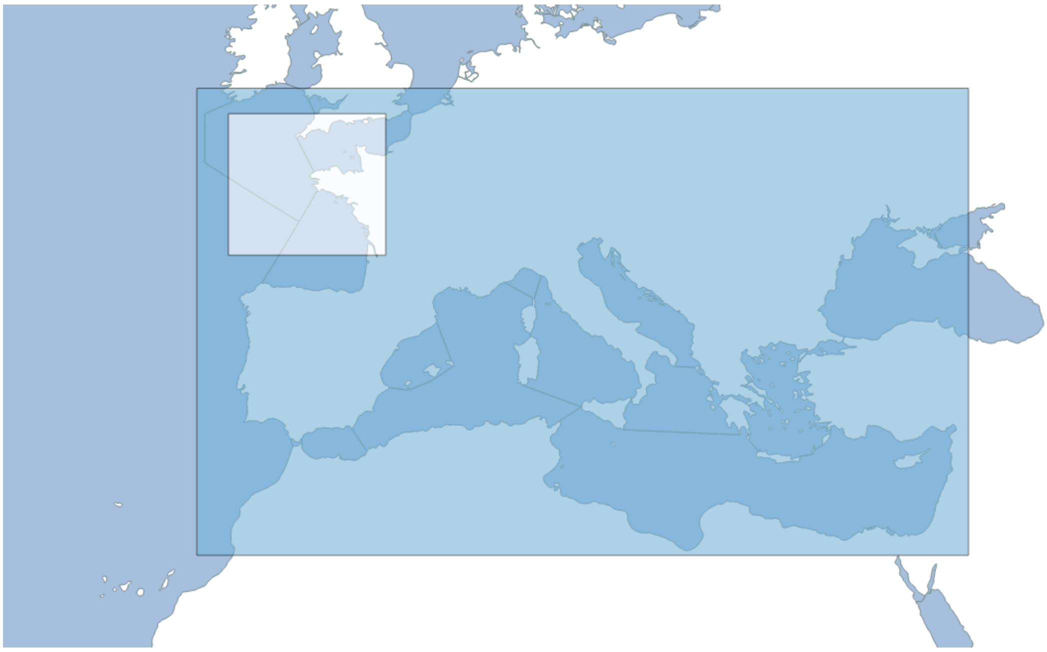


Figure 12: Spatial extents of Brest and European data sources

Training Dataset Characteristics							
NARI				IMISG			
Number of positions	Time period	Number of different ships	Average velocity	Number of positions	Time period	Number of different ships	Average velocity
19,152,196	October 2015 - March 2016 (6 months)	4802	77 messages per minutes	3,779,626	January 2016 (one month)	4799	104 messages per minutes

Figure 13: Main characteristics of the training dataset

3.3 Generation of pseudo-synthetic data for assessment

Ground truth information on vessel events might not be easily available, in particular for large areas under observation, where it is very sparse. The question of how to effectively test the robustness and performance of datAcron algorithms is raised in this context. In order to properly evaluate them, a comparison between a validated dataset with labeled and/or known trajectories, and the result of its treatment by the algorithms, is paramount.

The main issue in evaluating detection algorithms is therefore to compare their results to the reality (based on ground truth information). However, it is mostly unknown in the large volume of AIS messages used for datAcron. It is a hard task to both label carefully a real AIS dataset and meet requirements in terms of volume, variety, velocity and veracity. Datasets to be created for experimental validation might be purely synthetic and automatically generated, based on some motion models, or pseudo-synthetic, by modifying existing real data with a controlled process (Figure 14). In the first case they are more likely biased by the model applied. In the second case, they preserve some characteristics of the original observations they come from, but they cannot be produced massively, because the controlled labelling is done manually.

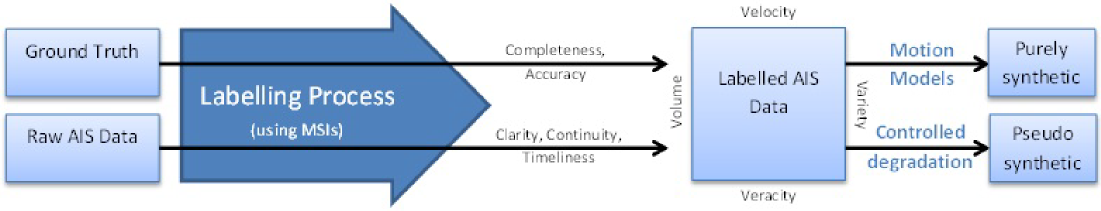


Figure 14: The labeled AIS datasets generating process.

For testing event detection and prediction algorithms at the MSI-level evaluation, the available surveillance data might need to be complemented by generated data exhibiting a typical scenario context/events. The generation of pseudo-synthetic data for assessment can be categorised by three typical alterations of datasets:

- *Kinematic*, which gathers the dynamic aspect of a trajectory: position, speed ... In this way, MSIs might be generated, for example by translating, rotating and reversing the direction of real vessel trajectories, simulating vessel moving in areas interdicted to circulation, or moving towards or inside protected areas, or travelling in the wrong direction, or colliding (cf. Figure 15).
- *Coverage*, which contains all the coverage aspect of the AIS tool: poor emission, poor reception, no voluntary emission (vessel "going dark"), introduce false contacts (e.g., false AIS messages), lack of coverage of sensors, ...
- *Spoofing*, for all the "static" and "dynamic" aspects of a trajectory, typically modifying destination, name, MMSI, ..., deleting fields in surveillance information (vessel type, NPOC, ETA, ...), simulating spoofing and GPS manipulation.

The generation of pseudo-synthetic data focused on AIS data can be accompanied by the alteration of real geographical areas, METOC information and other contextual data. This includes for example the modification of regulated or protected areas in space and time (i.e., moving a polygon, reducing the period for fishing, ...). A modification of a real trajectory to instantiate suspicious behaviours in the maritime security scenario can be accompanied with the addition of the ship in the black/wish list.

Figure 16 synthesizes all the steps from the real initial dataset (based on raw data) to the evaluation of the detection algorithms, through the production of a pseudo-synthetic dataset. Producing only some frozen pseudo-synthetic datasets, will not be sufficient. Generation of pseudo-synthetic data for assessment based on an interface enabling users to freely generate reusable and adaptable AIS pseudo-synthetic data would be beneficial for automation of experimental validation.

Figure 15: AIS data manipulation to simulate a collision between a fishing vessel and a Cargo vessel

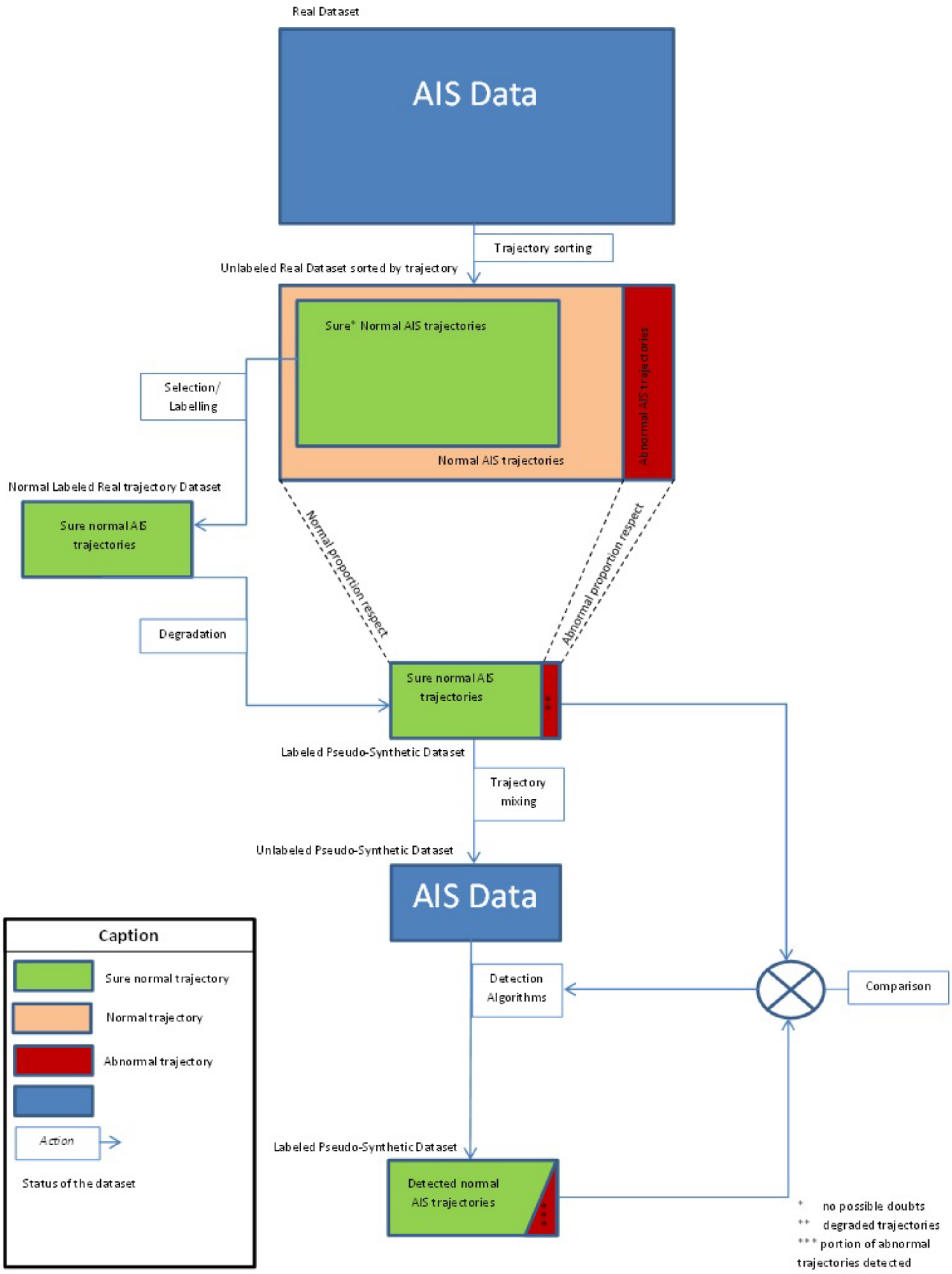


Figure 16: Pseudo-synthetic data production synthetic scheme

4 Maritime Experiments

This section presents an initial list of experiments to evaluate and assess the datAcron integrated prototype in the maritime domain.

We first introduce the experiments to evaluate fishing scenarios, focusing in particular on those that will be demonstrated at M18: *SC11 Collision avoidance*, *SC21Protection of areas from fishing*, and *SC22 Fishing pressure on areas*.

Information needs of maritime operators in the fishing scenarios are specified through MSIs, which are validated via specific experiments as presented in Section 4.3.

Then, example experiments for under-MSI functionalities, useful for the implementation and support to MSI, are presented. The experiments presented here are examples only, to give partners initial guidances on the design of their experiments aiming at evaluating their algorithms and developments in the maritime domain, but it is up to the different partners to design their own experiments in the corresponding WPs.

During the design and execution of the experiments, the experiment template can be adapted as needed. The template used in this document is meant to harmonise the different experiments to connect easily the different components and to enable comparison of the results obtained by algorithms implementing the same functionalities (i.e., the same MSI). The experiments are organised along the different project and scenario requirements, as well as along the semantic levels for assessment, addressing under-MSI functionalities, functions realising MSIs and evaluation of scenarios.

4.1 Experiments for Secure Fishing Scenarios

Experiments described in this section will evaluate how datAcron can concur to secured fishing by supporting the user in detecting and preventing collisions between ships and by optimising *rendez-vous* between rescuing ships in proximity of the vessel in danger and emergency services.

4.1.1 Experiments for Collision Avoidance (SC11)

In the collision avoidance scenario, the aim of the operator is to prevent and avoid a collision involving fishing vessels. The system could also enhance the situational awareness between vessels, anticipating that a vessel will be required to "give way" to a fishing vessel.

Objective - In order to prevent a collision of fishing vessels with other ships, the user wants to predict which other vessels (such as cargos, tankers, ferries) will cross the trajectory or the areas where the fishing vessels are fishing.

Actions - Upon the prevention of possible collisions, the user can send a warning to the fishing vessel and the vessels identified for possible collision so they can take the appropriate action. He will base his decision on the potential risk highlighted by the monitoring system.

Information needed by the user The most important fact in this case is the estimation of emergency. It depends on several criteria, including:

- *Estimated collision time:* How many minutes does the operator have to react?
- *The two ships maneuverability capacities:* If the ships have bad maneuverability capacities, it may be difficult to avoid the collision (for example, an extreme case is a fishing trawler vs. huge tanker).
- *Both ship's identifiers*

The operator detecting collision might take into consideration the size of the vessel, the vessel speed, the estimated fishing activity and the weather and ocean conditions to evaluate the maneuverability capacities of the vessels.

Experiment SC11.1

Validate the prediction of collision events between a fishing vessel and another vessel.

Addressed project requirements

R2.2 Pattern discovery

R2.3 Prediction of trajectories and locations

R3.1 Event detection and forecasting in the maritime domain

R4.1 Visual Analytics Requirements

MSIs supporting the scenario evaluation

The following MSIs detection functions are assumed to be available to the user, to be interactively parametrised by the user through Visual Analytics tools:

[MSI#2] Vessel within a given area

[MSI#3] Vessel on a maritime route

[MSI#4] Proximity of other vessels

[MSI#19] Vessel under way (using engine or sailing)

[MSI#23] Vessel engaged in fishing

[MSI#26] Loitering

[MSI#27] Dead in water, drifting

Functions to test

R2.3.2 Prediction of a vessel position at time T

R3.1.1 Event detection in the maritime domain

R3.1.2 Event forecasting in the maritime domain

Hypothesis to test

The available data together with the set of functions as encoded by the MSIs are sufficient to the user to detect and predict collisions between vessels between a fishing vessel and other ships for different scenario conditions (area, weather, sea state, vessel types, etc.). Suitable (offline) adaptation and fine-tuning of detection and prediction algorithm to these conditions is possible and feasible via Visual Analytics tools interfacing with R2.2, R2.3, and R3.1 (online) components.

Assumptions

The dataset contains potential collision events (known to the experiment designer as ground truth).

Input data

1) AIS stream (real and synthetic data)

2) Weather/ocean data

3) Ships maneuverability capacities (depending on the size, the speed, or on fishing activity)

4) Local geographical constraints (e.g., Traffic Separation Schemes)

Output data

1) Identification of ships (to be) involved in the collision

2) Estimated time of collision or of crossing "security area"

3) Emergency degree. Time of predicted collision

Steps to perform

1) Using a representative data sample of AIS data, interlinked with weather data and, if necessary, enhanced with collisions events involving ïňĄshing vessels, detection and prediction algorithms are interactively parametrized. Algorithm performance evaluation should focus on accuracy and recall. Usability evaluation should focus on functional coverage and feasibility in terms of analytical reasoning and interfacing with underlying algorithms in exploratory data analysis settings (offline setting).

2) Run the collision prediction detection algorithm on the AIS data stream input, interlinked with weather data and, if necessary, enhanced with collisions events involving ïňĄshing vessels (online setting).

3) Perform a usability evaluation of the system, varying algorithm parameters and data, evaluating effectiveness and user satisfaction. Algorithm performance evaluation should focus on real time processing performance. Usability evaluation should focus on effectiveness and expressiveness of visual representations – at least qualitatively in terms of user satisfaction; optionally, analysis of eye tracking data (captured from users operating the system) may additionally provide quantitative assessment of visualisation efficiency [7, 4].

Performance Criteria - Measure - Target

Timeliness - Latency - latency level is operational

Continuity - Latency along time - Latency level is kept along time

Accuracy - Recall and precision, measured against synthetic ground truth - All collision events are detected and no false detection

Clarity (see also expressiveness)- Confidence of the user in the collision prediction - 100%

Usability - Effectiveness All the alerts given by the system were correct, that is the emergency degrees were consistent with the maritime picture, and they were given enough in advance to prevent collisions

Expressiveness - ConïňĄdence of the user in the collision prediction - 100%

Algorithms' parameters variations

The parameters below may be varied either systematically (grid search), or more likely, interactively during offline algorithm training phases.

1) The size of the area around the ïňĄshing vessel. This will increase the number of vessels to consider

2) The size of the "security area" around the ïňĄshing vessels that other ships should not cross

3) The Closest Point of Approach threshold tuning it with the performance of the system

Data variations

Volume: Number of vessels in the area or size of the area

Veracity:

- Lack of coverage (artificially include areas with no AIS coverage);
- Include variable ratio of AIS errors in position (the AIS message sent is not conform to the actual vessels position).

Variety:

- AIS data only
- AIS + ships maneuverability
- AIS + METOC
- AIS + ships maneuverability + METOC
- AIS data only + geographical constraints
- AIS + ships maneuverability + geographical constraints
- AIS + METOC + geographical constraints
- AIS + ships maneuverability + METOC + geographical constraints

4.2 Experiments for Maritime Sustainable Development Scenarios

The experiments described in this section aim to validate how datAcron may support natural resources management, impact assessment and maritime planning estimating the spatial distribution and the intensity of fishing activities, including the illegal ones, and characterising their potential impacts.

4.2.1 Experiments for fighting IUU fishing (SC21)

In this scenario, the operator is controlling fishing in areas at the European level to detect and prevent IUU fishing. The system should be able to support him monitoring ships in real-time, detecting entrances, exits and movements inside the surveyed areas. Taking into consideration the identity declared by the ships as well as their type, the system should evaluate the right or not for these vessels to be in these areas of interest. The system should be able to detect and visualise fishing patterns. When the AIS has been switched off, the system should estimate fishing polygons and compare them with known fishing grounds to monitor. The user should be alerted about ships navigating and stopping in areas where protected species live (*e.g.* marine reserves).

Objective - In order to protect known areas from fishing (or navigation), the user wants to locate the set of geographical zones at the European level to be monitored. He wants to know if a vessel enters, exits, sails or spends time in such areas. When a vessel is located in the protected area, the user would like to know if there is fishing activity ongoing.

Actions - Detected offenders are tracked. Their trajectory and destination are verified. Navy, Coast Guards or port authorities control them and verify their freight. Erratic use of the AIS to mask such IUU should result in blacklisting of a fishing vessel.

Discussion of the scenario Two major situations can be considered as suspicious:

- *when AIS is on and the vessel is inside a protected area*: the vessel trajectory must be analysed to estimate if she is fishing. Low speed and erratic routes can be considered as characteristics behaviour of a vessel that is fishing. A definition of trajectory criteria matching fishing behaviour should be done
- *when AIS is on, and the vessel is blacklisted and is close to a protected area*: all blacklisted vessels for illegal or suspicious fishing should be permanently highlighted.
- *when AIS is off*: the fact for a ship to switch of her AIS must be considered as suspicious, especially when it is done near or inside a protected area. In this case, other medium like radar, can be used by the operator to control the ship.

For each situation, the operator should be alerted immediately by the system, to have the possibility to control the suspicious ship with another tool like radar or VHF communication, or to alert the local coast guards

Information needed by the user

- map with boundaries of protected areas, according to periods of validity. The user should have global vision of protected zone on the scope.
- All AIS trajectories in the monitored zone
- all blacklisted vessels for illegal or suspicious fishing should be highlighted.

Experiment SC21.1

Detection of potential illegal fishing occurring in protected areas.

Detection of *suspicious* behaviour close to a protected area.

Addressed project requirements

R1.1 Real-time integration/interlinking of spatial and/or spatio-temporal entities

R2.2 Pattern discovery

R2.3 Prediction of trajectories and locations

R3.1 Event detection and forecasting in the maritime domain

R4.1 Visual Analytics Requirements

MSIs supporting the scenario evaluation

[MSI#2] Vessel within a given area (i.e., a protected area)

[MSI#6] Vessel with null speed

[MSI#15] No AIS emission/reception

[MSI#16] AIS emission interrupted

[MSI#19] Vessel under way (using engine or sailing)

[MSI#23] Vessel engaged in fishing

[MSI#26] Loitering

[MSI#27] Dead in water, drifting

Functions to test

R2.2.4 Detection of fishing patterns

R2.3.1 Prediction of a vessel entering in a protected area

R3.1.1 Event detection in the maritime domain

R3.1.2 Event forecasting in the maritime domain

Hypothesis to test

The system provides timely and accurate information to support real-time monitoring of protected areas and detect (potential) IUU fishing. Interfacing with R2.2, R2.3, and R3.1 detection/prediction components facilitates all necessary set-up (such as protected area boundaries, minimum distances) and algorithm fine-tuning (e.g., via Visual Analytics tools) to adapt the system to the area under surveillance.

Assumptions

Area under control is covered by AIS and data coverage is sufficient to perform the mission

Input data

1) Surveillance data stream (raw AIS stream or AIS data synopses)

2) Protected areas, with boundary, protected species, and temporal validity. Temporal validity and boundary should be consistent with the monitored area and the time of the stream

3) Blacklist of fishing vessels

4) Fleet register, with the species they fish

5) Coastlines

6) Weather and ocean conditions, aligned in time and space with the surveillance stream

Output data

The user needs to be alerted in real time each time:

- a ship enters the protected zone and has a *fishing* or *suspicious* behaviour
- a ship switches off her AIS off when is close by (minimal distance of alert has to be defined) or when it is already in a protected area
- a blacklisted vessel sails near a protected zone (minimal distance of alert has to be defined). All blacklisted vessels for illegal or suspicious fishing should be permanently highlighted).

For each alert, the following information should be available to the user:

- vessel identifier of the vessel for which the alert has been generated
- Last known position of the suspicious vessel
- Detail of the suspicious vessel behaviour (e.g., close to protected area, AIS switched off)

For each situation, the operator should be alerted immediately by the system, to have the possibility to control the suspicious ship with another tool like radar or VHF communication, or to alert the local coast guards

Performance Criteria - Measure - Target

Timeliness - Processing time - Operational level (ms)

Continuity - Stream rate - Output positions per seconds / Input positions per seconds - 1

Accuracy - True positive rate (Correct relations / discovered relations) - 1

Algorithms' parameters variations

Temporal resolution Relax resolution of surveillance data to improve timeliness and continuity

Data variations

Velocity: Increase gradually the input stream rate to stress timeliness and continuity

Veracity: Integrate surveillance data with gaps or error in positions to stress accuracy

Steps to perform

1) Using a representative data sample of available data, detection and prediction algorithms are (interactively) parametrized (offline).

2) Run prototype ingesting real-time AIS data stream and evaluate event detection algorithm to detect suspicious behaviour and fishing activities in protected areas (online setting).

3) Evaluate performance criteria.

Experiment SC21.2

Detect fishing vessels entering in protected areas.

Addressed project requirements

R1.1 Real-time integration/interlinking of spatial and/or spatio-temporal entities

R2.2 Pattern discovery

R2.3 Prediction of trajectories and locations

R3.1 Event detection and forecasting in the maritime domain

MSIs supporting the scenario evaluation

[MSI#2] Vessel within a given area (i.e., a protected area)

[MSI#6] Vessel with null speed

[MSI#15] No AIS emission/reception

[MSI#16] AIS emission interrupted

[MSI#19] Vessel under way (using engine or sailing)

[MSI#23] Vessel engaged in fishing

[MSI#26] Loitering

[MSI#27] Dead in water, drifting

Functions to test

R1.1.1 Interlinking of real-time data streams of maritime moving objects surveillance data with METOC data (e.g., weather, ocean conditions and forecast) or contextual information

[MSI#2] *Vessels within a given area* with respect to a protected area

Hypothesis to test

Interlinking of AIS data with contextual data is accurate and fast enough to support real-time monitoring of protected areas.

Assumptions

Contextual data are valid when interlinking is applied.

Spatial and temporal resolution of the stream data and of contextual data is compatible.

Input data

1) AIS stream

2) Protected areas

3) Fleet register

4) Fishing licenses

5) Black lists

6) Historical AIS data

7) Fishing patterns

Output data

AIS stream interlinked in real-time with protected area

Performance Criteria - Measure - Target

1) *Timeliness* - Processing time - Operational level (ms)

2) *Continuity* - Stream rate - Output positions per seconds / Input positions per seconds - 1

3) *Accuracy* - True positive rate (Correct relations / discovered relations) - 1

Algorithms' parameters Variations

Temporal resolution Relax resolution of surveillance data to improve timeliness and continuity

Data variations

Velocity: Increase gradually the input stream rate to stress timeliness and continuity

Veracity: Integrate surveillance data with gaps or error in positions to stress accuracy

Steps to perform

Run prototype to ingest real-time AIS data stream and run interlinking with protected data for 1 day. Evaluate performance criteria. *Variation* Run a velocity variation increasing gradually the input stream rate (from ... to ..).

Variation Run a veracity variation running the test on dataset with gaps (dataset ID)

4.2.2 Experiments for Fishing pressure (density of fishing) (SC22)

In this scenario, the operator is using the system to preserve natural resources against overfishing. The system should support him evaluating and displaying cumulative fishing activities over time and seasons, helping him identifying overfishing areas and the consequent danger for the preservation of marine resources.

Objective - In order to identify overfishing areas, the user wants to identify fishing zones from positioning data. He would like to visualise and evaluate changes over time/seasons and see the cumulative impact.

Actions - Upon detection of intensive fishing areas and regarding concerned species, local, national and European authorities provide new regulations and update the list of protected areas.

Discussion of scenario Possible information to evaluate for fishing pressure is:

- the boundaries of zones for the different kind of fishing activities.
- the cumulative presence (absolute numbers of ratio) of fishing vessels in the zone
- the vessel types, or other characteristics such as length, tonnage that can reveal their fishing capacity, hence the impact they can have on natural resources.
- how long a fishing vessel stays in the zone (datAcron could try to figure out if there a link between the duration of the stay of vessels in the area and the abundance/lack of resources)

An algorithm for fishing pressure estimation should:

1. Identify of all fishing vessels close to / in the area
2. If a ship switches AIS of, consider that he is fishing in the area or,
3. Evaluate if a vessel has a fishing behaviour, even if not explicit in AIS data
4. Evaluate the cumulative length of fishing time in the area
5. Deduce the cumulative impact on species in a selected period

Experiment SC2.2.1

Estimate fishing pressure on an area, estimation of the impact on species.

Addressed Project Requirements

R2.2 Pattern discovery

R4.1 Visual Analytics Requirements

MSIs supporting the scenario

[MSI#2] Vessel within a given area (i.e., a protected area)

[MSI#6] Vessel with null speed

[MSI#15] No AIS emission/reception

[MSI#16] AIS emission interrupted

[MSI#19] Vessel under way (using engine or sailing)

[MSI#23] Vessel engaged in fishing

[MSI#26] Loitering

[MSI#27] Dead in water, drifting

Functions to test

R2.2.4 Detection of fishing patterns

R4.1 Visual Analytics Requirements

Hypothesis to test

Accurate estimation on fishing pressure in an area under surveillance can be obtained analysing surveillance data, given contextual information on the area (fished and protected species) and information on fishing vessels. Visual-interactive data exploration, as part of the analysis process, enables the domain expert to reason about model quality and required granularity of generated statistics.

Hypothesis

Quality and coverage of surveillance data is good

Estimation can be derived from visual-interactive data exploration and analysis of fishing activity

Ground truth on catches exists, detailed by fishing areas, period of catch and fish species

Input data

1) Surveillance data stream (raw AIS stream or AIS data synopses)

2) Fishing areas and protected area, with type of fish and period of fishing/restriction of fishing

3) Boundaries of different fishing areas

4) Fleet register, with the species the vessels fish and characteristics of the vessels

5) Blacklist of fishing vessels

6) Coastline

7) Weather and ocean conditions, aligned in time and space with the surveillance stream

Output data

1) Cumulative estimation of fisheries for a period in defined areas, detailed by species (with confidence intervals of estimation)

2) Statistics about fishing vessels presence in different areas

Depending on specific analysis task, generated statistical aggregates may vary in temporal and/or spatial granularity.

Steps to perform

1) Given a period of time, and an area, generate the statistics with appropriate granularity (cf. output data)

2) The statistics generated by the system are compared with the real results from local fishing committee

3) Performance criteria are evaluated

4) The statistics are re-generated varying algorithm parameters and data in input (see data variation) and performance criteria are re-evaluated

Performance Criteria - Measure - Target

Accuracy - Average Euclidean Error (AEE) - Minimise the error with ground truth statistics

Clarity - Maximise the degree of confidence of the operator

Algorithms' parameters variations

Vary the area for which the statistics are generated

Vary the period of interest for the generation of the statistics

Vary the species considered by the statistics

Data variations

Variety: Consider contextual information, such as historical series of weather and ocean conditions, characteristics of the fishing vessels, blacklist of fishing vessels

Volume: Vary the number of vessels included in the statistics

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4.3 Experiments to validate MSIs

In this section we present examples of experiments for validating MSIs. The list of MSIs is reported in Table 11, as it was previously introduced in Deliverable D5.1. MSIs, as specified in the same document, represent declarative operator's information needs regarding specific vessels' states or events, current or predicted. The operators queries the MSIs he/she is interested in discovering, that he/she wants to have highlighted in the maritime picture. The operator parameterises the MSIs according to the contextual requirements of the scenarios. In particular, MSIs have to be detected or predicted (forecasted), depending on the maritime mission the operator is involved in, as specified in the right side of Table 11. Note also that MSIs instantiate the project requirement *R3.1 Complex Event detection and forecasting in the maritime domain*, contextualising it according to the specific scenario.

In Table 11 each MSI should be split into an estimation at the current instant (denoted as MSI#$n(0)$) and its predicted counter-part (denoted as MSI#$n(t)$, where t will be a parameter to be selected by the user).

Table 11: Maritime Situational Indicators needs for each scenario. 0 means that the information is required at the current instant in time, while t means that it is required as a prediction for within a time to be set by the user.

Maritime Situational Indicators		Query parameters	SC11 Collision prevention	SC12 Vessel in distress / MOB	SC21 Protection of ecological areas	SC22 Fishing pressure	SC31 Migrants / human trafficking	SC32 illicit activities
Close to a critical infrastructure (CI)	MSI#1	CI locations, range					×	×
Within a given area	MSI#2	Areas locations	×		×	×	×	×
On a maritime route	MSI#3	Route locations	×	×			×	×
Proximity of other vessels	MSI#4	Range of distance	×	×	×	×	×	×
In stationary area (ports or offshore platforms)	MSI#5	Specific ports locations					×	×
Null speed	MSI#6		×	×	×	×	×	×
Change of speed	MSI#7	Change rate		0			×	×
Not compatible with range values from:								
- the current area	MSI#8				0	0	0	0
- the type of vessel	MSI#9				0	0	0	0
- the vessel's history	MSI#10	Time window			0	0	0	0
- user defined	MSI#11	Range of values	×	×	×	×	×	×
Change of course	MSI#12	Change rate	×				×	×
Not compatible with:								
- the vessel's expected destination	MSI#13		×	×	×		×	×
- user defined	MSI#14	Range of values	×	×	×	×	×	×
No AIS emission/reception	MSI#15		×		×		×	×
AIS emission interrupted	MSI#16		×	×	×	×	×	×
Change in AIS static information	MSI#17	AIS field			×		×	×
AIS error detection	MSI#18	Type of error			×		×	×
Under way (using engine or sailing)	MSI#19		×		×		×	×
At anchor or moored	MSI#20							
Movement ability affected	MSI#21			×				
Aground	MSI#22			×				
Engaged in fishing	MSI#23		×	×	×	×	×	×
Tugging (tugged or tugging)	MSI#24							
In SAR operation	MSI#25			×				
Loitering	MSI#26		×	×	×	×	×	×
Dead in water, drifting	MSI#27		×	×				
Rendez-vous	MSI#28				×	×	×	×

Distinct experiments will be used to validate detected or predicted MSIs. In both cases, quality criteria as introduced in Section 2.4.2 apply. Moreover, two different settings must be considered, to distinguish validation of MSIs in the the real-time case and for analysis. In this first case, latency target setting is operational, and Timeliness and Continuity quality criteria are crucial to evaluate if the MSIs detection or prediction is efficient enough to support the user in his/her task. When MSIs are detected for analysis purposes, latency can be relaxed and Accuracy, Clarity and Completeness criteria prevail. On the contrary, the targets of these criteria could be weakened in the real-time case.

In the rest of the section, we group MSI-level experiments according to the type of vessel status the MSIs detect or predict, because the assessment of MSIs of the same category require to evaluate analogous functionalities. From the MSI listed in Table 11, we can distinguish the following categories:

[MSI#1 - MSI#5] are positional MSIs, which evaluate or predict the vessel position with respect to existing infrastructures, areas of interests (e.g., protected areas), vessel routes, other vessels positions. In the easiest cases of positional MSIs detection, data management functionalities may support completely the MSIs (e.g., interlinking the current position of a vessel with contextual information on protected areas). In other cases, under-MSI functionalities are needed to provide a necessary source of information, needed to solve the MSI (this is the case of vessel route extraction for detecting and predicting MSI#4), or supporting functionalities, such as vessel routes prediction for MSI from MSI#1 to MSI#5.

[MSI#6 - MSI#11] evaluate and predict the vessel status based on the vessel speed. For this group, contextual information on vessel the type and engine may be used to check the consistency of the speed detected from surveillance data, or to predict it (MSI#9). Statistically derived information on the vessel history are required to solve MSI#10. Statistical information on vessel routes or contextual information on local regulations may be used to solve MSI#8.

[MSI#12 - MSI#14]evaluate and predict the vessel status based on the vessel course. These MSIs, together with the MSIs in the previous categories, evaluate the kinematic status of the vessel. MSI#13 requires the support of vessel routes prediction to compare the estimated and the declared destination.

[MSI#15 - MSI#18] evaluate the quality of surveillance data, in particular AIS. For MSIs prediction, historical analysis of source quality is needed, while detection may be supported by kinematic events detection as provided by synopses generation.

[MSI#19 - MSI#26] evaluate the navigational status of the vessel. For AIS data, these MSIs may be detected checking the navigational status fields. However, estimated status may be used to evaluate the consistency of these fields, not only for MSIs prediction but also for detection. In some cases, status may be estimated evaluating the position of the vessel with respect to areas of interest or infrastructures (MSI#20, MSI#22, MSI#23), or evaluating kinematic conditions (MSI#19, MSI#20, MSI#22, MSI#26). In the case of MSI#23 (Engaged in Fishing), patterns detection algorithms detecting fishing activities may also be used. MSI#24 may be detected comparing the kinematic of the vessel and the vessels in its vicinity.

[MSI#27 - MSI#28] are examples of complex MSIs where patterns detection functionalities are required.

It is worth mentioning that, given an MSI, multiple algorithms may be used to implement it. In the following, we present MSIs experiments that evaluate MSIs using a specific function or group of datAcron functions that may be used to implement the MSIs. Alternative functions should be evaluated against the same criteria and measures presented in the following experiments. The list of experiments can therefore be expanded, as novel functionalities are developed.

4.3.1 Experiments for evaluating vessel position events: MSI#01, MSI#02, MSI#03, MSI#04, MSI#05, MSI#23, MSI#28

Experiment for evaluating vessel position with respect to areas of interest

This experiment evaluates real-time interlinking of maritime surveillance data with contextual maritime datasets for critical infrastructures, protected areas, stationary areas or other areas of interest, directly supporting:

[MSI#01] Close to a critical infrastructure

[MSI#02] Approaching or within a given areas (e.g., protected area)

[MSI#03] On/outside a maritime route

[MSI#05] Approaching or in a stationary area

[MSI#23] Engaged in fishing

Addressed project requirements

R1.1 Real-time integration/interlinking of spatial and/or spatio-temporal entities

Functionality to test

R1.1.1 Interlinking of real-time data streams of maritime moving objects surveillance data with weather and ocean data or contextual information.

Semantic level

MSI-level

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

Testing Hypothesis

Real-time interlinking of surveillance data is efficient and accurate for detecting in real-time vessels approaching critical infrastructures or areas of interests (e.g., protected area under surveillance, fishing areas), or detecting vessels crossing or stationary within such areas.

Assumptions

Spatio-temporal relationships among moving objects positions and other datasets provide enough information to detect the MSIs

Input data

1) Stream of (positions of) maritime surveillance data (AIS stream)

2) Contextual data: port databases, facility areas, protected areas

3) Fishing areas

4) Maritime route network or Regulations including navigation channels

5) Range of distance (from protected areas or infrastructure when approaching, from route for violation)

Output data

Identifiers and last position of vessels approaching the areas under surveillance, the critical infrastructure, or travelling outside the maritime routes

Performance Criteria - Measure - Target

Completeness of interlinking - interlinked vessel positions /vessel positions - 100%

Accuracy of interlinking - True positive rate (Correct relations / discovered relations) - 1

Timeliness - Processing time - Operational level (ms)

Continuity - Stream rate - Output positions per seconds / Input positions per seconds - 1

Algorithms' parameters variations

1) Relax accuracy to improve latency and continuity performance

2) Change range of distance for alerting

3) Change spatial resolution of interlinking

4) Change temporal resolution of interlinking

Data variations

Velocity: Increase gradually the input stream rate

Veracity: Integrate surveillance data with gaps or error in positions

Steps to perform

1) Ingest real-time stream of AIS data

2) Apply real-time interlinking with contextual information

3) Evaluate performance criteria

Variations:

1) Stress velocity, relaxing completeness (reducing spatial and temporal resolution), accuracy, timeliness and continuity

2) Stress veracity, relaxing completeness (reducing spatial and temporal resolution), accuracy, timeliness and continuity

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Experiment for evaluating vessel position with respect to other vessels positions

This experiment evaluates real-time interlinking of maritime surveillance data, directly supporting:

[MSI#04] Close to other vessels

[MSI#28] Rendez-vous

Addressed project requirements

R1.1 Real-time integration/interlinking of spatial and/or spatio-temporal entities

Functionality to test

R1.1.1 Interlinking of real-time data streams of maritime moving objects surveillance data with weather and ocean data or contextual information.

Semantic level

MSI-level

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

Testing Hypothesis

Real-time interlinking of surveillance data is efficient and accurate for detecting in real-time vessels approaching or involved in rendez-vous, according to the range of distance given by the regulation or specified by the user and a period of time specified by the user

Assumptions

Spatio-temporal relationships among moving objects positions and other datasets provide enough information to detect the MSIs

Input data

1) Stream of (positions of) maritime surveillance data (AIS stream)

2) Contextual data: port databases, facility areas, protected areas

3) Fishing areas

4) Maritime route network or regulations including navigation channels and range of distance for secure navigation

5) Range of distance for alerting

5) Range of time for alerting about vessels being close to each other

Output data

Identifiers and last position of vessels travelling close to each other, or being stationary together for a given period of time ouside a maritime route or in an area under surveillance, excluding stationary areas, ports and fishing areas

Performance Criteria - Measure - Target

Completeness of interlinking - interlinked vessel positions /vessel positions - 100%

Accuracy of interlinking - True positive rate (Correct relations / discovered relations) - 1

Timeliness - Processing time - Operational level (ms)

Continuity - Stream rate - Output positions per seconds / Input positions per seconds - 1

Algorithms' parameters variations

1) Relax accuracy to improve latency and continuity performance
2) Change range of distance for alerting
3) Change spatial resolution of interlinking
4) Change temporal resolution of interlinking

Data variations

Velocity: Increase gradually the input stream rate

Veracity: Integrate surveillance data with gaps or error in positions

Steps to perform

1) Ingest real-time stream of AIS data
2) Apply real-time interlinking with contextual information
3) Evaluate performance criteria

Variations:

1) Stress velocity, relaxing completeness (reducing spatial and temporal resolution), accuracy, timeliness and continuity

2) Stress veracity, relaxing completeness (reducing spatial and temporal resolution), accuracy, timeliness and continuity

4.3.2 Experiment for evaluating speed violation events: MSI#08, MSI#09

The purpose of the following experiment is to evaluate event detection algorithms detecting speed related MSIs, specifically detection of speed violation events. For testing speed non conformal to the regulations applied in the area or inconsistent with the historical traffic, values to be used for comparison are needed.

Experiment for assessing vessel speed violations detection

This experiment evaluates event detection algorithms supporting:

[MSI#08] Detection of speed not compatible with range values from the area under surveillance

[MSI#09] Detection of speed not compatible with range values for the vessel type

Addressed project requirements

R3.1 (Complex) Event detection and forecasting in the maritime domain

Functions to test

R3.1.1 Vessel event detection

Semantic level

MSI-level

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

Testing Hypothesis

The comparison of vessel kinematic features of surveillance data with background knowledge on vessel routes, existing regulations on the area (e.g., speed thresholds for the area or the channel) or vessel characteristics (e.g., range of speed for vessel type, range of speed for vessel engine) may be continuously computed in real-time

Assumptions

Background knowledge on expected values for speed is available and sensor coverage is sufficient to perform the analysis

Input data

1. AIS stream for the area (or synopses)
2. Maritime route network with associated speeds or Regulations including navigation channels and speed
3. Vessel characteristics
4. Weather and ocean conditions or forecast
5. Speed range for alerting if not expressed by regulation

Output data

Identifiers and last position of vessels violating the speed limitation or being outside ranges with respect to values recorded for vessel routes, areas or vessels type

Performance Criteria - Measure - Target

Completeness – 100% (Surveillance data of all observed vessels are evaluated) *Accuracy* - F1 score - ideal is 100% i.e., all violations are detected and no false alerts produced; in practice, minimization of false negatives and false positives

Timeliness - Processing time - Latency level: operational

Algorithm parameters variations

Vary tolerance to speed violation to evaluate the robustness of the algorithm.

Vary integration of whether and ocean conditions or forecast (see variety below) to evaluate how they affect the motion model.

Data variations

Volume:

- Vary the number of vessels (MMSIs) in the area
- Vary the size of the area under observation
- Vary the number of areas under observation

Velocity: Vary the AIS stream sampling (or the compression rate of vessel synopses)

Variety: Incorporate additional contextual data: weather data, vessel characteristics, areas statistics (i.e., vessel routes)

Veracity: Introduce noise and gaps in event stream

Steps to perform

1. For each vessel in the area of interest, calculate the speed between waypoints and compare it with regulation, average values for vessel routes and vessel characteristics
2. Compute the criteria of performance per vessel

4.3.3 Experiments for predicting vessel route and destination: MSI#1, MSI#2, MSI#3, MSI#4, MSI#5, MSI#13, MSI#28

The purpose of these experiments is to test an approach for predicting the route followed and to be followed by a vessel, as well as the future destination. The approach relies on a vessel-to-route association algorithm, followed by a prediction of destination based on the network of routes previously built.

Experiment for Vessel route and destination prediction

This experiment will detect the following:

[MSI#1] Vessel close to a critical infrastructure - Prediction

[MSI#2] Vessel within a given area - Prediction

[MSI#3] Vessel on a maritime route - Current time and prediction

[MSI#4] Vessel close to other vessels - Prediction

[MSI#5] Vessel in stationary area - Prediction

[MSI#28] Vessel rendez-vous - Prediction

The output will be required for:

[MSI#13] Course not compatible with the expected vessel's destination

Addressed Project Requirements

R2.3 Prediction of trajectory and location

Functions to test

R2.3.1 Prediction of which vessels will cross a certain area (in a time dT)

R2.3.2 Prediction of vessel position at time T

R2.3.3 (on-line) Trajectory forecasting

Semantic level

MSI-level

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

Testing Hypothesis

The network of maritime routes between ports coupled with a vessel-to-route association algorithm is appropriate to detect vessels future location and destination

Assumptions

The vessel is actually going toward a port. First big vessels will be considered, in a second step, fishing vessels going back to port will be considered

Input data

1) AIS contacts for the vessel of interest
2) Maritime route network (between ports first, then between fishing areas and ports)
3) Coastline

Output data

1) Set of possible routes associated to a given vessel and associated probabilities
2) Set of the most probable destinations and associated probabilities
3) Predicted position at t and associated uncertainty

Performance Criteria - Measure - Target

Clarity - Entropy
Timeliness - Processing time
Accuracy - Sensitivity/Recall of the predicted destinations
Continuity - Processing time $<$ contact rate

Algorithms' parameters variations

1) Distance measure from vessel to route
2) Features in the distance calculation (position, COG, SOG, type, ETA, NPOC, etc)
3) Range in association

Data variations

Volume: Number of vessels (MMSIs) in the area
Veracity:

- Lack of coverage (artificially include areas with no AIS coverage);
- Include variable ratio of AIS errors in position (the AIS message sent is not conform to the actual vessels position)

Variety:

- Use several AIS sources (IMISG, CMRE for La Spezia area, NARI for Brest area);
- World Port Index and information from port (e.g., expected cargo).

Steps to perform

1) From each vessel in the area of interest, perform the association to routes;
2) Compute the criteria of performance per vessel and average for the overall area;

2) Perform a sensitivity analysis by varying:

- The set on internal parameters (data fixed);
- The volume only (parameters, veracity, variety fixed);
- The veracity only (parameters, volume, variety fixed);
- The variety only (parameters, veracity fixed). The volume necessary vary with the variety as we include other datasets. What is to be compared here is the possible complementarity of the sources.

4.3.4 Experiments for detecting vessels engaged in fishing: MSI#02, MSI#23

Experiment to detect or predict fishing activities: MSI#2 and MSI#23

Addressed project requirements

R2.2 Pattern discovery

Function to test

The following will support directly the evaluation of the MSIs:

R2.3.1 Prediction of which vessels will cross a certain area (in a time dT)

R2.3.2 Prediction of vessel position at time T

R2.3.3 (on-line) Trajectory forecasting

R2.2.4 Fishing patterns detection

Semantic level

MSI-level

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

Hypothesis to test

The functions are accurate and efficient to identify vessels while fishing, and to predict they will fish

Assumptions

Coverage of sensors in the area under evaluation is good. Missing vessel positions are likely due to vessels switching off their AIS and not by poor coverage

Input data

1) Real-time AIS stream including kinematic and static information or trajectory synopses
2) Fishing areas from regulation or other sources
3) Estimated fishing areas (cf. R2.2 and R2.3)
4) Restricted areas
5) Whether and ocean conditions and forecasts
6) Port database
7) Coastline
8) fishing vessel register
9) Blacklist of IUU fishing vessels
10) Spatio-temporal constraints to apply on input data
11) Temporal range of interest for prediction

Output data

Identifiers and last positions reported of vessels involved in fishing/ of vessels that are predicted to fish in a given amount of time, with area

Fishing patterns

Performance Criteria - Measure - Target

Completeness - Processed vessels / Vessels in input in the stream - 100%

Clarity -

Timeliness - Processing time - Latency level: operational

Continuity - -Latency level: operational

Algorithms' parameters variations

Varying parametrisation in order to qualitatively and quantitatively evaluate the extracted sets of points and the coverage of the activity areas based on ground-truth activity areas

Data variations

Data variations

Volume:

- Vary the number of vessels (MMSIs) in the area
- Vary the size of the area under observation
- Vary the number of areas under observation

Velocity: Vary the AIS stream sampling (or the compression rate of vessel synopses)

Variety: Incorporate additional contextual data: weather data, vessel characteristics, areas statistics (i.e., vessel routes)

Veracity: Introduce noise and gaps in event stream

Steps to perform

1) From each fishing vessel in the stream in the area of interest, check if last position is inside estimated or provided fishing areas, or was approaching if AIS is off, or is following an estimated fishing pattern

2) Compute the criteria of performance per vessel

4.3.5 Experiments for detecting kinematic events: MSI#07, MSI#08, MSI#09, MSI#12, MSI#16

The purpose of the following experiment is to evaluate algorithms and approaches for the detection of kinematic events. For testing speed and course non conformal to the regulations applied in the area or inconsistent with the historical traffic, values to be used for comparison are needed.

Experiment for detecting kinematic events and gaps in surveillance data stream

This experiment evaluates event detection algorithms supporting:

[MSI#07] Detection of change of speed

[MSI#08] Detection of change of speed not compatible with range values from the area under surveillance

[MSI#09] Detection of change of speed not compatible with range values for the vessel type

[MSI#12] Detection of change of course

[MSI#16] Detection of vessels that interrupted communications. Issue a notification when AIS emission from a vessel has been interrupted at least T time units ago.

Addressed project requirements

R3.1 (Complex) Event detection and forecasting in the maritime domain

R2.4 Computation of surveillance data synopses, reconstruction of trajectories by data synopses

Function to test

R2.4.2 Maintain trajectory synopses. Given positional streams, track synopses critical points, where major changes along each object's movement occur

R2.4.2 Identify communication gaps from a vessel

Semantic level

MSI-level

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

Testing Hypothesis

Synopses preserved critical points are accurate enough to discover violations

Assumptions

Background knowledge on expected values for speed and maritime network is available and sensor coverage is sufficient to perform the analysis

Input data

1. Surveillance data (AIS) Synopses
2. Port database
3. Coastline
4. Protected areas
5. Maritime network with speed and course regulation
6. Vessel routes with estimated values for speed and course
7. Whether and ocean conditions and forecast
8. Spatial area of interest
9. Range of speed and course tolerance violations
10. Time range of acceptable transmission gaps

Output data

Identifiers and last position of vessels violating the speed/course limitation or being outside ranges with respect to values recorded for vessel routes, areas or vessels type or estimated having switched off the AIS

Perforance Criteria - Measure - Target

Completeness - Evaluated synopses / synopses of observed vessels- 100% *Accuracy* - 1 - RMSE Avg and Max Root Mean Square Error in comparison with synthetic ground truth events - 100% i.e., all violations and gaps are detected and no false alerts produced

Timeliness - Processing time - Latency level: operational

Continuity - Latency along time - Continuous flows are evaluated and delay is not introduced

Algorithm parameters variations

Tune compression ratio of synopses (positions dropped / raw positions available, or reporting frequencies from few seconds vs. few minutes) to improve Accuracy, Timeliness and Continuity Vary speed and course violation range to evaluate the algorithm efficiency

Potential data variations

Volume: varying number of vessels in monitored fleet (e.g., by vessel type or geographical area)

Variety: Incorporate additional contextual data: weather data, vessel characteristics, areas statistics (i.e., vessel routes)

Veracity: Introduce noise and gaps in event stream

Steps to perform

1. For each vessel in the area of interest, evaluate synopses critical points with respect to the ranges specified by the user or in the regulation, average values for vessel routes and vessel characteristics
2. Compute the criteria of performance per vessel

4.4 Experiments for additional functions of interests

Beside MSIs, which are combined for the realisation of scenarios, several under-MSI functions are applied to prepare data in input of MSIs algorithms or to provide basic functions that are needed for MSIs implementation. Experiments for under-MSI functions implementing project requirements will be designed and formalised in the corresponding WP deliverables. In this section, we provide example of experiments for functions of particular relevance for the fishing scenarios, following the template used in the previous sections.

In particular, we propose examples of experiments for data management functions (RDF query of integrated data), for the detection of fishing areas and patterns, and for maritime route extraction, that support the detection and the prediction of several MSIs, solving the missions described in the fishing scenarios. These experiments may be used as they are, or may be examples of validation for under-MSI functions in support of the maritime use case and the detection and prediction of MSIs. For the sake of completeness, Tables in Figure 17, 18, and 19 map MSIs with the datAcron functions that will be developed in WP1-4 to implement project requirements. Visual analytics functionalities integrate such functions and may potentially support all MSIs and scenarios.

												WP4	
						Position MSIs	Speed MSIs	Course MSIs	AIS quality MSIs	Navigational Status MSIs	Complex MSIs	R4 Visual Analytics requirements	
		Requirements	Functions	Input	Output	MSI#1-5	MSI#6-11	MSI#12-14	MSI#15-18	MSI#19-26	MSI#27-28	R4.1 Visualization techniques to enable human analyst to observe and reason about data and patterns	R4.2 Interactive visual interface (data and algorithm selections, parameterization) with immediate feedback regarding impact of parameter change
WP1	R1.1	Real-time integration/interlinking of spatial and/or spatio-temporal entities	Integrate surveillance data with weather and contextual information in real-time, based on positions of moving objects under surveillance. Identify point-	stream (of *positions*) of moving objects, weather data, contextual data	(*positions* of) moving objects interlinked with spatial or spatio-temporal entities	MSI #1-2,4-5					MSI #28	real-time visualization of integrated stream	
WP1	R1.2	Interplay of in-situ and stream processing components	Accelerate processing of data stream, relying on WP2 and WP3 processing for: stream compression, event detection, event forecasting, concept drift monitoring, model building	stream of moving object *positions* (object-id,timestamp, position), parameters, contextual information, predictive models	pre-processed data streams	MSI #1-28						real-time visualization of pre-processed stream	Interactive setting of user defined parameters and threshold for MSI#11, MSI#14, MSI #19-28
					streams of (detected/forecasted) events	MSI #1-28							
					concept drift alerts, model updates	MSI #1-28							Interactive setting of user defined parameters and threshold for MSI#11, MSI#14,
WP1	R1.3	Integration/interlinking of trajectories and events over stored data	Interlinking trajectories and events with stored (at rest) data (weather,contextual), based on spatio-temporal criteria, or FK identifiers	a detected or predicted trajectory of a moving object, weather data, contextual data (sector or Areas of interest), aviation regulations, others	a trajectory associated with external data	MSI#1-5				MSI#20, MSI#21		real-time visualization of integrated stream	Interactive setting of user defined parameters and threshold for MSI#1-5
			Interlinking events with stored (at rest) data (weather,contextual), based on spatio-temporal criteria, or FK identifiers	a detected or forecasted event, weather data, contextual data (sector or Areas of interest), aviation regulations, others	an event associated with external data	MSI #1-28							Interactive setting of user defined parameters and threshold for MSI#1-5,11,14,19-28
			Interlinking of events with relevant trajectories of moving objects, based on spatio-temporal criteria	a detected or forecasted event, *relevant* trajectories	an event associated with trajectories	MSI #1-28							Interactive setting of user defined parameters and threshold for MSI#1-28
WP1	R1.4	Spatio-temporal RDF querying of integrated data	Scalable querying of spatio-temporal RDF data from a distributed RDF store	RDF query parameters (source RDF information, spatio-temporal and RDF constraints)	RDF entities that comply with input constraints	MSI #1-28						real-time visualization of integrated stream	Interactive setting of query parameters
WP1	R1.5	Retrieval of spatio-temporally constrained subsets of integrated data	Retrieve trajectories enriched with interlinked data	spatio-temporal query constraints	RDF entities that comply with input constraints	MSI #1-28						real-time visualization of integrated data	Interactive setting of user defined parameters and threshold for MSI#1-28

Figure 17: Maritime datAcron functions and how they support MSIs: WP1 functions

		Requirements	Functions	Input	Output	Position MSIs	Speed MSIs	Course MSIs	AIS quality MSIs	Navigational Status MSIs	Complex MSIs	WP4 R4 Visual Analytics requirements: R4.1 Visualization techniques to enable human analyst to observe and reason about data and patterns	WP4 R4 Visual Analytics requirements: R4.2 Interactive visual interface (data and algorithm selections, parameterization) with immediate feedback regarding impact of parameter change
						MSI#1-5	MSI#6-11	MSI#12-14	MSI#15-18	MSI#19-26	MSI#27-28		
WP2	R2.1	Computation of trj similarity and clustering	Calculate similarity of two semantic trajectories	Pair of (semantic) trajectories	similarity score, matching (spatio-temporal and semantic) components	MSI#3 to infer the future locations of a moving object from its similar trajectories or to find the clusters of moving objects which share the same moving pattern							Interactive setting of algorithm parameters and visual support for parameter evaluation
WP2	R2.1		Identify cluster of trajectories	Set of (semantic) trajectories, constraints (events, area, time, speed, altitude)	group of similar trajectories	MSI#1-#4					MSI#28		
WP2	R2.2	Pattern discovery	Routes detection	Set of (semantic) trajectories	Frequent paths	MSI#3		MSI#12		MSI#19-#21	MSI#27,MSI#28	real-time visualization of output patterns	Interactive setting of algorithm parameters and visual support for parameter evaluation
WP2	R2.2		Detection of hot-spots spatial areas (spatial areas where a high number of fishing vessels are located frequently)	A spatio-temporal constraint, Set of fishing vessels positions within the constraint	Hot-spot areas	MSI#2-#5				MSI#23	MSI#27,MSI#28		
WP2	R2.2		Detection of fishing areas	A spatio-temporal constraint, Hot-spot spatial area, Set of fishing vessels positions within the constraint	Spatio-temporal sequential patterns where fishing activities takes place	MSI#2,MSI#4				MSI#23	MSI#27,MSI#28		
WP2	R2.2		Trajectory detection, fishing pattern detection	AIS static and kinematic information, measurement/model uncertainty, WPI DB		MSI#2				MSI#23	MSI#27		
WP2	R2.3	Prediction of trj and locations	Predict which vessels will cross a certain area (in a certain time)	Set of moving objects, prediction time, historical patterns (opt), , weather/ocean forecast	a set of moving objects, predicted future locations	MSI#2,MSI#4,MSI#5				MSI#23	MSI#28	real-time visualization of output trajectories	Interactive setting of algorithm parameters and visual support for parameter evaluation
WP2	R2.3		Predict vessel position at time T	A moving object, prediction time, historical patterns (opt), weather/ocean forecast	a moving object, predicted future location	MSI#2,MSI#4,MSI#5				MSI#23	MSI#27,MSI#28		
WP2	R2.3		(on-line) Forecasting of trajectory of a vessel	A moving object, prediction time, historical patterns (opt), weather/ocean forecast, WPI DB, coastline, static and kinematic AIS information	a moving object, predicted future trajectory	MSI#2,MSI#4				MSI#23	MSI#27,MSI#28		
WP2	R2.4	Computation of surveillance data synopses, reconstruction of trajectories by data synopses	Reconstruct trajectory from surveillance data	Raw stream of surveillance data,contextual information (vessels, ports)	updated trajectory	MSI #1-28						real-time visualization of synopses stream	Interactive setting of algorithm parameters and visual support for parameter evaluation
WP2	R2.4		Maintain trajectory synopses. Given positional streams, track synopses critical points, where major changes along each object's movement occur	Raw stream of surveillance data	trajectory synopses, derived stream of critical points for each moving object	MSI#1-#5	MSI#7-MSI#11	MSI#12-MSI#14		MSI#21-#26	MSI#27-#28		
WP2	R2.4		Identify communication gaps from a vessel	Raw stream of surveillance data for a vessel historical trajectories	notification that contact from a vessel is lost				MSI#15-16	MSI#23-#24	MSI#27-#28		

Figure 18: Maritime datAcron functions and how they support MSIs: WP2 functions

WP4

		Requirements	Functions	Input	Output	Position MSIs	Speed MSIs	Course MSIs	AIS quality MSIs	Navigational Status MSIs	Complex MSIs	R4 Visual Analytics requirements	
						MSI#1-5	MSI#6-11	MSI#12-14	MSI#15-18	MSI#19-26	MSI#27-28	R4.1 Visualization techniques to enable human analyst to observe and reason about data and patterns	R4.2 Interactive visual interface (data and algorithm selections, parameterization) with immediate feedback regarding impact of parameter change
WP3	R3.1	Event detection and forecasting in the maritime domain	Event detection	vessel characteristics, vessel history (blacklist), trajectory synopses, protected ares,sishing areas, suspicious areas (?), regulations about areas, vessel routes, weather data	vessel moving in a protected area, vessel fishing in a protected area, vessel moving along a known route, area with high fishing pressure	MSI #1-28						real-time visualization of streamed data/selected events	Interactive setting of algorithm parameters and visual support for parameter evaluation
			Event forecasting		vessel moving towards a protected area, vessel moving along a known route, area with high fishing pressure	MSI #1-28							
WP4	R4	Requirements for the integrated datAcron system	Visualization techniques to enable human analyst to observe and reason about data and patterns	data accessible through the integrated system; Models and parameterization from WP2 and WP3	enriched input data; new spatio-temporal objects, additional relations between entities, set of parameters	MSI#1-28							
			Interactive visual interface (data and algorithm selections, parameterization) with immediate feedback regarding impact of parameter change			MSI#1-28							

Figure 19: Maritime datAcron functions and how they support MSIs: WP3 and WP4 functions

Experiment to evaluate spatio-temporal RDF querying of integrated data

Addressed project requirements

R1.4 Spatio-temporal RDF querying of integrated data

Functions to test

R1.4.1 Querying integrated data by employing spatio-temporal constraints

Semantic level

Under-MSI

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

MSIs potentially relying on this functions

[MSI#1] Vessel close to a critical infrastructure

[MSI#2] Vessel within a given area (i.e., a protected area)

[MSI#3] Vessel on a maritime route

[MSI#4] Proximity to other vessels

[MSI#5] Vessel in stationary area (ports or offshore areas)

[MSI#23] Vessel engaged in fishing

[MSI#28] Rendez-vous

Testing Hypothesis

Querying functionality for spatio-temporal RDF data is efficient

Assumptions

Due to the large volume of integrated data, the querying functionality is provided over a distributed storage system and by means of a parallel processing framework

Input data

1) Integrated data stored in RDF form

2) A spatio-temporal constraint

3) Additional constraints (not spatio-temporal) posed on the RDF representation

Output data

Integrated data complying with the input constraints

Performance Criteria - Measure - Target

Timeliness - Processing time - Tactical/Strategic level depending on the query

Algorithms' parameters variations

Vary query selectivity to test how the query processing performance is affected

Vary query complexity to test how the query processing performance is affected

Data variations

Volume: Increase size of stored/integrated data, in order to study effect on performance

Steps to perform

1) Formulate a query by means of constraints (both spatio-temporal as well as other constraints)
2) Run the querying algorithm to retrieve the result set
3) Increase size of stored/integrated data
4) Evaluate performance criteria

Experiment to evaluate Maritime route extraction and synthesis algorithms

Experiment description

The purpose of this experiment is to extract a network of maritime routes between the main ports of a given area (to be determined). Two approaches will be tested and compared:

[A1] Trajectory-based approach: The TREAD algorithm originally defined in [10] and supplemented by the association of routes to ports labels according to the World Port Index;

[A2] Contact-based approach: A port-to-port data filtering followed by a synthesis of individual routes.

Addressed project requirements

R2.2 Pattern discovery

Function to test

R2.2.1 Routes detection

Semantic level

Under-MSI

MSIs of interest

This derivation of the patterns of life is required for the detection of:

[MSI#3] Vessel on/outside a maritime route

[MSI#5] Vessel in stationary area

[MSI#13] Course not compatible with the expected vessel's destination

Functions to test

R2.2.1 Route extraction

R2.2.1 Extraction of stationary areas

Labelling of stationary areas

Synthetic route derivation

Synthetic route labeling

Testing Hypothesis

The AIS dataset allows to derive meaningful maritime routes between the main ports

Assumptions

The traffic between two ports is high enough to derive a route.

Input data

1) AIS stream

2) World Port Index

3) Coastline

Output data

1) Port areas

2) Maritime route network connecting ports of interest

3) Synthetic route for each route of the network

Steps to perform

1) From a given input dataset, for a given set of internal parameters (area, time period, volume, veracity, and variety), extract the route network between ports through methods [A1] and [A2]

2) Perform a comparative analysis of both approaches by varying:

- The set on internal parameters (data fixed);
- The volume only (parameters, veracity, variety fixed);
- The veracity only (parameters, volume, variety fixed);
- The variety only (parameters, veracity fixed). The volume necessary vary with the variety as we include other datasets. What is to be compared here is the possible complementarity of the sources.

Performance Criteria - Measure - Target

Clarity - Purity, inverse purity, F-measure

Timeliness - Processing time

Completeness - Ratio of contacts effectively building the routes

Consistency - With the topology (the route does not cross land)

Algorithms' parameters variations

[A1] Internal parameters of the TREAD algorithm (clustering): e.g., minimum number of contacts to detect a route, maximum speed for detecting a stationary area, etc.

[A1] Weight field for weight distances in the origin-destination distance matrix

[A1] Association method for stationary area polygons to ports poligons in World Port of Index (distance range vs Nearest Neighbor)

[A2] Distance calculation method for measuring concentrations (Euclidean distance, Mahalanobis distance)

[A2] Range for vessel in port detection

Data variations

Volume: Number of AIS contacts

Veracity:

- Lack of coverage (artificially include areas with no AIS coverage);
- Include variable ratio of AIS errors in position (the AIS message sent does not conform to the actual vessels position)

Variety: Use several AIS sources (IMISG, NARI for Brest area, CMRE for La Spezia area, etc.)

Experiment to evaluate algorithms for the detection of fishing areas

Addressed project requirements

R2.2 Pattern discovery

Function to test

R2.2.2 Detection of hot-spots spatial areas where a high number of fishing vessels are located frequently)

R2.2.3 Detection of fishing areas

R2.2.4 Fishing patterns detection

Semantic level

Under-MSI

Potential scenarios of interest

SC11 Collision avoidance

SC12 Vessel in distress, Man overboard

SC21 Protection of ecological areas

SC22 Fishing pressure

SC31 Migrants/refugees and human trafficking

SC32 Illicit activities

MSIs of interest

This derivation of patterns of life and fishing areas is required for the detection of:

[MSI#02] Vessel within a given area (i.e., potentially fishing in a a protected area)

[MSI#23] Vessel engaged in fishing

Hypothesis to test

The functions detect accurate fishing areas from surveillance data

Assumptions

Coverage of sensors in the area under evaluation is good. Missing vessel positions are likely due to vessels switching off their AIS and not by poor coverage

Input data

1) Historical AIS stream

2) Port database

3) Coastline

4) Fishing vessel register

4) Fishing areas from regulation or from other sources for comparison

Output data

Fishing areas

Fishing patterns

Performance Criteria - Measure - Target

Accuracy - GAE - ideal 1

Clarity - cluster similarity - high intra-cluster similarity, low inter-cluster similarity

Algorithms' parameters variations

Spatio-temporal constraints for area under evaluation

Comparison of synthetic traffic models

Vary clustering parameters

Data variations

Volume: Vary number of vessels or of vessel trajectories

Veracity: Run algorithms on historical data with gaps or error in AIS

Steps to perform

1) Run functions for the detection hot-spot areas for fishing and fishing areas

2) Run functions for fishing pattern detection

3) Merge the areas detected

4) Compare the detected fishing areas with ground truth, or historical information if available. If not, apply clustering evaluation

References

[1] D1.1 Big Data Analytics for Time Critical Mobility Forecasting - Requirement Analysis, 06 2016.

[2] D5.1 Big Data Analytics for Time Critical Mobility Forecasting - Maritime Use Case description, 04 2016.

[3] D5.2.1 Big Data Analytics for Time Critical Mobility Forecasting - Maritime Data Preparation and Curation (interim), 06 2016.

[4] Gennady L. Andrienko, Natalia V. Andrienko, Michael Burch, and Daniel Weiskopf. Visual Analytics Methodology for Eye Movement Studies. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2889–2898, 2012. Best Paper Award IEEE VAST 2012.

[5] Y. Bar-Shalom, X. Rong Li, and Thiagaligam Kirubarajan. *Estimation with Applications to Tracking and Navigation*. Jon Wiley and Sons, 2004.

[6] Carol M. Barnum. *Usability Testing Essentials - Ready, Set...Test!* Morgan Kaufmann, 2011.

[7] A. Çöltekin, S.I. Fabrikant, and M. Lacayo. Exploring the efficiency of users' visual analytics strategies based on sequence analysis of eye movement recordings. *International Journal on Geographical Information Science*, 24(10):1559–1575, 2010.

[8] Jianjun Gao, Haibin Ling, Erik Blasch, Khanh Pham, Zhonghai Wang, and Genshe Chen. Pattern of life from wami objects tracking based on visual context-aware tracking and infusion network models. volume 8745, pages 87451K–87451K–9, 2013.

[9] Abbas Harati-Mokhtari, Alan Wall, Philip Brooks, and Jin Wang. Automatic identification system (ais): data reliability and human error implications. *Journal of navigation*, 60(03):373–389, 2007.

[10] Giuliana Pallotta, Michele Vespe, and Karna Bryan. Vessel pattern knowledge discovery from AIS data - A framework for anomaly detection and route prediction. *Entropy*, 5(6):2218–2245, 2013.

[11] X. Rong Li and Zanlue Zhao. Measures of performance for evaluation of estimators and filters. In *Proc. of SPIE Conference on Signal and Data Processing of Small Targets*, 2001.