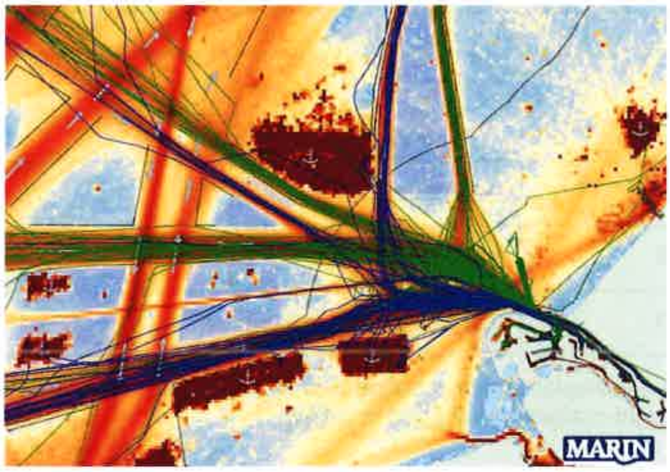
Systems & Advanced Technologies Engineering S.r.l.

MARIN

USING GNSS AND BIG DATA TECHNIQUES TO IMPROVE SAFETY IN CRITICAL MARITIME OPERATIONS

DELIVERY 8.2 – EXECUTIVE SUMMARY



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REVISION SHEET

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Document history

Rev.	Date of issue	Description
0	29/04/2019	Issue for approval
1	16/05/2019	Clarified sentence in sec. 7 and added Advisory Board composition

Changes other than typing/grammar proofing, brought with Rev. x, are marked by the following annotation on the right margin and shaded in yellow. Rev. x

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1 SCOPE

This document is the executive summary of the project under contract N° 4000121510/17/NL/LF between S.A.T.E. and ESA regarding the "USING GNSS AND BIG DATA TECHNIQUES TO IMPROVE SAFETY IN CRITICAL MARITIME OPERATIONS". It provides an overview of the results achieved during the project.

This document represents Delivery 8.2 of the Contract (Ref. 2.1.1).

2 REFERENCES AND DEFINITIONS

2.1 Project documents

1. Contract N° 4000121510/17/NL/LF between S.A.T.E. and ESA.
2. S.A.T.E. Technical Proposal 916200-SPE-ESA-C002/T-Rev.0 dtd. 16-02-2017.
3. S.A.T.E. Implementation Proposal 916200-SPE-ESA-C002/I-Rev.0 dtd. 16-02-2017.
4. S.A.T.E. Financial Proposal 916200-SPE-ESA-C002/F-Rev.0 dtd. 16-02-2017.
5. S.A.T.E. Contractual Proposal 916200-SPE-ESA-C002/C-Rev.0 dtd. 16-02-2017.
6. Contract N° 4000121510/17/NL/LF between S.A.T.E. and ESA.
7. Contract between SATE (main contractor) and MARIN (subcontractor), "Contractual proposal between SATE and MARIN to execute the ESA project "USING GNSS AND BIG DATA TECHNIQUES TO IMPROVE SAFETY IN CRITICAL MARITIME OPERATIONS"", dtd 18/09/2017.
8. Minute of the first Advisory Board meeting, S.A.T.E. Doc. No. 710014-MOM-WP8-G005 – Rev. 0 dtd. 10/12/2017.
9. "Use Case selection", Delivery 1.1, S.A.T.E. Doc. No. 710014-REP-WP1-T001-Rev.0, dtd. 20/12/2017
10. "Path content specification", Delivery 2.1, S.A.T.E. Doc. No. 710014-REP-WP2-T001-Rev.1, dtd. 01-03-2018
11. "Data collection and classification report" – Delivery 3.5 and 4.4, S.A.T.E. Doc. No. 710014-REP-WP4-T002-Rev.0 dtd. 21/12/2018.
12. "Data collection and classification software user manual", Delivery 3.6 and 4.5, S.A.T.E. Doc. No. 710014-MAN-WP4-T001-Rev.0, dtd. 17/09/2018
13. Delivery 4.1 – "Classified dataset", dtd. 04/09/2018
14. Report "Data Processing" – Delivery 5.4, S.A.T.E. Doc. No. 710014-REP-WP5-T001 – Rev. 2 dtd. 08/04/2019.
15. "Certified Paths Extractor User Manual" – Delivery 5.5, S.A.T.E. Doc. No. 710014-MAN-WP5-T002 – Rev. 1 dtd. 08/10/2018.
16. "Experimentation phase", Delivery 6.3, S.A.T.E. Doc. No. 710014-REP-WP6-T001-Rev.0, dtd. 10-04-2019
17. "Demonstration website user manual", S.A.T.E. Doc. No. 710014-MAN-WP6-T002-Rev.0, dtd. 12-04-2019.
18. "Lessons learnt and way forward", Delivery 7.1, S.A.T.E. Doc. No. 710014-REP-WP7-T001 – Rev.1, dtd. 16/05/2019. Rev. 1

2.2 Other documentation

1. ITU (International Telecommunication Union) "Recommendation ITU-R M.1371-5" http://www.itu.int/rec/R-REC-M.1371/en, 2014
2. IMO Resolution A.1046(27), dtd. December 2011.
3. Italian Coast Guard, "Trieste VTS – User's Handbook", Edition No 001, October 2012
4. ACCSEAS, ACCSEAS final report, May 2015
5. AD1: IMO, "Ships' Routeing", 2017 edition
6. RD1: IMO (International Maritime Organization): "Report of the Maritime Safety Committee on its eighty-fifth session (MSC 85/26)"; 19/12/2008, London, UK.

7. IMO (International Maritime Organization): NAV 58/14 “Report to the maritime safety committee”, July 2012
8. IMO (International Maritime Organization): NCSR 5/22/1 “Update of the IMO e-navigation Strategy Implementation Plan (SIP)”, November 2017
9. IMO (International Maritime Organization): MSC 83/28/Add.3 “Adoption of the revised standards for Integrated Navigation Systems (INS), October 2006

2.3 Acronyms and abbreviations

Symbol	**Description**
AB	Advisory Board
AIS	Automatic identification system
ARPA	Automatic Radar Plotting Aids
AtoNs	Aids to Navigation
COMSAR	Sub-Committee on Radiocommunications and Search and Rescue
COG	Course Over Ground
CPA	(Distance between ships at the) Closest Point of Approach
CPR	Certified Path Requirement
CSV	Comma Separated Values
DGPS	Differential GPS
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Navigation Chart
ETA	Estimated Time of Arrival
GNSS	Global Navigation Satellite Systems
IMO	International Maritime Organization
INS	Integrated Navigation System
MSC	Maritime Safety Committee
NAV	IMO's Sub-Committee on Safety of Navigation
NCSR	Navigation Communications and Search and Rescue
PNT	Positioning Navigation Timing
ROT	Rate Of Turn
RNS	Radio Navigation System
RTK	Real Time Kinematic
SAR	Search And Rescue
SIP	Strategy Implementation Plan
SOG	Speed Over Ground
SOLAS	Safety Of Life At Sea
STW	Standards of Training and Watchkeeping / Speed Trough Water
TCPA	Time to Closest Point of Approach
UKC	Under Keel Clearance
VTS	Vessel traffic services

Symbol	Description
VTSO	Vessel Traffic Services Operators

2.4 Websites

1. MarineTraffic.com https://www.marinetraffic.com/
2. Vesseltracker.com https://www.vesseltracker.com/
3. ARPA: http://www.osmer.fvg.it/archivio.php?ln=&p=dati
4. https://www.knmi.nl/kennis-en-datacentrum/achtergrond/data-ophalen-vanuit-een-script
5. https://waterinfo.rws.nl/
6. Project website: http://mar.esa.sate-italy.com/

3 INTRODUCTION

This project was intended to contribute to the implementation of the *e-navigation* concept (as defined by IMO, Ref. 2.2.6), with primary focus on the navigation in restricted waters, such as harbours, lagoons or regions where the traffic congestion can create conditions for accidents or inefficient operations.

It must be clarified that, in the context of restricted navigation areas, there exist a limited number of possible water ways. These can be the result of morphological characteristics of the basin, such as in the Venice harbour that is inside the Lagoon, or practical constraints that the port authorities impose to effectively and safely manage the ships traffic, such as in large harbours. Besides the peculiar situation of Venice, it must be remarked that large ships have limited access areas also in large harbours due to their draught and the, sometimes, limited dredging activities by the Port authorities.

Indeed large ships, such as deep sea container vessels, having a length of up to 400 m and a lateral windage area of up to 12,000 m^2, and large bulkers or tankers having a draught of up to 22 m, are facing restrictions on path, tidal level and water depth and challenging meteo-ocean conditions (wind, fog, tidal current and waves) when entering and leaving a port. On top of this there are special regimes for vessels with dangerous cargoes such as the large LNG-carriers and the smaller LNG bunker barges that are now entering the large European ports.

The sheer number of vessels and the pressure to handle all those vessels in a swift and safe manner is continuously present. The freedom of manoeuvring is space wise very limited as ships traffic is already highly regulated; there is simply not so much space for this. It is the timing of all these vessel positions and speeds that is causing headaches to ship officers, pilots, tug-masters, boats-men and port authorities. Therefore, there are not many possibilities nowadays for route deviation and variability for a large scale route inside a harbour. Instead there can be important deviations and variability at the small scale level of the route, e.g. when the ship must manoeuvre to enter a branch channel in the harbour or reach the loading/unloading gate.

In the traditional approach, ports have a number of guidelines for entry to the port, berthing and exit of the port, which vary according to the tide, weather conditions, traffic and vessel length, weight, draught and cargo. Nevertheless, pilots are necessary to guide operations and manoeuvres in the port. They are qualified to assist the ship master in navigation while entering or leaving a port. It is to be stressed the fact that several casualties can be caused by faulty master/pilot relationships.

In this context, even in harbours where the canals width is less than twice the maximum ship breadth, the suggestion of a “certified path” or “preferred route” is meaningful and useful to better manage future ship navigation in harbours, especially taking into account that the “preferred route” is meant to provide not only spatial but also temporal information. Indeed, the availability of the temporal information implies that “preferred routes” could also be used to forecast the future positions of ships leading to safer operations.

This is not yet part of the traffic management in harbours, yet it would allow also optimising traffic inside the port. This because the use of “preferred routes” would allow knowing in advance the position of the ship in a given route, enabling improvements in routes planning and exploiting at the best the waters that may be navigated in terms of space and time under certain environmental and traffic conditions.

During the project, the concept of certified path was discussed during the Advisory Board meetings, involving: Rev. 1

- Italian Coast Guard Headquarters
- Venice Coast Guard
- Dutch Coast Guard
- Rotterdam Port Authority
- Venice Port Authority
- Trieste Port Authority

- Italian Port Pilots Association
- Venice Port Pilots
- Assicurazioni Generali (Insurance Company)
- Venice Center for Tides Forecasts

All the members of the AB meetings suggested to use the term “preferred route” instead of “certified path”, because these routes, extracted from AIS historical data, shall be used to rationalize as much as possible traffic flows and monitor ships’ behaviour, but should not be meant as a mean to “certify” traffic safety. In this framework the term certified path could suggest a greater impact on safety of navigation than that achievable with the information extracted automatically from the data. Nevertheless, the extracted preferred routes can be a valuable starting point for the selection of routes to be suggested and, if possible, certified in the future to assure safety of navigation in view of autonomous vessels.

4 IMO SPECIFICATIONS AND PREFERRED ROUTES OBJECTIVES

4.1 IMO specifications for Ships' Routeing and reporting

The guidelines for Ship Routing as published by IMO (Ref. 2.2.5) are restricted to geographical route structures. There are no provisions for preferred routes or certified routes that can be suggested to specific ships with a certain destination.

However, in a recently concluded project (Interreg project ACCSEAS), experiments have been done with the exchange of intended route services. It was concluded that the overall concept is useful but should not be used as a collision avoidance tool in close quarter situations.

From the ACCSEAS project it is also clear that preferred routes and the exchange of route information is a service in e-navigation.

There are a number of relevant documents that define the strategy for the implementation of e-navigation. Furthermore, IMO executed a gap analysis to identify missing elements for the introduction of e-navigation. This gap analysis is used for the definition of a e-navigation Strategy Implementation Plan (SIP).

As regards route planning this SIP refers to the performance standards for Integrated Navigation Systems, which provides guidelines for route planning and monitoring. From these guidelines one can conclude that human action and supervision is assumed and that there are no standards for automatic route definition or route exchange.

More details on IMO specifications review and ACCSEAS project results can be found in Ref. 2.1.10.

4.2 Preferred routes objectives

The objectives that can be addressed by the adoption of the “preferred route” concept are the following:

1. Port traffic planning, aimed at increasing safety conditions together with port efficiency
2. Traffic monitoring with the possibility of comparing it with what is planned
3. Aid to port navigation for pilots and master of ships
4. Management of port infrastructure

These objectives determine the requirements of the preferred route, which as a basis should include at least the following ones (see Ref. 2.1.10):

- Preferred route shall be compliant with IMO rules[1]
- The preferred route shall be defined as a spatio-temporal route
- Each preferred route shall be characterised by a set of parameters, allowing the selection of the route to be suggested on the basis of:
    a. Type of vessel
    b. Length and beam of the vessel
    c. Draft of the vessel
    d. Environmental conditions (e. g. wave, wind, current, visibility)
    e. Traffic conditions, classified on the basis of risk

[1] Preferred routes resulting from AIS data analysis are expected to comply automatically with geographically route structures defined by IMO, being based on actual routes. Not compliant ones shall not be taken into consideration for the operational use.

5 PREFERRED ROUTES EXTRACTION

5.1 Preferred routes extraction approach

The “Data processing” task (WP5) foresees the extraction of a set of *certified paths* or *preferred routes* for the three selected ports: Venice, Trieste and Rotterdam.

These will be routes to suggest to the ships entering or exiting the ports based on the specific ships characteristics and environmental conditions.

This task was accomplished by processing the “classified” trajectories, extracted from the ships raw AIS data and environmental data. The classified trajectories are the ships trajectories (space and time information) enriched by metadata and other features:

1) ships characteristics (ship type, length beam, etc),
2) traffic flow (identified by means of geospatial crossing segments defined for the three ports)
3) environmental conditions (wind, tide and current, where available).

The approach to the extraction of the *preferred routes* is based on clustering algorithms for the extraction of groups of trajectories that are similar both in the time and space domain.

For each cluster, a *representative trajectory* is identified, described by a set of waypoints, characterised by tolerance bounds in both time and space, which are determined by the historical AIS data. In addition, the cluster composition is analysed in order to define the applicability of the representative trajectory (for example, which environmental conditions characterise the cluster, which ship types and lengths, which traffic flow direction).

From the set of *representative trajectories*, a set of *preferred routes* could be extracted according to the following criteria:

A. Compliance with the maritime navigation rules;
B. Reliability of the clustering result (evaluating each cluster).

It is possible that more than one *preferred route* will be applicable to a same situation. The set of options will be proposed with a priority value assigned to each path.

The *crossing lines* defined for each selected port were considered to evaluate the results of the clustering methods against the known traffic flows into the ports.

For example, Figure 2 shows all the *journeys* of the ships of length above 200 m entering or exiting the port of Trieste in the year 2016. A *journey* is defined as a sequence of positions that have speed greater than zero and at most 30 minutes between consecutive positions. On this figure, it is also possible to see the *crossing lines* that have been defined for the port of Trieste to identify traffic flows.

Based on the *journeys* and on the *crossing lines*, *stages* are extracted as follows:

- A *stage* is a part of the *journey* in which a particular route is sailed. The route is defined by (mostly) two crossing lines that are crossed in a particular direction and order. The stage starts 15 minutes before passing the first crossing line, and ends 15 minutes after passing the last line.
- If two routes overlap (for example a route through the entire port, and a route only half way through the port), only the longest route is assigned.
- If a journey contains two routes that do not overlap, the journey has two stages (for example arriving in the port and departing from the port).

An example of stages obtained for the port of Trieste is provided in Figure 2. Greater details on the definition of *crossing segments* and *stages* can be found in Ref. 2.1.11.

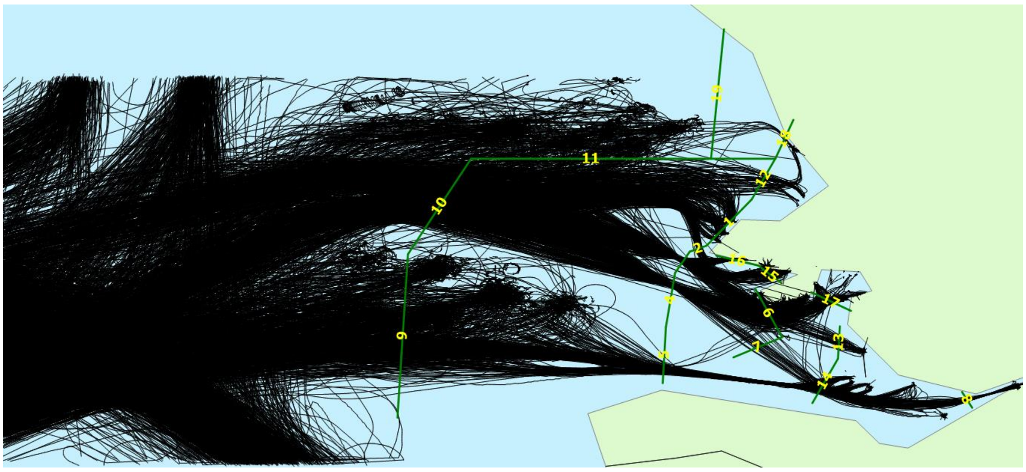

Figure 1 – Example of segments definitions and journeys for the port of Trieste.

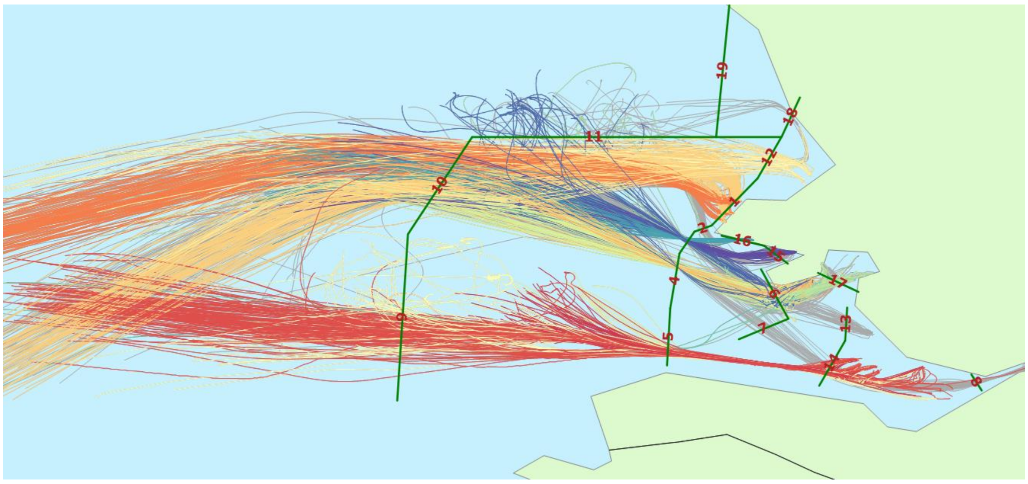

Figure 2 – Example of stages inside the port of Trieste.

5.2 Waypoint representation

The reference trajectory and its waypoints are presented as result of the data processing as shown in Figure 4, where the main reference trajectory is represented by the continuous black line. The coloured tracks are a subset of the trajectories belonging to that cluster, which are plotted to visualise the cluster variability and the waypoint clouds.

The waypoints are indicated by markers on the reference trajectory indicating the time at which the ship should reach that waypoint (in the format HH:MM:SS). The waypoint tolerance in the space domain is represented by the black dashed line around each waypoint. The boundaries visualised correspond to areas actually covered by ships (for this reason, they are not simple circular boundaries). The colour of each point of the tracks is associated to the time values. This allows having an overview also of the time variability into each waypoint.

In addition, the waypoint time variability can be better visualised by a boxplot, as shown in Figure 5. The boxplot is a work tool allowing the graphical representation of a set of measures, highlighting its quantiles, as shown in Figure 3. Therefore, this plot shows the distribution of the times variations into each waypoint, based on data of the trajectories belonging to the group. The time values plotted in each box of Figure 5 are the differences of the times of each trajectory point inside the waypoint from the marked time stamp (of the reference path).

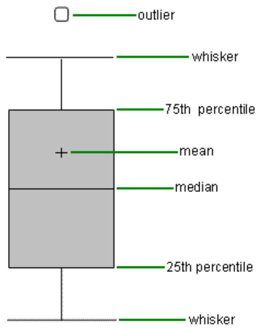

Figure 3 - Structure of a boxplot.

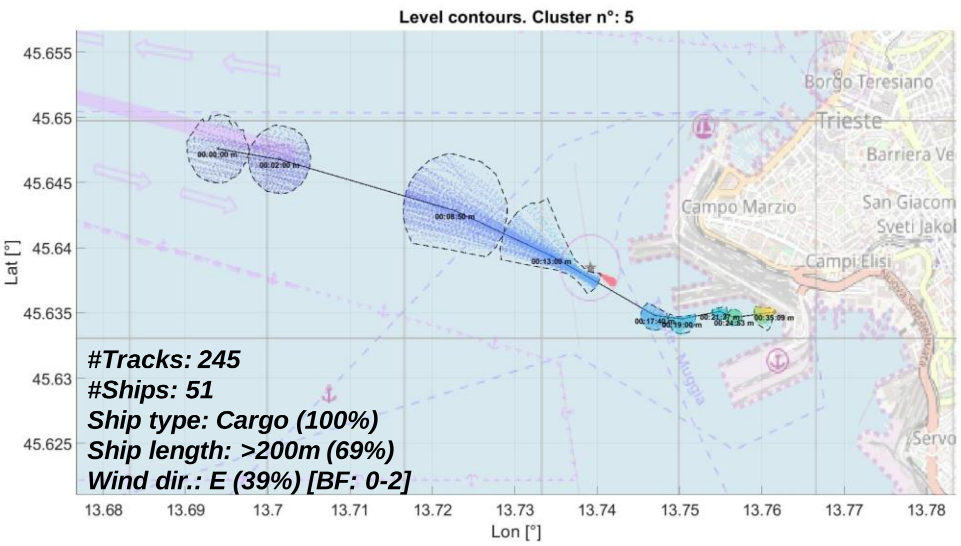

Figure 4 – Waypoint visualisation example. Points are coloured based on the time at which the ships are in that geographical position. Black dashed lines contour the waypoint area.

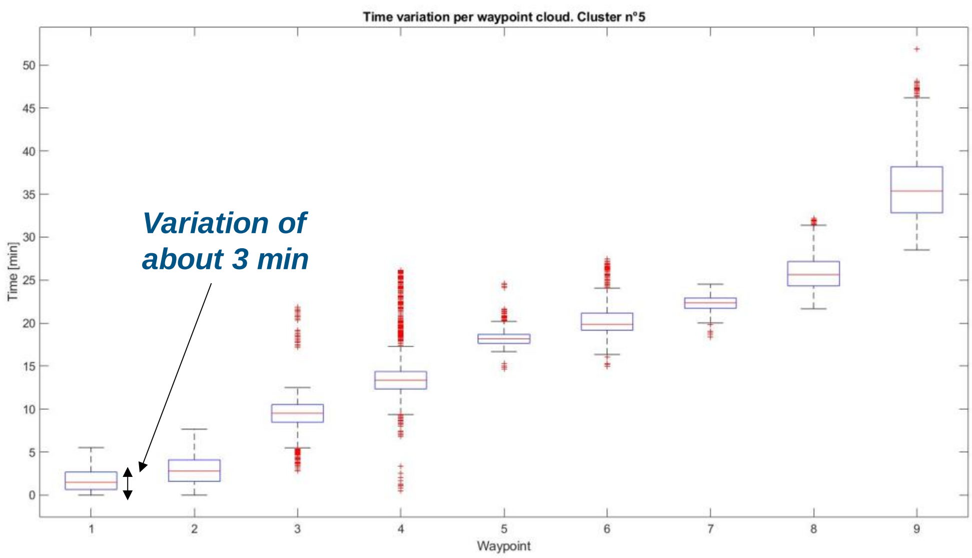

Figure 5 – Example of Time variation per waypoint.

5.3 Preferred routes extraction on the entire dataset

5.3.1 Introduction

The operational steps that shall be performed to apply preferred routes during maritime operations are the following:

1) Extract typical routes followed by ships based on historical data;
2) Select the preferred routes as the typical routes that are compliant with the navigation rules and that are well grouped by similarity;
3) Assign preferred routes to ingoing and outgoing ships, simulating the operational use of preferred routes.

The following sections illustrate the results of the extraction of the typical routes followed by the ships and the selection of the preferred routes for each port.

During the Advisory Board meetings it was agreed to focus the analyses for the preferred routes extraction on vessels of type: Passenger, Cargo, Tanker and Other (AIS class 90), so to discard the trajectories performed by less relevant ships, such as smaller ships, tug boats, fishing boats, etc. These however were considered in the experimental phase, in which preferred routes are used to monitor the ships navigation considering the actual traffic situation.

In the initial phase of the project (WP1) three European ports were identified, for which it could be assessed the preferred routes concept applicability and usefulness in view of safety or efficiency of port operations. The three selected ports were Venice, Trieste and Rotterdam. Greater details on the ports characteristics and selection procedure can be found in Ref. 2.1.9.

5.3.2 Trieste

5.3.2.1 Input data set

The preferred routes extraction for the port of Trieste is performed on the data described in Table 1. The resulting number of trajectories is 4768 performed by 611 different ships during the year.

Port	Period	Ship types	Tot. #Trajectories	Tot #Ships
Trieste	Jan-Dec. 2016	Passenger, Cargo, Tanker, Other	4768	611

Table 1 – Trieste data set for preferred routes extraction.

5.3.2.2 Example results

The complete set of routes extracted for the port of Trieste is summarised in the table provided in Ref. 2.1.14. This section provides examples of the routes that may be used as recommended paths for ships of type Passenger, Cargo and Tanker, entering or exiting the port of Trieste.

Figure 6, Figure 8 and Figure 9 show examples of ingoing paths extracted for ships mainly of type Cargo with length greater than 200 m. It can be noticed that they all correspond to similar wind conditions. It shall be commented that the last path shall not be included in the set of preferred routes, because the route does not follow the ingoing channel that should be used by ships entering the port, unless they receive different indications by the maritime authorities due to special situations. The Italian Coast Guard Headquarters found this example a very interesting case to be further analysed on their side, as the route is performed several times always by the same 5 ships. The reasons why these do not follow the traffic separation schemes shall be verified.

Figure 7 shows the boxplot of the time variation into each waypoint of cluster number 5. It can be seen that the first waypoint is reached by the ships in times differing about 3 min among them. This typical range of time variability was commented with the Italian Coast guard, who confirmed the fact that this kind of variability is normal and that it is a suitable indication for this type of operations. There are cases in which this time variability is even larger due to the fact that some specific waypoints may correspond to the areas in which a ship may need to wait for the port pilot or for the access for berthing.

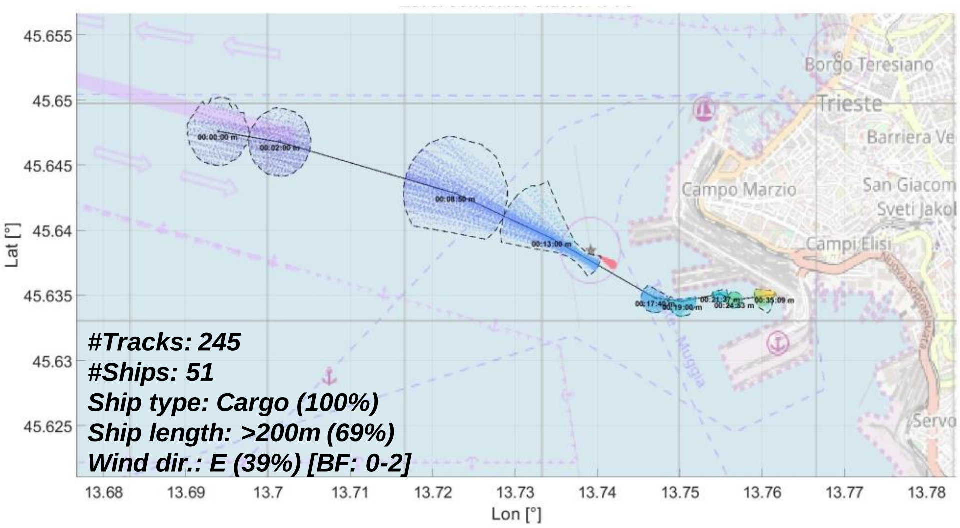

Figure 6 – Trieste - Cargo Ingoing path (Cluster ID 5).

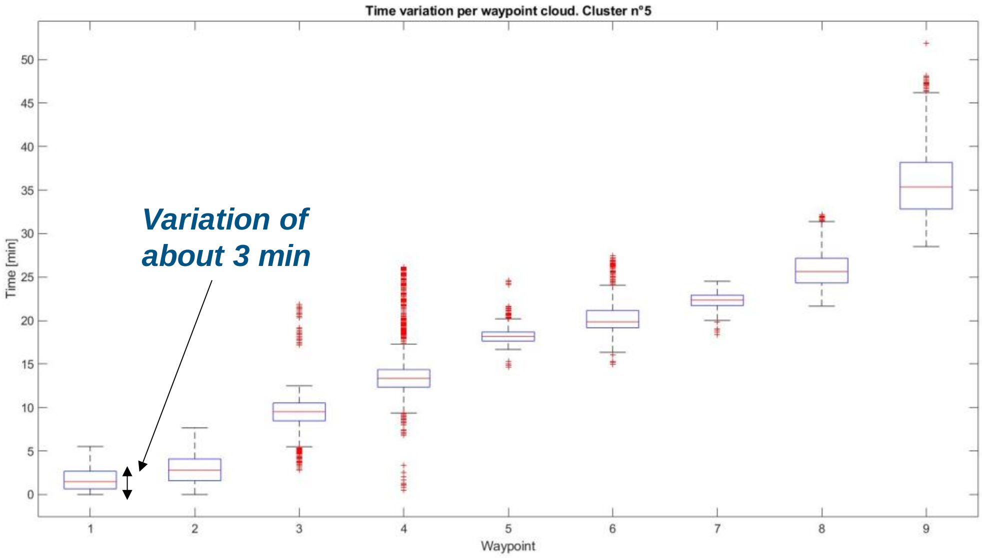

Figure 7 - Trieste – Cargo Ingoing path (Cluster ID 5) - Time variation per waypoint.

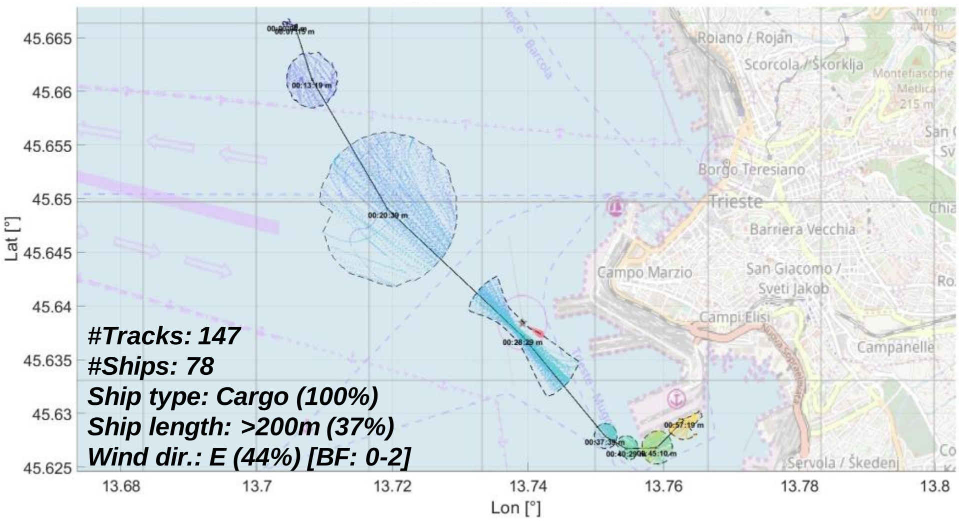

Figure 8 – Trieste – Cargo Ingoing path (Cluster ID 14)

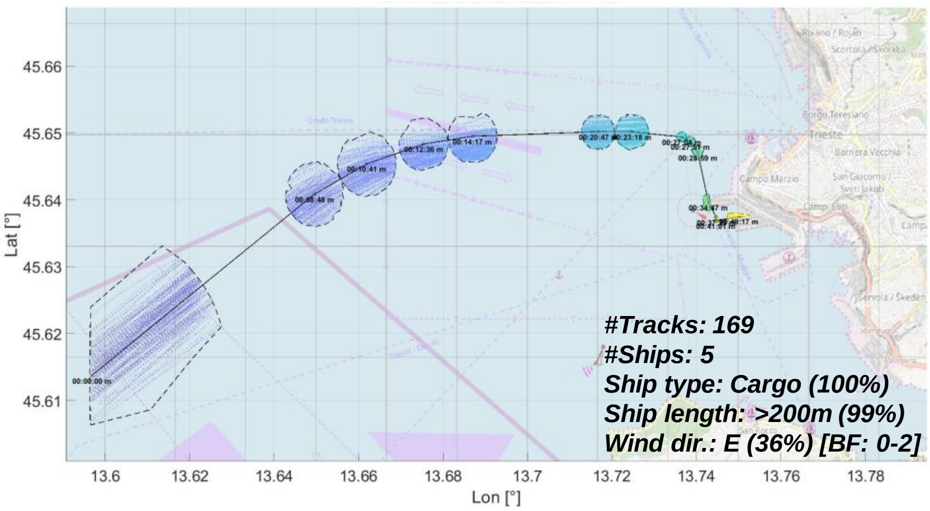

Figure 9 - Trieste – Cargo Ingoing path (Cluster ID 12)

Figure 10 and Figure 11 show examples of paths extracted for ships of type cargo and of length between 100 m and 150 m. It is observed that these paths are performed less frequently in the year 2016 than those presented in the figures above. It is also noticed that while the paths presented in the figures above are observed for low wind force (wind force in Beaufort scale is between 0 and 2), the tracks shown in Figure 10 and Figure 11 are observed in correspondence of wind force values between 3 and 5, in the same Beaufort scale.

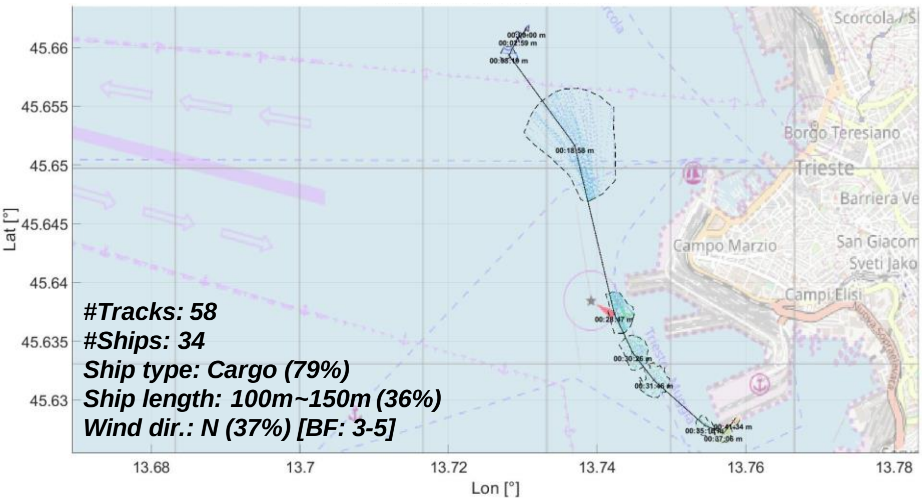

Figure 10 – Trieste – Cargo Ingoing path (Cluster ID 20)

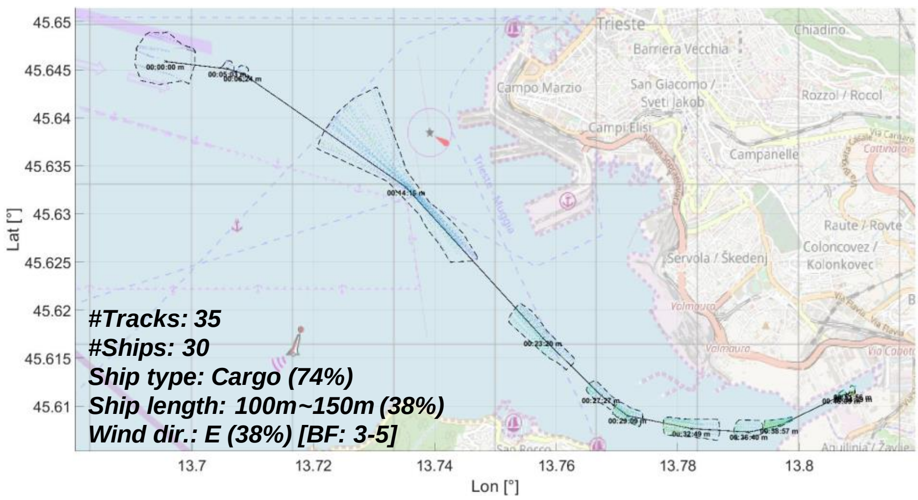

Figure 11 – Trieste – Cargo Ingoing path (Cluster ID 24)

Figure 12 and Figure 13 show two outgoing paths extracted for ships mainly of type cargo and length greater than 200 m. They both represent valid preferred routes for the port of Trieste, provided that the last waypoint of the former path is limited into the outgoing channel.

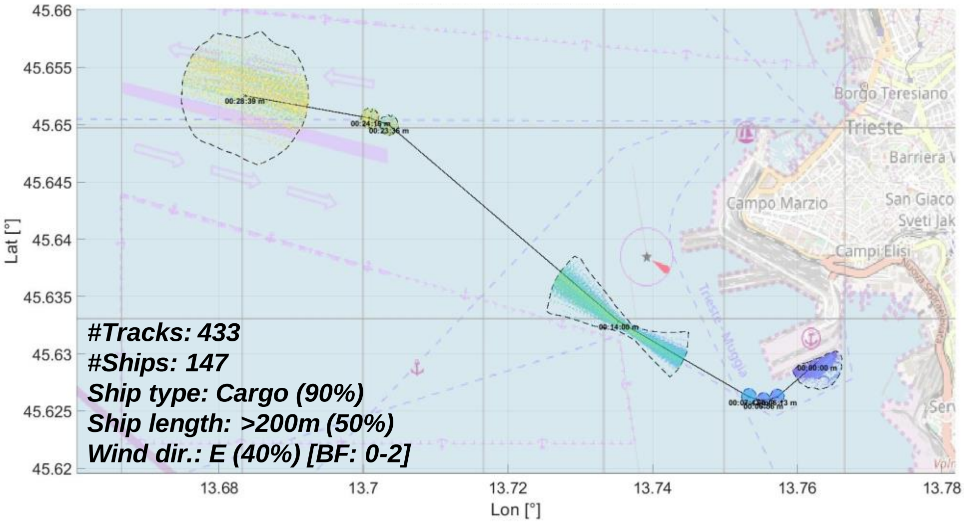

Figure 12 – Trieste – Cargo Outgoing path (Cluster ID 1).

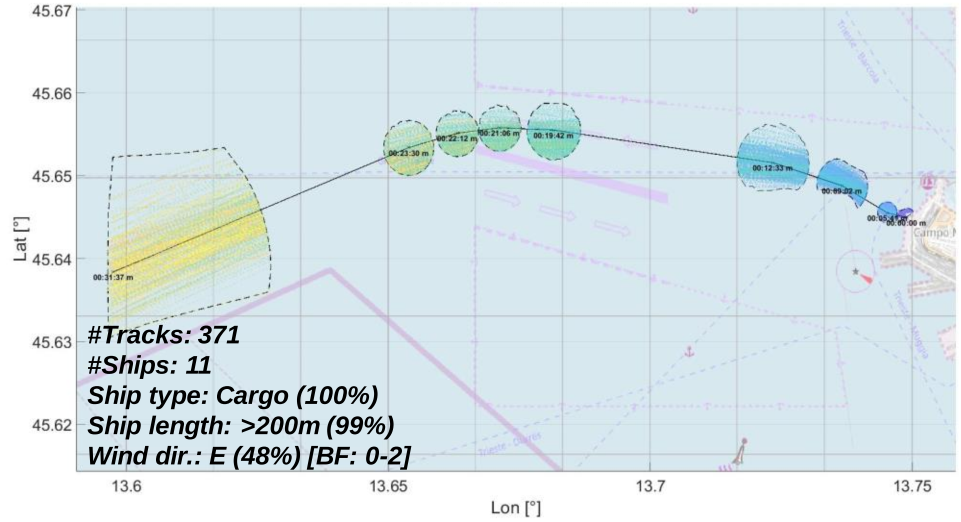

Figure 13 - Trieste – Cargo Outgoing path (Cluster ID 6).

5.3.3 Venice

5.3.3.1 Input data set

The preferred routes extraction for the port of Venice is performed on the data described in Table 2. The resulting number of trajectories is 6033 performed by 1008 different ships during the year.

Port	Period	Ship types	Tot. #Trajectories	Tot #Ships
Venice	Jan-Dec. 2016	Passenger, Cargo, Tanker, Other	6033	1008

Table 2 – Venice data set for preferred routes extraction.

5.3.3.2 Example results

The complete set of routes extracted for the port of Venice is summarised in the table provided in Ref. 2.1.14. This section provides examples of the routes that may be used as recommended paths for ships of type Passenger, Cargo and Tanker, entering or exiting the port of Venice.

As a general comment, it was observed that the tide and tidal current data do not change significantly from one cluster to another. It was commented with the Venice port authority that indeed it is expected that tides do not influence the routes of large ships as those considered in the present analysis. It was also reported that since autumn 2017, tidal current measurements could be available for future analyses. In the present case, the tidal current data are estimated by a model, and considering only the astronomic component. In addition, visibility sensors were recently installed at the port entrance, from the Malamocco channel, which could also introduce relevant information to be integrated into future possible analyses.

Figure 14 shows a route identified for ships of type passenger. Figure 15 shows also the time variability around each waypoint for the first path. As can be seen, the time variability around each waypoint is very limited for the case of Venice, compared to Trieste.

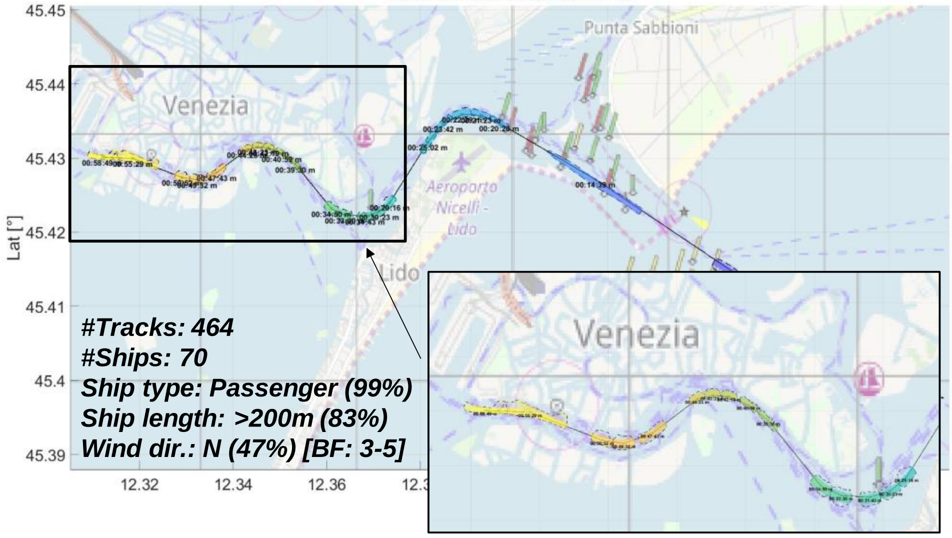

Figure 14 – Venice – Passenger Ingoing path (Cluster ID 10)

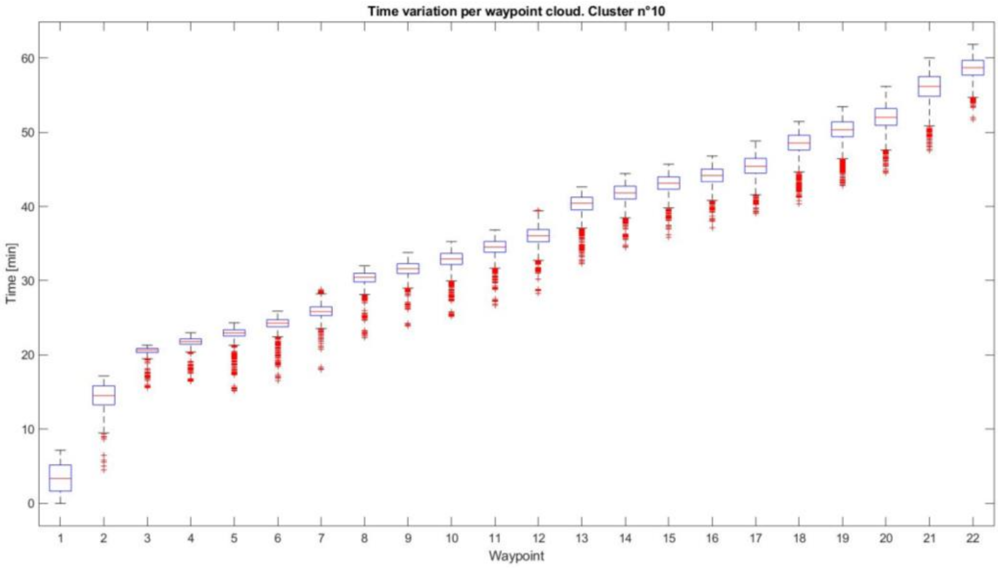

Figure 15 – Venice – Passenger Ingoing path (Cluster ID 10) – Waypoint Time variability.

Figure 16 shows an example of ingoing path performed mainly by cargo ships with length above 200 m or between 150 m and 200 m.

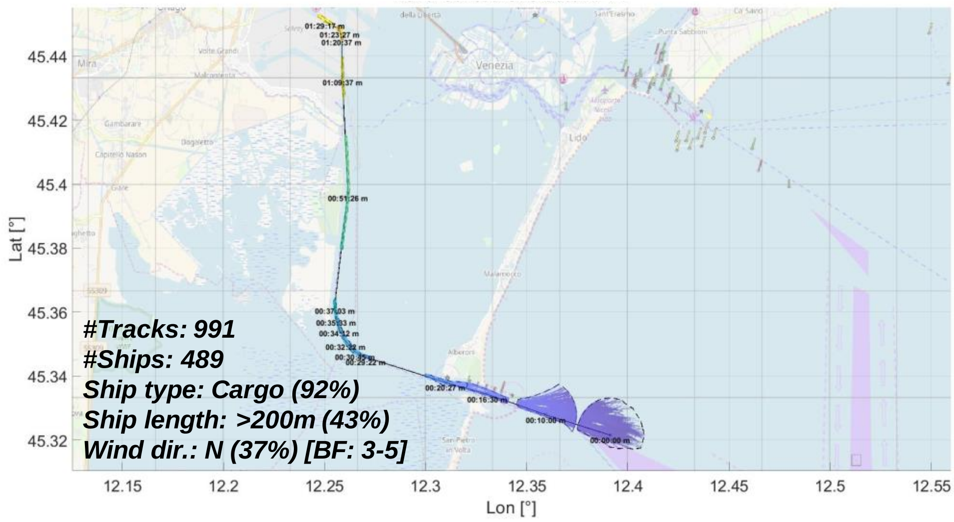

Figure 16 – Venice – Cargo Ingoing path (Cluster ID 1)

The position of the waypoints centres of the above routes was checked against the waypoints defined by the Venice port Authority under a different study, aimed at identifying the waypoints to be provided as virtual AtoNs to the ships accessing and exiting the port (see Figure 17 and Figure 18). This comparison confirmed the validity of the waypoints identified by S.A.T.E. under this study and provided to the port authority additional information related to the time instants at each waypoint and their tolerances.

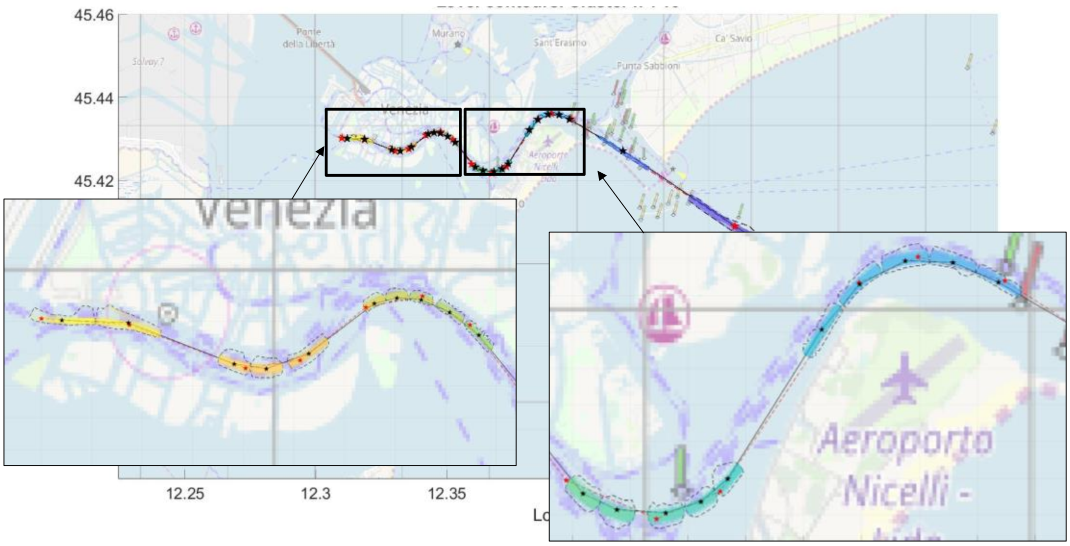

Figure 17 - Venice – Passenger Ingoing path (Cluster ID 10). Overlap between SATE's waypoints and those defined by the Venice port Authority in a different study.

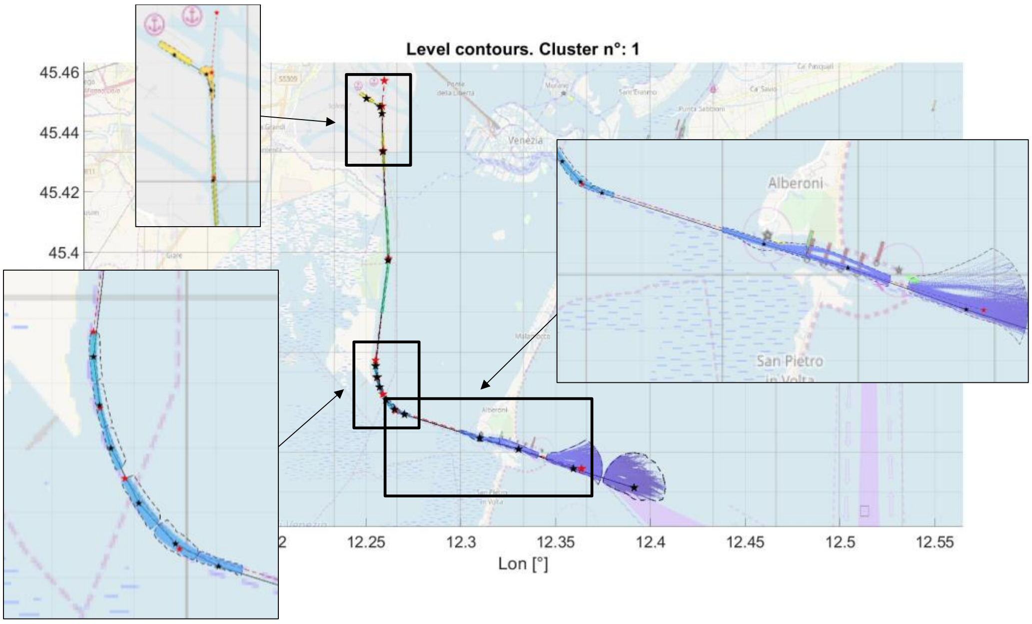

Figure 18 - Venice – Cargo Ingoing path (Cluster ID 1). Overlap between SATE's waypoints and those defined by the Venice port Authority in a different study.

5.3.4 *Rotterdam Maascenter*

5.3.4.1 Input data set

The preferred routes extraction for the port of Rotterdam Maascenter is performed on the data described in Table 3. The resulting number of trajectories is 16907 performed by 3076 different ships during the year.

Port	Period	Ship types	Tot. #Trajectories	Tot #Ships
Venice	Jan-Jun. 2016	Passenger, Cargo, Tanker, Other	16907	3076

Table 3 – Rotterdam Maascenter data set for preferred routes extraction.

5.3.4.2 Example results

The complete set of routes extracted for the port of Rotterdam is summarised in the table provided in Ref. 2.1.14. This section provides examples of the routes that may be used as recommended paths for ships of type Passenger, Cargo and Tanker, entering or exiting the port of Rotterdam.

An example of outgoing path that is followed by passenger, cargo and tanker ships is that of Figure 20. This path is the most recurrent one; as can be seen in the figure, this cluster of trajectories includes 4975 routes of 1820 different ships.

The port authority commented that this is an expected route. The wider waypoints in the large Maascenter area are in correspondence of areas in which normally port pilots get offboard.

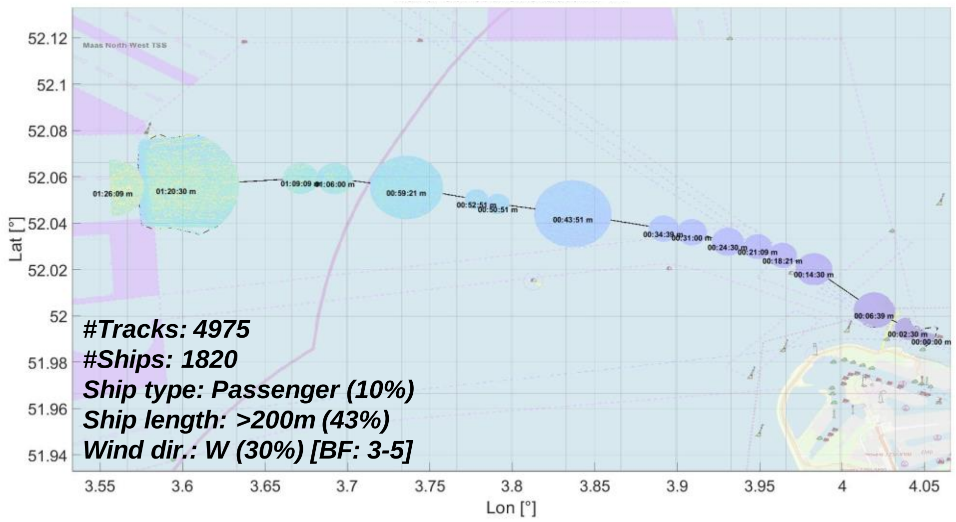

Figure 19 - RDM Maascenter – Passenger Outgoing path (Cluster ID 1)

Figure 20 and Figure 21 show two very similar paths, both starting from the southern entrance channel. The former (Figure 20) is a cluster of 3756 trajectories performed by 1677 different ships in the analysed period. The latter (Figure 21) is a cluster of 292 trajectories performed by 209 different ships.

They differ between them for the time duration of the trajectory and for the typical ships length. The former path is followed with higher speed than the second (its duration is of about 1 hour and 20 minutes) and by a higher number of ships of length below 200 m. Instead, the latter is performed in almost 3 hours and by a higher number of ships of length above 200 m.

Also this example was commented by the port authority explaining that ships need to slow down their route to wait until the port pilot is available or the port authority communicates the availability for berthing.

Figure 22 and Figure 23 show two paths extracted for ships mainly of type tanker, exiting the port of Rotterdam. The two routes have different trajectories. It has to be clarified with the port authorities and the coast guard whether the second trajectory is fully compliant with the maritime regulations, because it passes very close to the northers entrance channel. The second path was deemed of interest for the port of Rotterdam, who will further investigate the reasons for this route, which is not exactly the expected and normal path. They commented that this different route may be determined by the traffic conditions.

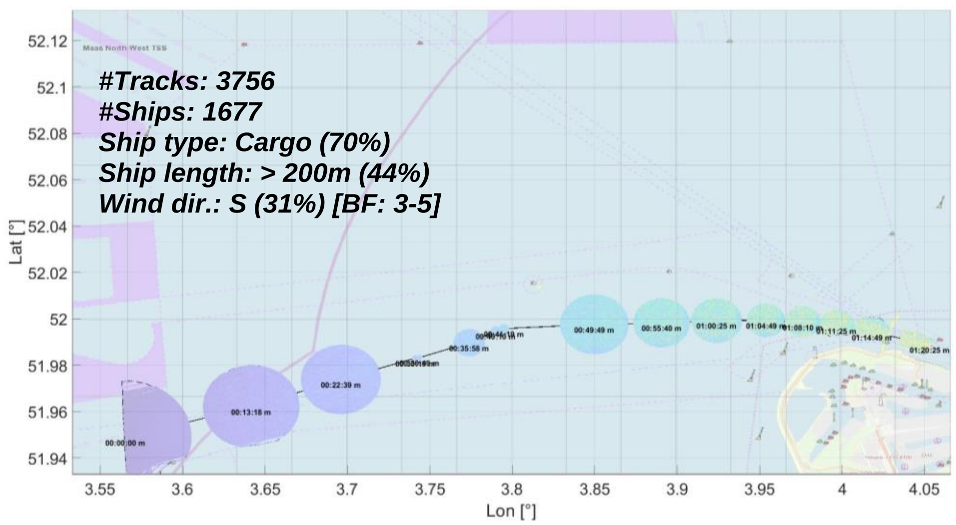

Figure 20 - RDM Maascenter – Cargo Ingoing path (Cluster ID 2)

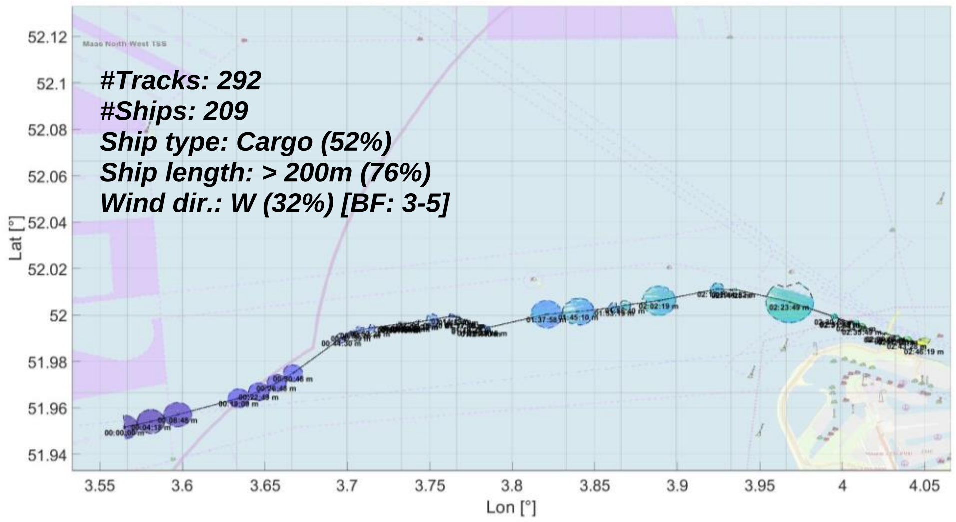

Figure 21 - RDM Maascenter – Cargo Ingoing path (Cluster ID 10)

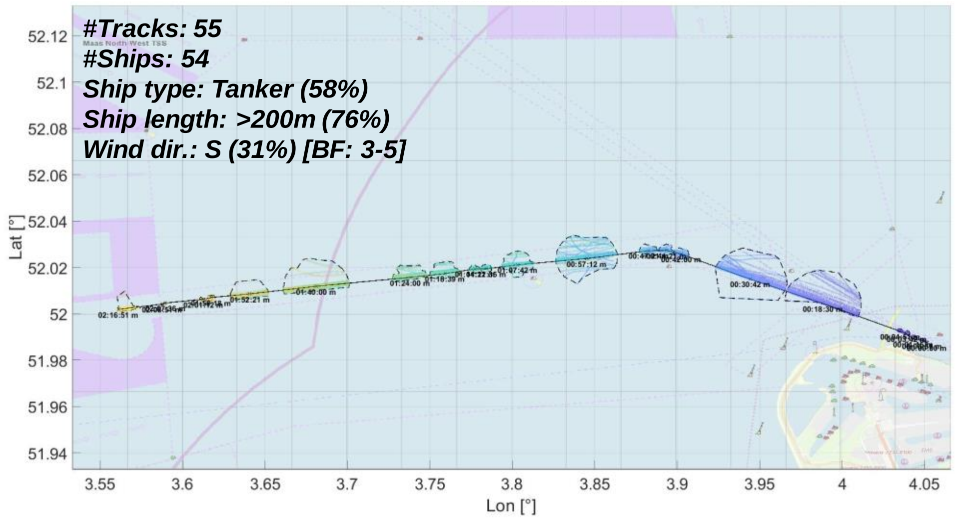

Figure 22 – RDM Maascenter – Tanker Outgoing path (Cluster ID 14)

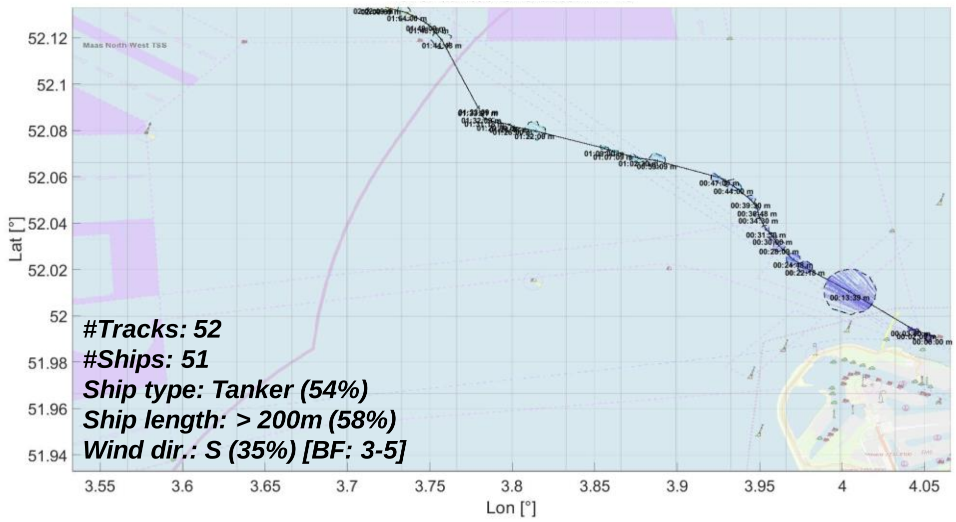

Figure 23 - RDM Maascenter – Tanker Outgoing path (Cluster ID 16)

6 EXPERIMENTAL PHASE

The possible final scenario for the use of preferred routes can be summarized as follows:

- Suggestion of the preferred route to follow to an incoming or leaving ship, both with a list of way-points and the relevant time;
- Monitoring of the conformance of the actual route of the ship with positions and times of the preferred route assigned to the ship.

A ***Demonstration Website*** was developed in order to evaluate the possible benefits, associated with the use of "preferred routes", for the three major European ports identified: Venice, Trieste and Rotterdam.

The website has today no access to real time data, but it has been developed in order to simulate as much as possible the final scenario thanks to the access to the database where all the AIS data available for the three ports have been stored, including those used for the identification of the preferred paths.

An example of experimental test performed with the ***Demonstration Website*** is relevant to one of the possible approaches to the port of Trieste. With reference to Figure 24, the approach is according to the traffic separation scheme (red arrow) and the final destination is the berth circled in red.

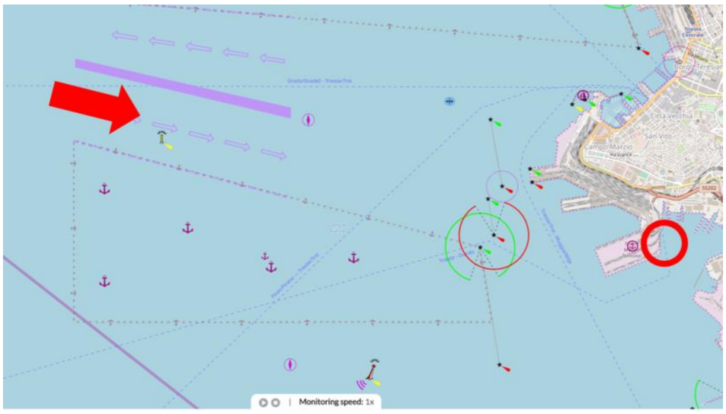

Figure 24 – Approach to the port and final destination

The preferred path proposed by the system is shown in Figure 25.

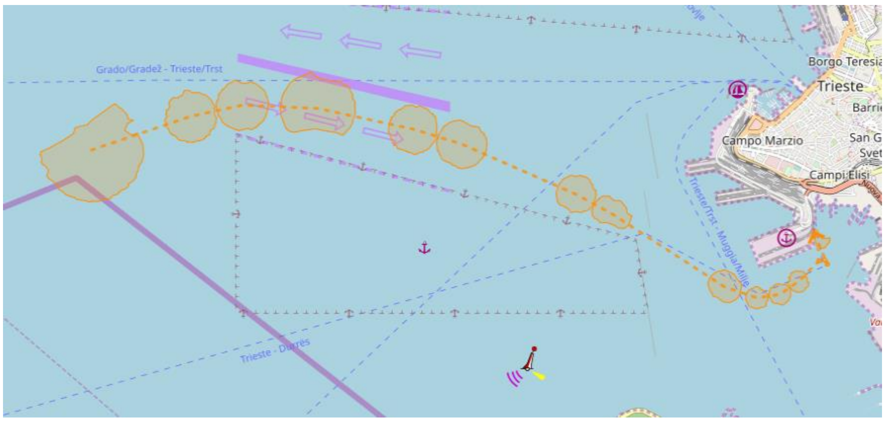

Figure 25 – Preferred path (#11)

This approach and berthing are used mainly by passenger ships. Hence the list of vessels proposed by the system, composed by all the vessels with the same destination and passing through the same starting area, has been filtered in order to reduce the choice to passenger ships. Moreover, constraints have been put on the length of the vessels and on wind direction and force.

In this case the initial position of the vessel coincides with the initial waypoint of the preferred path, as shown in Figure 26.

As shown in Figure 27, the vessel is well inside the warning/alarm frames along the route. It is worthwhile mentioning that in principle the system could cover also the area of manoeuvring and berthing, as shown in Figure 28, so opening a possibility to unmanned vessels if and when the level of technology will allow such a solution.

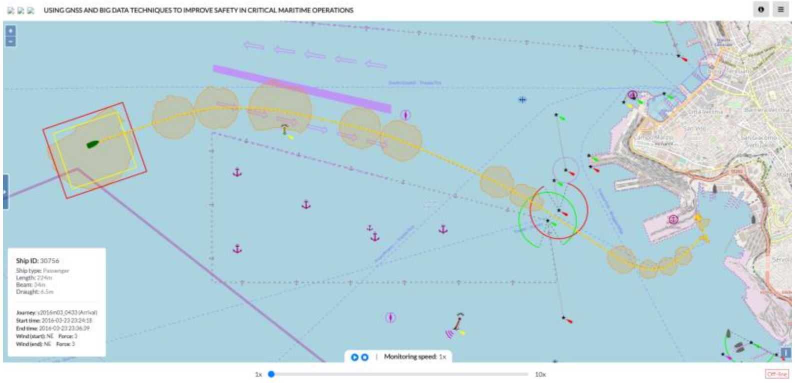

Figure 26 – The monitoring starts at the initial position of the vessel

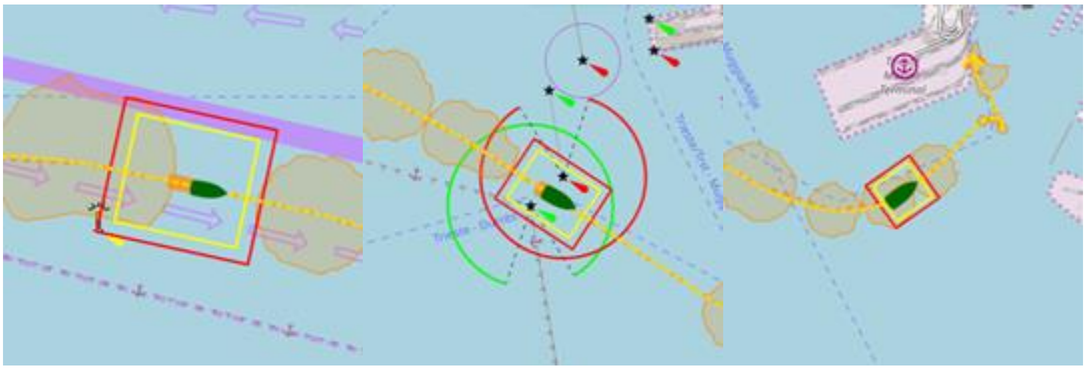

Figure 27 – Vessel positions and timing along the route compared with the preferred path

Figure 28 – Vessel manoeuvring close to the berth

7 PROJECT CONCLUSIONS AND WAY FORWARD

7.1 Main conclusions

The main conclusions and lessons learnt of the project can be summarised as follows:

1. The “certified path” concept should be modified into “preferred route” concept.
2. Big data techniques can be effective at extracting preferred routes, characterized by waypoints with time and geospatial boundaries.
3. The use of *crossing segments* is useful to select relevant traffic flows for the preferred routes definition.
4. The way AIS data are handled and stored should be improved to avoid jumps in the data.
5. The results evaluation was positive, as discussed with the relevant maritime stakeholders. Each of the three ports analysed showed different characteristics but for all of them the preferred route concept can be valuable.
6. This kind of analyses could be applied to monitor the traffic in the open sea or in anchorage areas, and to optimise logistics and pilots operations.
7. The preferred routes should be meant as a tool for monitoring the traffic and extracting unexpected situations.
8. The end users of the preferred routes information are mainly coast guards and port authorities.

7.2 Way forward for GNSS and big data techniques application for safer maritime operations

The approach developed in the project and the results obtained showed that the routes structure and preferences can be extracted from the available GNSS data, gathered by AIS systems, using big data techniques and applying limited knowledge of maritime operations.

The results of the project show that several techniques are needed to implement an effective data analysis and extraction of relevant information.

Filtering and pre-processing of the GNSS data are also extremely important in view of the application of other data mining techniques such as data reduction and clustering of trajectories, to remove noise and outliers.

As a possible way forward of this project, the integration of other data sources could be envisaged, considering that the quality and availability of AIS raw position data is not always sufficient to attain safety of operations.

For example, Earth Observation data could be integrated to identify ships or monitor ships navigation when AIS signalling has been turned off or is unavailable. It shall be considered, however, that the frequency of the EO data may pose some limitation on the possible level of traffic monitoring.

7.3 Future Satellite Navigation and Communication Systems

As already mentioned, the approach based on big data techniques applied to AIS data highlighted the importance of the performance of the AIS systems, especially in terms of availability and accuracy.

The present AIS systems use GPS and its augmentation system (DGPS or EGNOS). However, AIS is a ‘ship-based system’, so the performance of the system depends on the quality of the installation on board. For example, it happens that the AIS is not using the vessels GPS receiver but the receiver built in the AIS system. This is often not connected to a good quality antenna or to an antenna properly positioned, so the reception of this receiver is often worse than the ships system. Often the settings in the AIS are not correct. When the position of the receiver is incorrect one can have an error of approximately half a ship’s length. At the port of Rotterdam, these errors are noted by the shore based VTS, which compares AIS positions with radar observations. In the

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VTS the ship's position is corrected using the radar data. The pilots can receive these updated positions in their Personal Pilot Unit (PPU).

Pilots navigating large vessels entering or leaving ports often carry a PPU on board of the ship they assist. These units use high fidelity GPS receivers capable of using DGPS, EGNOS or RTK. The pilots carry the equipment on board because they do not want to rely on instrumentation on board of the vessels as the accuracy and reliability of onboard systems is often insufficient for piloting the ship. This refers to the position accuracy but also to the set up of the system on board and the onboard available chart material. In some approaches the pilots use charts that are regularly updated. These are more detailed and more up to date than commercially available ENC's. It should be realised that some of the manoeuvres pilots in the Port of Rotterdam do are impossible without the support of such a system.

In the Italian ports analysed in the project, port pilots are not adopting PPU, currently. However, augmentation systems are used to improve position accuracy and send position error to the ships through the AIS network.

Therefore, it shall be considered that the full system performance of the positioning system is determined by the performance of the GNSS and augmentation systems, of the AIS base stations and of on-board AIS receivers, which often have different quality levels.

In this regard, the main recommendation for the use of such techniques to improve safety in maritime operations, in addition to routes extraction and monitoring, is to promote and incentivize the use of accurate positioning systems with high availability.

Furthermore, the use of Galileo (with EGNOS) may be extremely relevant to improve quality of the data to be processed, to assure high availability during operations, in addition to its increased spoofing detection capabilities compared to GPS.

Based on the results of the project, it is possible to assess the desirable full system requirements in order to enable safer operations based on GNSS, which can be achieved by the GNSS system plus an augmentation system.

In particular, it is deemed important to consider tighter requirements in terms of accuracy. For example, Venice channels are as narrow as 10 m and are typically one-way channels. In these cases, the full system accuracy shall be below 1 m, especially considering the application of preferred routes in intense traffic situations and low visibility conditions. In addition, taking into account that the preferred routes provide indications on the speed of execution of the trajectory, a position error in the order of 10 m may imply also unacceptable errors in the time stamps of the trajectories that are extracted as preferred routes. It is highlighted that 1 m accuracy is within the performances obtained through DGPS or EGNOS augmentation systems, which therefore play an extremely relevant role in harbour approach applications.

ANNEXES

NONE