SIFLOW21. PREDICTIVE SIMULATION OF NAVIGATION CHANNELS AND PORT INFRASTRUCTURE CAPACITY WITH AUTOMATIC IDENTIFICATION SYSTEM (AIS) DATA ASSESMENT

Raul Redondo (1), Carmen Ayuso (2) and Jose R. Iribarren (3)

(1) Siport21, C/Chile 8, 28290 Las Rozas, Madrid, Spain, raul.redondo@siport21.es

(2) Siport21, C/Chile 8, 28290 Las Rozas, Madrid, Spain, carmen.ayuso@siport21.es

(3) Siport21, C/Chile 8, 28290 Las Rozas, Madrid, Spain, jose.r.iribarren@siport21.es

Keywords: Traffic Flow simulation, port efficiency, AIS data, Risk Assessment.

1. **ABSTRACT:** Port development projects require reliable data for cost-benefit evaluation of the investment and selection of the best alternative. The objective of the analysis is to confirm that they will respond to the future capacity of the port together with an adequate safety/risk level, optimizing the dedicated resources. A methodology is described combining a mathematical model of traffic forecast with the evaluation of nautical risks. As a result, it allows to establish the service&safety level of the navigation channel or the new infrastructure and to set the basis for decision-making. SiFlow21 is a predictive simulation model for maritime traffic, developed by Siport21. It allows to quantify the movement of ships in the waterplane area of a port. It takes into account the topology of the port, the various traffics with their particular volume and seasonal distribution, the navigation rules, tidal conditions and local maritime climate. It is extremely versatile to adapt to channels and ports that can become very complex.

2. INTRODUCTION

Port infrastructure development projects require reliable data for the cost-benefit evaluation of the investment and the selection of the best alternative [1]. The dredging works to deepen port access channel are an outstanding example to illustrate this kind of projects. The objective of the analysis is to confirm that these development projects respond to the planned capacity of the port in the future, providing admissible congestion levels, together with their level of safety/maritime risk, optimizing the port resources and, therefore, the associated costs [2].

At the request of several international entities and companies, Siport21 has developed a very versatile mathematical model, which is able to complete this kind of analysis in a wide range of complex environments and with different types of traffic. Siflow21 (Maritime Traffic Flow Simulation) allows reproducing the movement of ships in a navigation channel or port area considering their specific characteristics. The construction of the model includes as a first step the calibration against the real situation described by the AIS (Automatic Identification System) data [3] [4], and detailed port terminal data, which ensures its reliability. Thus, future scenarios are compared with the current situation based on the definition of a set of evaluation indices. These refer to both service levels of the port or waterway (congestion, delays, use of resources, ...) and safety levels (risks of grounding, collision, ...).

To determine safety levels a preliminary assessment of the individual risk per ship type based on different parameters (manoeuvring models, navigation areas, encounter & grounding areas) is required. Further on, with the SiFlow21 results the future risk levels can be estimated based on the infrastructure and operational modifications together with the increase in the number of ships, encounters, overtaking, … [5] [6]

3. METHODOLOGY

The methodology applied combines a mathematical model of traffic prediction with the evaluation of nautical risks, thus allowing to establish the optimum safety&service [19] levels of the navigation channel or the future port infrastructures (basins and/or berths).

These studies typically start with the AIS data analysis, allowing to accurately describe quantitatively the traffic movements in the current scenario (type of vessels, number, sizes and drafts, routes, speeds, crossing / overtaking manoeuvres, anchorage operations, scheduled calls, seasonality, traffic interferences, berths occupancy, etc.). Given the enormous volume of data (millions of records each year), the analysis is based on Big Data, Data Analytics and DataViz techniques [7] (algorithms to identify space-time relationships between the different traffics and physical conditions with advanced representation methods).

The AIS data analysis allows defining most of the inputs required for the accurate building of the maritime traffic simulation model (base model). Siflow21 is an in-house predictive simulation model of port capacity. It allows to accurately quantify the movement of ships in the port waterplane, taking into account the topology of the port area (access channels, berths, basins and anchorage areas), the different types of traffic with their particular frequency, seasonal distribution, navigation rules (DST, priorities, maximum speeds, minimum UKC, Pilot or tug assistance, crossing rules, ...), the tidal conditions and the local maritime climate; all of this with a great versatility to adapt to channels and ports that can become very complex.

The program modules describe the different system components with their particular attributes and the interaction among them. Once the system is defined, ship arrival/departure processes are launched according to the observed statistical distributions [8] (AIS data) and tackling current navigation regulations.

Once the model is built, it is calibrated against real data (mainly extracted from the AIS analysis and other available sources). Then, future scenarios are described and quantified (infrastructure works, new terminals, changes in navigation rules, increase in traffic volume). The different scenarios are simulated using a random method that covers typical periods of one year. The corresponding quality and safety KPIs [9], defined ad-hoc for each specific project, are computed. In this way, a reliable assessment of the future situation is available as a basis for decision-making.

This methodology has already been applied in numerous cases: Bahía Blanca (Argentina), a project to expand the channel in a long estuary operating with tidal windows, interference with LNG traffic (channel priority); Buenaventura (Colombia), cost-benefit of an expensive deepening project; Río de La Plata-Hidrovía (Argentina), with demanding draft limitations, new traffic, increased volume; Guadalquivir River (Spain), optimization of operations, increase in capacity of the fairway without dredging, rescheduling of manoeuvres; bays in the Philippines, with high anchorage congestion in mixed traffic areas; Tarragona (Spain), new terminal close to the port access channel, interference and risk assessment. Some case studies and the benefit of the results obtained are shown.

3.1 AIS data analysis

The AIS system [3] [4] allows the identification and tracking of ships, automatically, from other ships, or coast stations. This system is based on a device installed on board that continuously and automatically transmits information that allows other ships in the area or onshore stations to identify them and to find out their position and movement parameters.

The AIS has been developed under the auspices of the International Maritime Organization (IMO) and its installation and use in ships, subject to the SOLAS Convention (Safety of Life at Sea), is mandatory since December 31, 2004. The vessels obliged to incorporate these devices are:

- All vessels on international voyages with a gross tonnage (GT) greater than or equal to 300
- All vessels on non-international voyages with gross tonnage (GT) greater than or equal to 500
- All passengers regardless of size

The AIS equipment emits messages containing data related to the position and state of the ship movement with a variable periodicity depending on the navigation status, speed, and the manoeuvre she performs.

Once the quality and reliability of the available AIS data has been verified, a large number of variables are analysed in order to know with a high accuracy level the behaviour of maritime traffic within the port system, as well as to define the input data required for the maritime traffic simulation model [18]. Some of the most relevant variables in this type of studies are listed below:

- Analysis of ships during navigation:
  - Type of vessels according to cargo and size

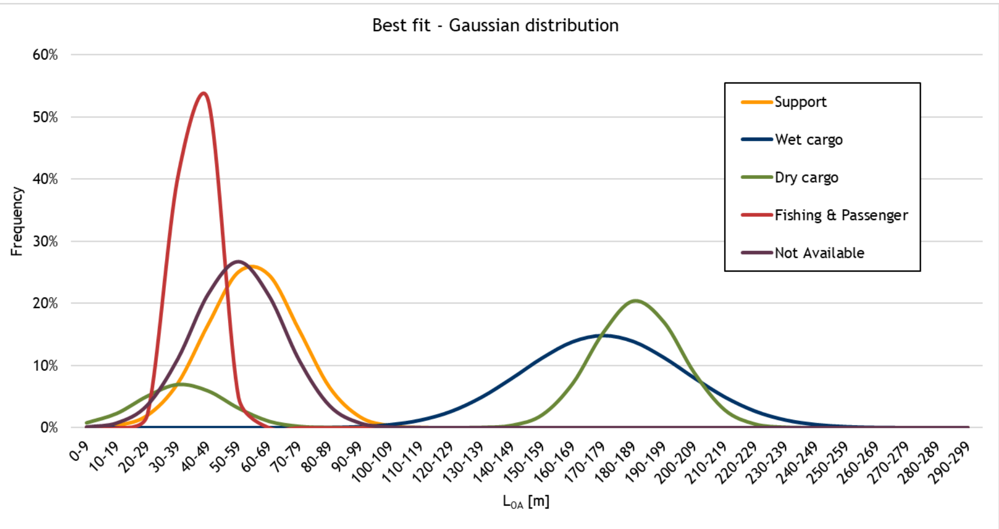

Figure 1: Vessels size according to the cargo. Source: Siport21

  - Calls frequency and seasonality (cruise ships, for example)
  - Crossing / overtaking manoeuvres: if any, location and frequency of these events, combined dimensions of meeting ships, speed and distance, etc.
  - Manoeuvring strategy: waiting, turning areas, navigation speed, use of tugboats

- Load condition based on access or departures and, therefore, type of operation (import or export)

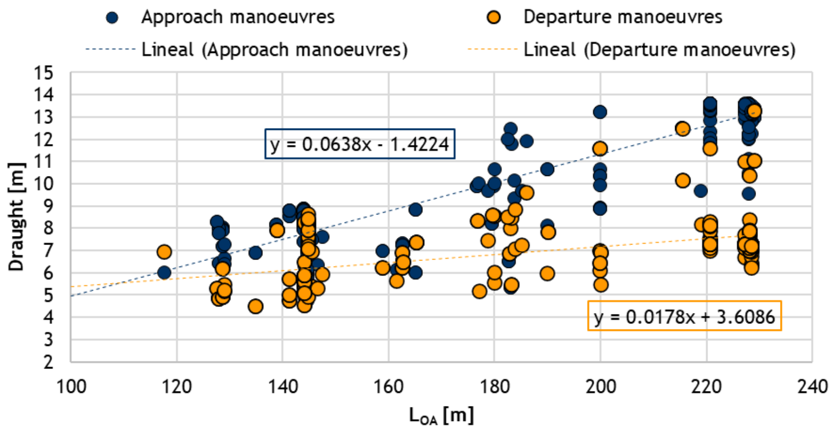

Figure 2: Import and export operations analysis. Example of loading condition for approach and departure manoeuvres. Source: Siport21

- Vessels' route: access channel to the system, exit channel and intermediate points (anchorages, terminals)

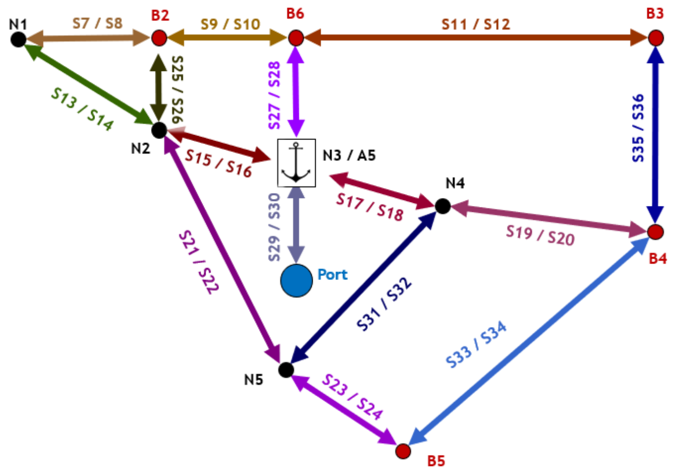

Figure 3: Route analysis. Example of a ship route in a complex system. Source: Siport21

- Analysis of ships at anchorage:
  - Frequency of anchorage operations (ratio anchoring vessels/ total vessels)
  - Type of vessels that usually anchor (cargo and size) and priority traffic (unusual anchorage, direct access without waiting)

- Time spent at anchor depending on the type of vessel
- Anchorage preferences: area in which ships usually anchor depending on the type of ship (cargo and size) and terminal
- Occupation of the anchorage areas (average occupied area, number of simultaneous vessels)

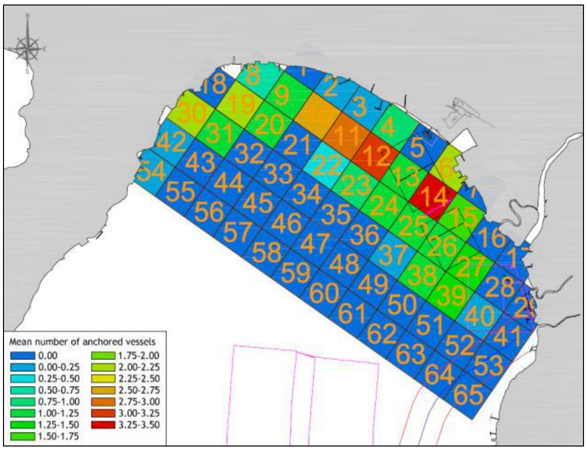

Figure 4: Occupation analysis of anchorage areas. Example of a bay occupation map. Source: Siport21

- Analysis of ships at berth:
  - Type and size of vessels that access each terminal
  - Occupancy level of the terminals

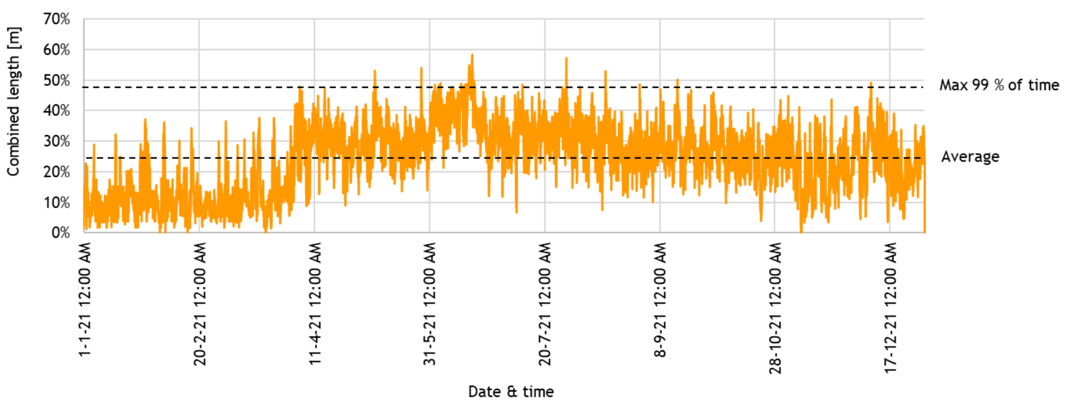

Figure 5: Occupancy level time series. Source: Siport21

  - Time spent at berth depending on the terminal (efficiency of loading / unloading equipment), cargo and size of ships

The results of the AIS data analysis can be collected in a wide variety of graphs, from point clouds to single track plots, occupancy density maps ("heatmaps") or position distributions.

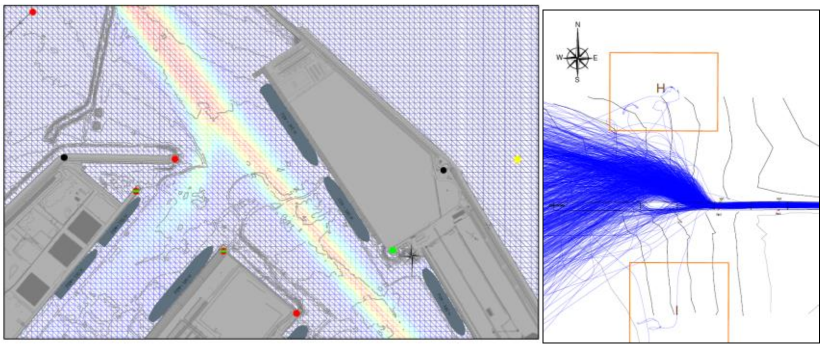

Figure 6: Occupancy density of port areas (left) and access trajectories to a navigation channel (right). Source: Siport21

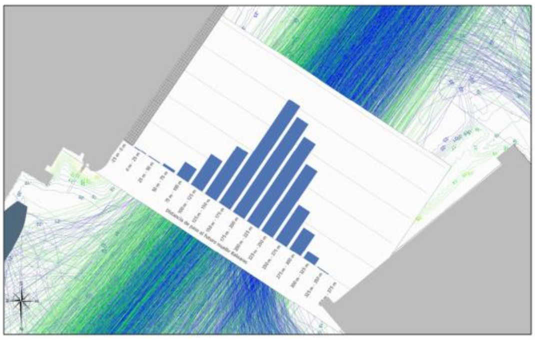

Figure 7: Geometric distribution of vessels in a relevant passage section. Source: Siport21

3.2 Definition of Key Performance Indicators (KPIs)

In order to facilitate decision-making, a series of key indicators is defined that will allow different future scenarios to be compared with the current situation. The KPIs (Key Performance Indicators) [9] must be aligned with the objectives and particularities of the project. In addition, the same indicators will serve as the basis for the calibration process of the maritime traffic model.

After calibrating the maritime traffic model and analysing the different scenarios proposed, the ad hoc indicators are elaborated, and the advantages and disadvantages of the different measures considered (infrastructure projects) are compared.

The most common indicators in this type of studies are those referring to the efficiency of the port system. However, there are other indicators such as risk or economic indicators that may be relevant in decision-making [10].

Some examples of the most common key indicators are highlighted below:

- Related to the use of the terminals: the occupation of the terminals as well as the fraction of time that the ships remain berthed and are not waiting (efficient time at berth) are indicators of both capacity (extra margin of the terminals to absorb more traffic) and efficiency (demurrage in the terminals).

- Related to the use of the anchorage areas: as with the terminals, the occupation of the anchorage areas also indicates the capacity of the system (extra margin of the anchorages to absorb more traffic). Likewise, higher use of anchoring areas indicates greater congestion and, therefore, less efficiency.

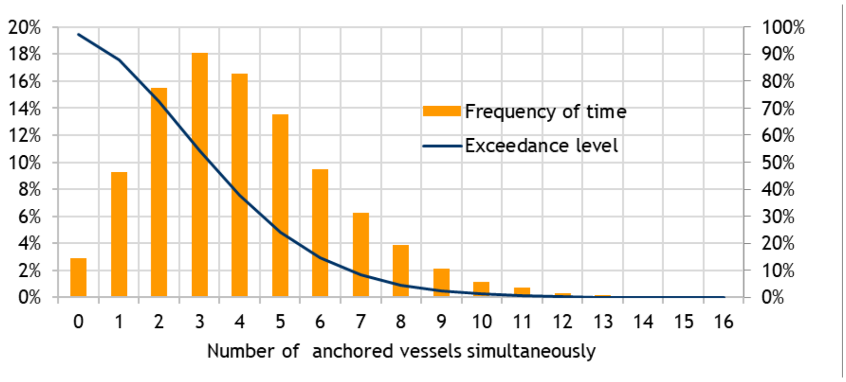

Figure 8: Indicators related to the use of anchorage areas. Simultaneously anchored vessels. Source: Siport21

- Related to the vessels that access the system: waiting times, depending on their size, draught, cargo and target terminal:
  - Average waiting time
  - Area where they wait
  - Reason for waiting. Bottlenecks identification [11]
- Related to economic income: if enough information is available, the economic income derived from nautical activities can be estimated, such as port entry fees, use of the VTMS service, use of anchorage, terminal, pilotage, towing and mooring fees.

3.3 Model building

The model building consists of defining and characterizing the following elements, which make up the creation of a navigation system:

- Vessels: all the characteristics of the vessels to be generated are described in this module to create a random arrival sequence close to reality (according to type: destination, arrival patterns, route to be sailed, destination, minimum time at berths, …). The time it takes to navigate each section of the channel is also defined, linked to navigation speed (according to type/size of vessel, approach / departure). This module also determines how many ships are generated according to the type of fleet and how the arrival time varies between ships, including seasonality.
- Static elements of the port:
  - Terminals. Points where the ships access, remain for a determined minimum time required to carry out the loading / unloading operations and wait in the terminal before starting the departure manoeuvre, only if needed. The main parameters are the maximum number of simultaneous vessels, the berthing length available and the depth.
  - Anchorages. Points where ships wait, only if needed. It is also possible to require ships to wait a minimum time before continuing their route for carrying out any kind of activity such as pilot

boarding. The main parameters are the maximum number of vessels anchored simultaneously, the available anchoring area and depth, as well as special anchorages (dangerous cargo, for example).
    - Channel sections. These are the sections transited by ships between elements of the port (channel to anchorage, anchorage to terminal, etc.). The depth and the maximum number of vessels that can navigate simultaneously through a section of channel are defined.
- Navigation rules (traffic control, Pilots). This extensive module describes (for each navigation area and ship type) the rules applicable to crossing and overtaking manoeuvres, minimum distance during navigation and minimum underkeel clearance. Finally, the environmental limits (tide, wind, current and waves) are also included.
- Wind, wave, and visibility conditions: annual/seasonal distributions of wind (direction and speed), waves (direction, period, wave height), and visibility (good or bad) are described in this module, representing the local climate.
- Tide and current: the variations of the water level and current intensities are defined in the different elements of the system (terminals, anchorages and sections of the navigation channel) throughout the year.

3.4 Simulation

Once all the modules of the model have been defined, the simulation process starts with the 'vessels' module, random generation of vessel arrivals based on statistical distributions tuned to the AIS data. After the generation of each ship, the restrictions along its pre-defined navigation route are checked. The checking process is as follows:

- Regulations are checked at the closest port element where the vessel can wait (water level and availability/capacity).
- Once the feasibility of waiting at the closest possible port element has been verified, the regulations are checked during the route from the current position to the mentioned waiting point. In each section of this route, the regulations are verified:
    - Crossing events: based on the navigation area, vessels type and size, the crossing is allowed or not.
    - Minimum safety distance: to the nearest vessel, depending on the type and size of the vessels.
    - Minimum under keel clearance.
- In case there are restrictions:
    - During the route to the nearest waiting point, the vessel will wait before starting its navigation until this navigation is feasible in compliance with the applicable regulations.
    - At the closest waiting point: the vessel will wait before beginning its navigation through the corresponding sections until waiting in this area is feasible in compliance with regulations or until complete navigation to the next waiting area is feasible.

This verification process is repeated along the complete route of the ship. The terminals are considered as a point where ships can also wait. However, unlike anchorages, ships must remain for a pre-defined service time in the terminals (whether they wait there or not).

Once the model is built, the calibration is carried out running the model in an iterative process of simulation - analysis of results - adjustment until reaching results close enough to reality. The calibration process is always carried out based on a real scenario, from which information on the behaviour of maritime traffic is available with an adequate level of detail and accuracy.

The level of detail required to achieve reliable results is based on the analysis of AIS data. However, there is some information that cannot be extracted from its analysis, such as the actual draft or the causes of waiting events. Therefore, it is advisable to consult additional sources and hold interviews with local experts who can expand the available information.

3.5 Alternative scenarios assessment

In general, the new alternative scenarios of interest will be those that have an impact on the current traffic flow, such as increase in traffic volume, changes in infrastructure (new terminals, channel expansion dredging, additional entrances, ...), new regulations (VTS, traffic separation schemes (TSS), organization of anchorages, crossing, minimum UKC, assignment of Pilots or tugboats, ...), new types of significant traffic for the port system (for example, LNG import), etc.

Once the model has been built and calibrated, the results of the current situation are used as a reference for the comparison of the KPIs of the alternative scenarios. Siflow21 is a very versatile tool that allows to adapt the model and include various changes in order to assess their impact (positive or negative) on traffic behaviour, based on the key indicators defined for each study.

On the other hand, and with the objective of analysing the impact of relevant changes in the traffic flow not only in the short term, but throughout a certain period of time (lifetime of a new infrastructure, for example), a minimum of 3 traffic volume scenarios must be analysed in order to allow interpolations with an adequate level of precision.

The traffic volume for future scenarios is defined through forecast studies, considering relevant information such as historical evolution of traffic, investment needs and capacity improvement, master plans for expansion of current facilities and planning of new terminals [12].

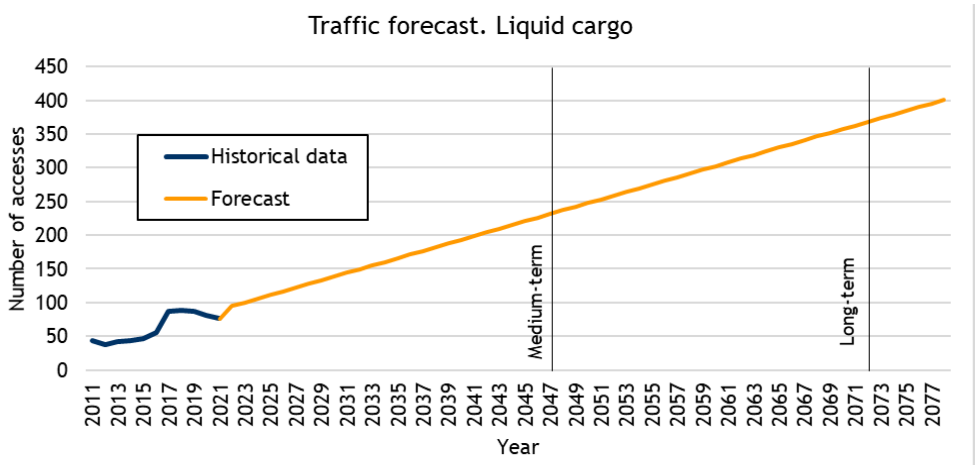

Figure 9: Example of traffic forecast based on historical data. Source: Siport21

The analysis of several traffic volume scenarios also allows to determine the capacity of a given infrastructure scenario (maximum number of vessels that can access the system), under congestion acceptability criteria (waiting times) according to the type of traffic. This process makes it possible to establish recommendations regarding the most appropriate corrective action, at the most appropriate moment.

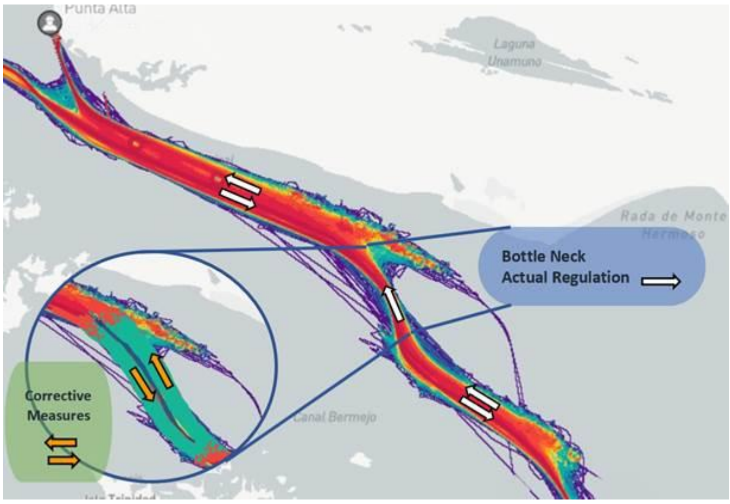

Figure 10: Example of corrective measure (crossing area, double lane) for a scenario with high congestion levels (single lane area). Source: Siport21

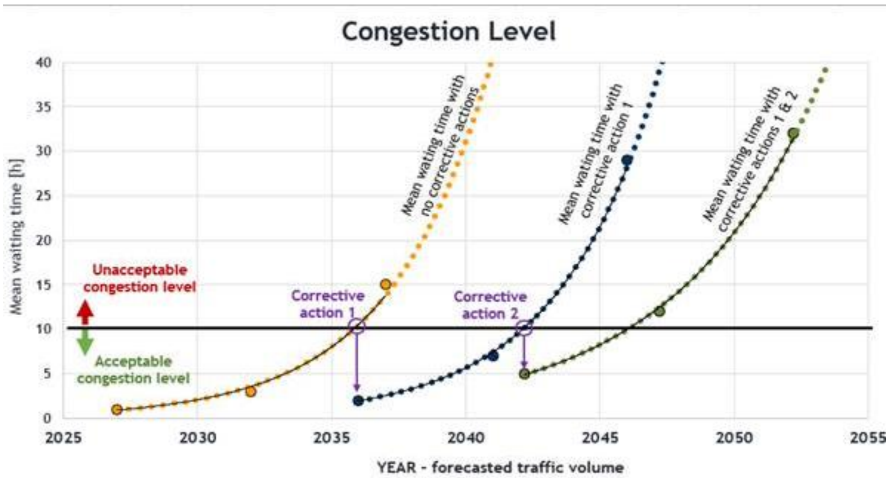

Figure 11: Example of application of corrective measures at the optimum application time (unacceptable level of congestion). Source: Siport21

Based on a preliminary assessment of the individual collision and grounding risk per ship type and size in the different channel stretches and port area, it is possible to estimate the future global risk of the navigable area based on the future number of accesses per each ship type and size, and the number of estimated encounters/overtakings for each of the alternate scenarios.

Finally, the combination of key indicators results allows to determine the optimum combination of actions on the scenarios, establishing adequate combined levels of congestion and safety for nautical activities [13] [14].

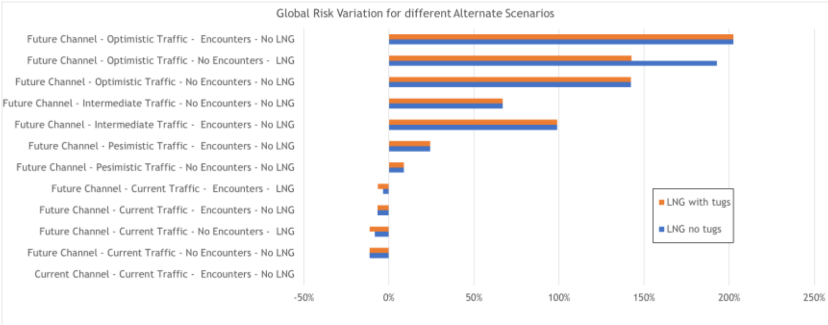

Figure 12: Nautical risk assessment for the alternative scenarios. Source: Siport21

4. CONCLUSIONS

The methodology described involves carrying out studies with a high level of detail in order to accurately reproduce both current and future scenarios, by means of a verification process of the reliability of the results. Likewise, Siflow21 model allows many variables to be introduced as input parameters that precisely define the reality of maritime-port traffic systems with high complexity. As a result, the optimum safety&service can be given for any complex maritime system for both, current and future scenarios. Some of the most relevant case studies, due to their innovation or relevance, are shown below:

- Channel deepening project. When access to a navigation channel is determined by the tidal level, one of the most effective measures to reduce waiting events is to deepen the corresponding navigation areas to increase the tidal windows. In this sense, maritime traffic simulation makes it possible to find out to what extent a given dredging project reduces traffic congestion and, likewise, determines the capacity of the new dredged channel (how many more ships per year can access after dredging). A balance point is sought between the dredging depth (with the corresponding cost) and the operating gain due to the reduction of demurrage.
- New dangerous cargo terminals. The LNG transport, especially, entails the implementation of a series of strict and specific safety measures. One of the main concerns is, therefore, the possible effect that this new traffic may have on the general behaviour of a given port.
- Enabling of crossing areas. Crossing areas are frequently applied to reduce congestion. However, these are critical areas in terms of nautical risk. Maritime traffic simulation studies support decision-making, finding the optimum point for congestion reduction while keeping safety level.
- Rearrangement of anchorage areas. There are port systems, such as bays or refuge areas, in which anchorage operations represent a common and important operation. As the volume of traffic grows in these areas, it is common for the anchorage operation, to evolve into more chaotic and optimizable situations. Different criteria for rearrangement of the anchorage areas can be simulated, also including changes in the regulation. This evaluation can achieve a substantial improvement not only in the efficiency of the system, but also in nautical risks.
- Global or individual increase in traffic intensity (number of arrivals). In terminal expansion projects that involve a significant increase in the number of calls or access for larger vessels with

more demanding restrictions (draft, towing, weather limitations), the impact of this increase on system congestion can be assessed. The same can be said of an organic increase in port traffic.

5. REFERENCES

1. Davide Sartori, Geslomina Catalano, "Guide to Cost-benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020", 2020
2. Mihai Neagoe, Hans-Henrik Hvolby, Mohammad Sadegh Taskhiri And Paul Turner, "Using discrete-event simulation to compare congestion management initiatives at a port terminal", 2021
3. IALA, "Establishment of AIS as an Aid to Navigation 1062", 2008
4. IALA, " Management and Monitoring of AIS Information 1050", 2005
5. Xavier Bellsolà, Winnie Daamen, Tiedo Vellinga And Serge P. Hoogendoorn, "Risk Assessment Methodology for Vessel Traffic in Ports by Defining the Nautical Port Risk Index", 2019
6. Groenveld, R., Beimers, B. And Vis, F.C., "A Simple Method to Assess Nautical Risks". Copedec Conference, Colombo, Sri Lanka, 2003
7. Dong Yang, Lingxiao Wu, Shuaian Wang, Haiying Jia And Kevin X. Li, "How big data enriches maritime research – a critical review of Automatic Identification System (AIS) data applications.", 2019
8. Shelby L. Brumelle, "A Generalization of Erlang's Loss System to State Dependent Arrival and Service Rates", 1978
9. Ioannis Kaparias And Michael G. H. Bell, "Key Performance Indicators for traffic management and Intelligent Transport Systems", 2011
10. E. Peris-Mora, J.M. Diez Orejas, A. Subirats, S. Ibáñez And P. Alvarez, "Development of a system of indicators for sustainable port management", Marine Pollution Bulletin, Volume 50, Issue 12, 2005
11. Dietmar P.F. Möller, Jens Froese And Hamid Vakilzadian, "Bottleneck-Analysis on Intermodal Maritime Transportation Chains"
12. Zhe Xiao, Xiuju Fu, Liye Zhang And Rick Siow Mong Goh, "Traffic Pattern Mining and Forecasting Technologies in Maritime Traffic Service Networks: A Comprehensive Survey", 2019
13. M Kia, E Shayan And F Ghotb, "Investigation of port capacity under a new approach by computer simulation" 2002
14. Jan De Weille And Anandarup Ray, "The Optimum Port Capacity" ,1974
15. IALA, "Use of Simulation as a Tool for Waterway Design and Aids to Navigation Planning 1058", 2011
16. PIANC MarCom WG 121, "Harbour Approach Channels – Design Guidelines", 2014
17. Puertos Del Estado, "ROM 3.1-99 Proyecto de la Configuración Marítima de los Puertos; Canales de Acceso y Áreas de Flotación", 1999
18. Tortosa, E. Y Rebollo, J.F., "La red AIS portuaria: La tecnología AIS aplicada a la explotación portuaria y a las ayudas de la navegación. Puertos nº 158, pp. 9-21", 2010
19. Groenveld, R. Onassis, I. And Van Wijhe, H.J., "Safety and Capacity Wet Infrastructure Puerto America Venezuela. PIANC-AIPCN Congress, Sydney, Australia, CD S7B P102, 1-14", 2002