TOWARDS A COMPLETE DESIGN OF THE MANOEUVRING AREAS ADDITIONAL FACTORS INVOLVED IN THE DETAILED DESIGN

by

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ABSTRACT

In order to establish the dimensions of approach channels and manoeuvring areas, PIANC guidelines consider two phases: **Concept Design** and **Detailed Design**.

The **Concept Design Stage** includes preliminary design of channel width, depth and alignment using empirical formulae, together with limited data related to ships and environmental conditions. Only rough estimates of the dimensions of the proposed channel (width, depth and alignment) are determined. The results are conservative sometimes, because general guidelines cannot assess all case-specific features and conditions.

The **Detailed Design Stage** is a more rigorous process intended to validate, develop and refine the Concept Design. The operational aspects are checked, referred to weather conditions, ship size and manoeuvring capacity, tug assistance, piloting, etc. If the conditions are relatively simple and all the design criteria are easily fulfilled, there may be no need to make significant adjustments to the Concept Design. But in most cases additional analyses are necessary to determine a **more accurate design** that will definitely be safe and usable without unnecessary expense. In this case, much more detailed information is needed regarding fairway geometry, weather and current conditions, ship characteristics, manoeuvring strategies, etc.

Real-time Manoeuvring Simulation is the most advanced tool to be used in this process. A realistic, detailed, complete representation of the port and its particular physical conditions is built. Ship behavior in shallow waters and restricted channels can be accurately reproduced, together with the assistance of specific tugs. Moreover, Pilots and Captains can take part in the analysis, so their expertise and the perception and decision-making factors are incorporated to the design.

Real-time simulation, if properly defined and executed, can absolutely help to define a more accurate design and operation conditions of a port area. A detailed approach based on specific local conditions (geometrical and environmental), specific ships (dimensions, propulsion and steering capacity), AtoN and tug assistance will provide complete, accurate and detailed indications on the execution of manoeuvres, both in normal and emergency conditions. Therefore, precise **operation limits, manoeuvring strategies** and **contingency plans** can be elaborated also involving human factor.

In some cases, the analysis of **new scenarios** is outstanding, such as the access of new larger ship classes to existing ports (container vessels, LNG carriers, cruise vessels, …). The limitation in space and therefore the reduction of the manoeuvring areas becomes a **critical factor**. The final design will depend not only on the dimensions obtained from the statistical analysis of the simulation results but also on many other factors involved. These concern mainly **Change Management** (adaptation to key factors of the project in their new configuration) as well as the creation of a **Confidence Building Process**.

For this purpose, a **technical committee** representing the main experts in the project (Port Authority, Operators, Designers, Maritime Authority, Shipowners, Pilots, Tug Companies, ...) is recommended to be created to participate in common workshops during the design process, in order to check input data and assumptions, survey the simulations, contribute to the discussions and finally **validate** the simulation results and include their opinions.

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This process is considered decisive in relevant projects involving such new scenarios, where important changes are proposed (increase in the size of vessels or significant changes in the geometry of the manoeuvring areas, especially if additional dredging is required).

In this way, the **management of the change of all relevant factors** by seafarers in charge of the manoeuvre (detailed knowledge of the behaviour of the **new vessels**, modified operational limits, training process of the new manoeuvring strategy, detailed knowledge of the modified manoeuvring areas and new AtoN, definition of communication procedures between Pilots and Tug operators, definition of operation procedures, ...) is totally connected with the proposed design. This process will finally conclude with the definition of a **detailed procedure** describing all relevant factors to take into account so as to operate the design vessel in the port.

Consequently, in most cases, the **final manoeuvring areas** (geometry and dimensions) are directly related to the manoeuvring skills and **confidence level** that Local Pilots are able to transmit to the main stakeholders of the project.

1. INTRODUCTION

During years of port design studies related to navigable areas, the experience is that it is quite often necessary to explain why the manoeuvring areas obtained are sometimes so optimized in dimensions. From the point of view of the nautical advisor and port designer, it is important to highlight that the final design does not only consist of a set of dimensions to be defined, but also a detailed procedure to be fulfilled. This allows to, step by step, reach the final goal, which consists of operating the Design Vessel in the Port under the limiting conditions using the optimum required navigable areas. So, this complete design concept includes not only a geometrical description of the manoeuvring areas but also the consideration of a relevant set of nautical factors and human behaviour.

Operations of vessels at port are the result of the interaction of three main factors:

1. The vessel (with her propulsion and steering characteristics, capacity, onboard equipment ...)
2. The physical environment (vertical and horizontal dimensions of fairways and basins, meteorological and maritime conditions)
3. The human factor (Masters and Officers, Pilots, Tug Masters, Vessel Traffic Systems...)

Figure 1: General view of a Real-time Full Mission Ship Simulator (Siport21)

Thus, in the design process of port infrastructures or in the definition of operational conditions all three elements must be taken into account. It will only be possible to reach an adequate safety and operability level if all three factors are integrated. Nowadays advanced simulation tools are available allowing for a precise assessment of these aspects. Among them there are moored ship dynamic models, ship to ship interactions models, traffic flow simulation models, and real time manoeuvring simulators.

This paper describes these tools and their application in the complete design process of port terminals (infrastructure and equipment), establishment of operational rules (access, towing, load/unload, ...), risk assessment and contingency plans (dangerous goods terminals) and the transfer of this information to the stakeholders through education and training.

2. MAIN OBJECTIVES

The design of a port terminal of any kind (oil, containers, LNG, passengers, etc.) has to take into account the nautical aspects related to piers, mooring equipment, fenders, fairways and manoeuvring areas (geometry and vertical and horizontal dimensions), met-ocean analysis and operational procedures (access and mooring of design vessels, access of larger vessels, operational limits, traffic analysis, tug requirements, mooring analysis, passing ships, ...).

A detailed nautical risk assessment is required for hazardous goods such as crude oil, refined or chemical products and LNG. This assessment should also include a HAZID/HAZOP procedure.

At last, it is therefore highly recommendable to carry out education and training programmes for Pilots, Captains/Officers and Tug Masters by using real-time simulators.

3. TOOLS AND METHODOLOGY

Several advanced software tools are available to support the accuracy of the analysis:

3.1. Moored/anchored ship dynamic models

The objective of these models is the assessment of the berthing conditions of a vessel in operational (loading/unloading) or survival conditions. These models reproduce the behaviour of a specific ship at berth under the combined action of wind, waves and current. The system solves the equations of ship motion in 6 degrees of freedom (surge, sway, yaw, heave, pitch, roll) in the time domain, without limitations on the motion amplitudes. The simulation results assess the motion amplitudes of the ship and the loads transmitted to the fenders and the mooring lines under the combined action of typical environmental factors (tidal levels, currents, waves, wind).

The main application of these models is the design and optimization of mooring layout and equipment in maritime terminals.

Figure 2: Mooring equipment for specialized LNG terminal

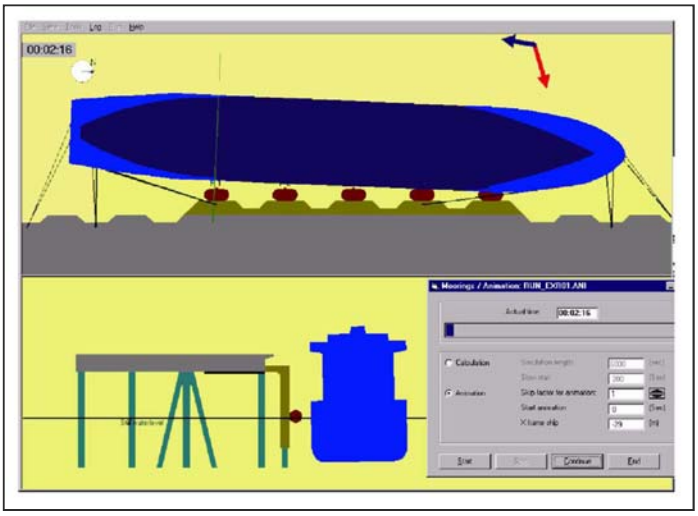


Figure 3: Dynamic Mooring Analysis (DMA) numerical model (Ship-Moorings, Alkyon-Arcadis)

3.2. Passing ships

The objective of these models is to evaluate the hydrodynamic interaction (forces and moments) that one or more passing vessels generate, through a narrow navigation channel, on one or more moored vessels on the specified area, as well as over the mooring structures present on the channel in terminals exposed to navigation fairways (access channels, inner channels, rivers ...), especially in narrow areas and under constrained depth.

The model takes into account the specific hull forms of each vessel, considering the effects of bathymetry changes and lateral restrictions (navigation channels, vertical structures, slopes, ...). This way, and due to the suction forces and moments generated by the “passing vessels” it is possible to assess the transmitted loads to fenders and mooring elements of the terminal by the moored vessels, identifying risk situations and establishing traffic control proceedings (allowable passing speed and distance for ships of different types and dimensions).

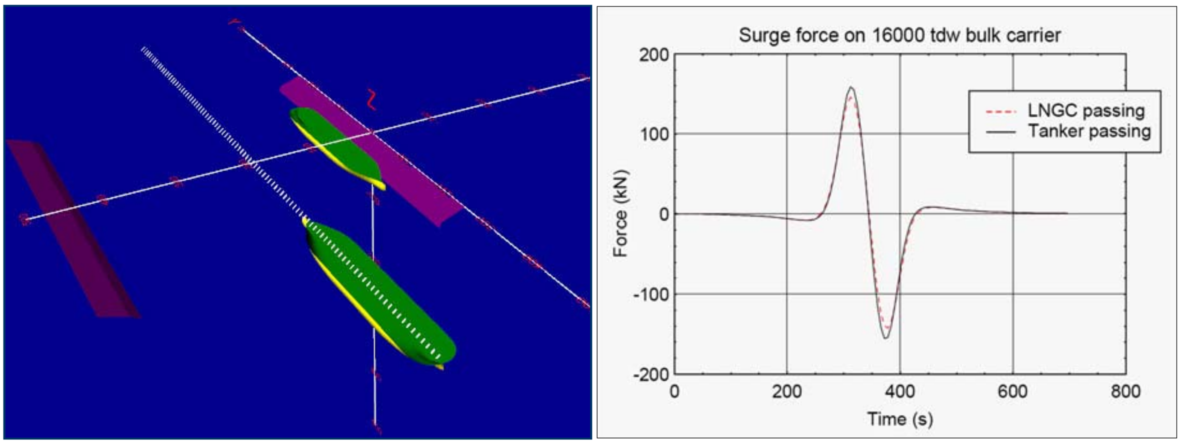


Figure 4: Passing ship analysis numerical model

3.3. Traffic simulation

The objective of these models is to assess the port capacity in order to verify the design requirements in terms of port facilities and forecasted traffic (anchorage areas, number of pilots, number of tugs, channel and quay dimensions, ...).

These numerical models provide ways of identifying possible bottlenecks and of establishing response measures. These simulation models cover the navigation and manoeuvring areas of the port and simulate the ships movements in the area. The objective is to assess the capacity of those areas considering different alternatives or development phases. Usually, the port capacity will depend on the navigation and manoeuvring area dimensions, on the met-ocean conditions and the traffic distribution.

This capacity index should be certified with the admissible values according to the safety and service levels. The level of service is stated by: waiting times of vessels in the different facilities, both for channels occupation and terminals occupation, tug usage, Pilots usage, anchorage occupation ... These models also allow to express the safety level as a function of the potential number of ship encounters (overtaking and meeting) that could lead to risky situations.

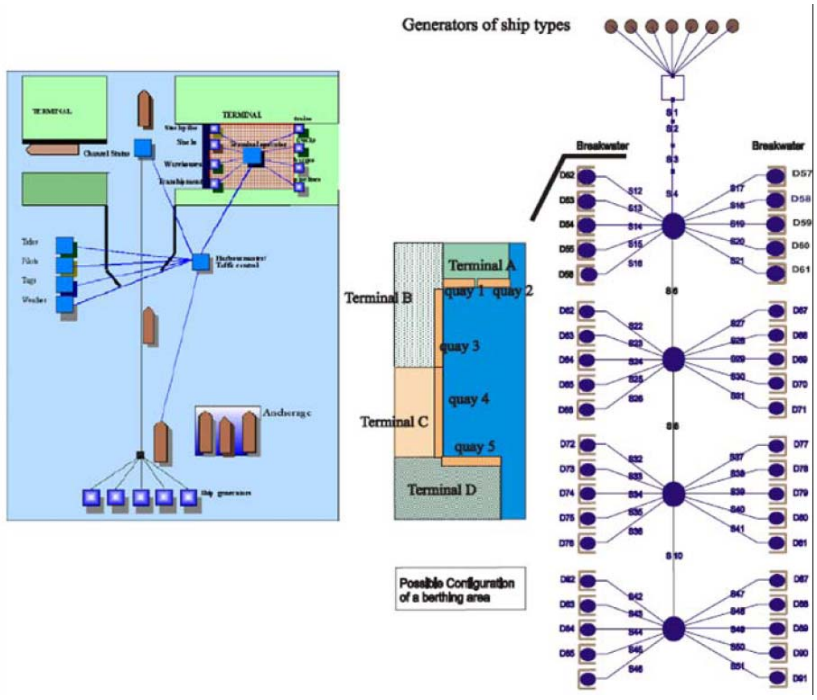


Figure 5: Block diagram of a Traffic Flow Simulation model (HARBOURSIM)

3.4. Ship manoeuvring simulation

The "Fast-Time" manoeuvring models and real time manoeuvring simulators allow reproducing the behaviour of specific vessels in particular areas under the control of an autopilot or a real Captain/Pilot respectively.

Real-Time Simulation incorporates human factor in the development of ship manoeuvres. Therefore, accurate and reliable results are obtained, which incorporate most of the relevant factors involved in real manoeuvres. As a consequence, this way of working is most adequate for the detailed analysis of complex manoeuvring conditions, when human factor (perception and decision making) becomes more important.

Figure 6: Ship Bridge in a real-time simulator

The autopilot mathematical model computes the track of the centre of gravity of the vessels, the course angle and rudder actions. Rudder, engine and tug control is effectuated by a track-keeping auto-pilot that anticipates deviations from the desired track defined by the user and changes in currents. This allows assessing the feasibility of a particular access or departure manoeuvres under different meteorological conditions, orientations about the manoeuvre strategy and defining the tug requirements (number, type and power). In this process wind, waves, currents, shallow waters, and bank suction are also taken into consideration.

In an autopilot numerical model the initial position and the desired track are fixed. The autopilot acts sequentially over the propeller and rudder in order to track-keep the desired fixed trajectory. By removing the human factor it is possible to compare objectively different manoeuvre conditions (different alternatives on the project, different type/dimensions of vessels, different meteorological conditions, ...).

A Real Time Manoeuvre Simulator is characterized by the interactivity of a professional (Captain, Pilot) with the system. The Captain operates on a bridge mock-up and works immersed on an environment similar to reality. Real instruments, ECDIS and a radar screen are available, and the movements of the ship and the image of the port are perceived in a screen with large dimensions. It is possible to interconnect several manoeuvring simulators in the same scenario in order to emulate traffic situations (ships meeting or overtaking) and interaction with other vessels (tugs assisting the sailing vessel), operated as well by Captains, Pilots or Tug Masters.

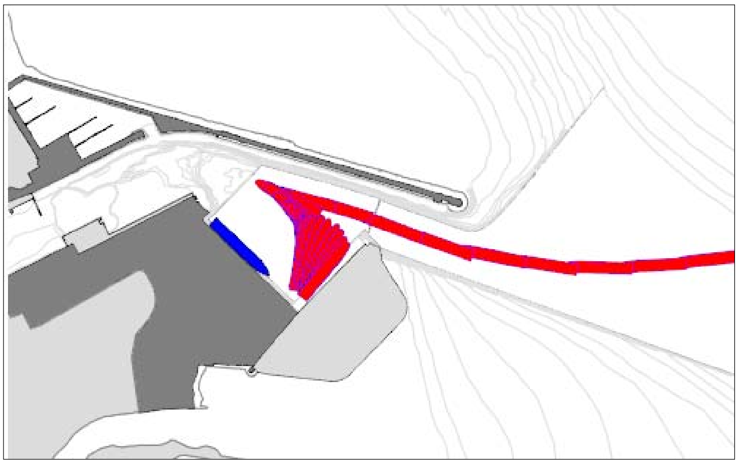


Figure 7: Manoeuvring numerical model (simulated trackplot)

Figure 8: Combined Simulation: Containership (Pilot on board) in bridge A and tugs (Tug Masters) on bridges B and C

4. INFRASTRUCTURE DESIGN

In the Project stage different alternatives for the development of a terminal are considered. Each type of terminal will have standard requirements of space and distribution, both inshore and offshore. Therefore, special attention is paid to the access fairways, navigable and manoeuvring areas, turning basins and quays and jetties (both in dimensions and position).

Horizontal and vertical dimensions of navigable areas and fairways are usually designed following different guidelines such as PIANC (World Association for Waterborne Transport Infrastructure). The definition of the UKC (Under Keel Clearance) is also a basic issue in this stage. These results can be optimized trough the usage of the real time simulator, which will also allow establishing safer access conditions for vessels at the terminals.

Designing the mooring equipment should be done carefully and following guidelines such as PIANC, SIGTTO (Society of International Gas Tanker and Terminal Operators) and OCIMF (Oil Companies International Marine Forum). Again, the numerical models allow optimizing the standard designs and adapting them to the specific conditions of each terminal.

Figure 9: Verification of fairway and basin for Valemax bulkcarrier. Simulator image

5. OPERATIONAL PROCEDURES

Before vessels can access terminals and port areas, operational limits for access and loading/unloading operations should be defined. International rules and regulations are quite demanding for specific traffics (oil and gas mainly) where safety issues are essential. In this way tide and current limits, wind and waves thresholds and visibility should be fixed, depending on the type and size of the vessel.

Tug requirements (number, type, power and bollard pull) need to be clearly defined as a function of vessel dimensions and met-ocean conditions, taking into account the efficiency when working on wave conditions, ... In particular tug usage for approach manoeuvres (eventually escorting), berthing operations and stand-by tugs.

Limits and preliminary requirements are derived from publications and existing guidelines. Nevertheless, the use of more precise tools, such as numerical models or real time simulators, allows for a better definition of those factors.

Figure 10: Tugs assisting a LNG carrier

In the same way, the design of vessels' mooring layout should take into account local conditions (wind, waves, currents…). Depending on the capacity and dimensions of the vessels and the admissible motions limits (cranes tolerances, loading arms limits, …), the optimization of the mooring system can provide a sensitive increase of the availability (reduction of downtime) of the Terminal. Cost-benefit relation of this type of analysis is highly profitable and allows calculating and verifying fenders, bollards and quick release hooks, as well as specific and optimum mooring layouts for every type of vessel. This type of studies is specially recommended for exposed terminals, which require a highly accurate definition of local waves.

The assessment of traffic, mainly in congested ports or with limited resources will define requirements such as safety distances, single or double lane fairways, priority use of the fairway, safety areas surrounding dangerous goods terminals or passing distances for vessels in transit.

6. ACCESS OF LARGER SHIPS

The strong tendency to the increase of vessel capacity is well known, mainly during recent years and in specific traffics. It is due, naturally, to the scale economy in all different transport phases. This has happened with LNG carriers, large container vessels and cruise ships as outstanding traffics.

Port infrastructure is designed for an operational life time that lasts more than vessels life time. Therefore, it is frequent that ports and terminals have to accommodate vessels with dimensions over those initially planned. Appearance of new types of vessels forces to review the capacity of navigable and manoeuvring areas, as well as the terminals. Therefore, it is essential to develop a feasibility study for the access and operation of these new vessels in already existing ports.

This work is focused in nautical aspects (navigation, manoeuvring, safety, mooring, …) even though there are many other aspects to be assessed (loading/unloading equipment, tank storage capacity, container storage areas, facilities for reception and transport of passengers, electricity and provisioning supply, ...). From this point of view, it is necessary to verify the applicability of the current nautical regulations (meteorological or tidal conditions, towing requirements, emergency procedures, …) as well as the capacity of the facilities and the equipment (fenders, bollards, loading/unloading systems compatibility, …).

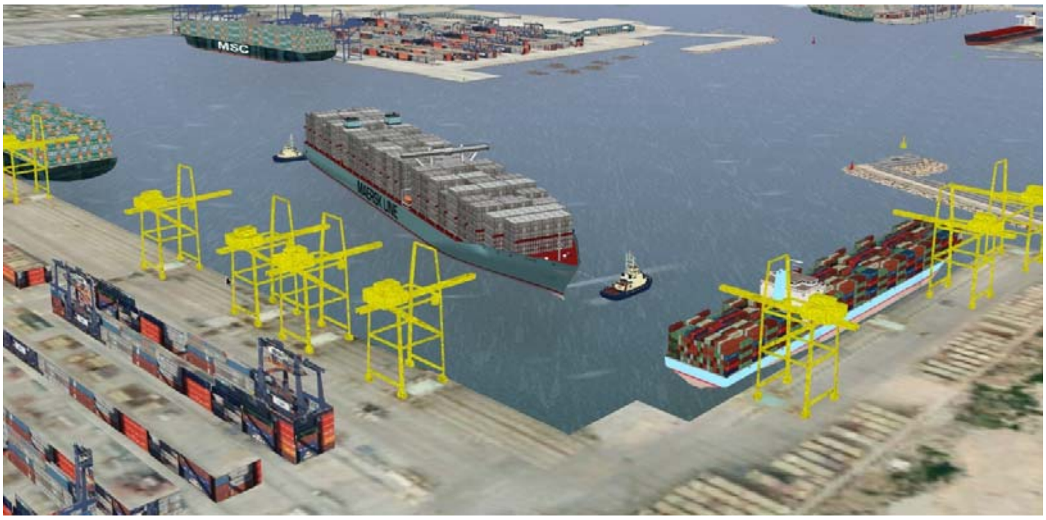


Figure 11: 3E Maersk containership access manoeuvre. Simulator image

This assessment will lead to an adaptation of the regulations, to updates in equipment, or even to the reinforcement of port structures. In the extreme side, it will be necessary to perform relevant construction works to increase the capacity of access channels (deepening and widening dredging works) and terminals or even build new quays. In all these analyses, the use of advanced simulation methods is already an established, required and useful procedure.

It is crucial to count on the join participation of several stakeholders: Port Authorities, Terminal Operators, Pilots, Tug Masters, Captains and shipping companies, port designers, ... Therefore, all parties have to reach an agreement on updated operational procedures, which might include defining training programs for Masters, Officers and Pilots prior to the access of new vessels.

Figure 12: Access manoeuvre of “Oasis of the Seas” cruise vessel. Simulator image

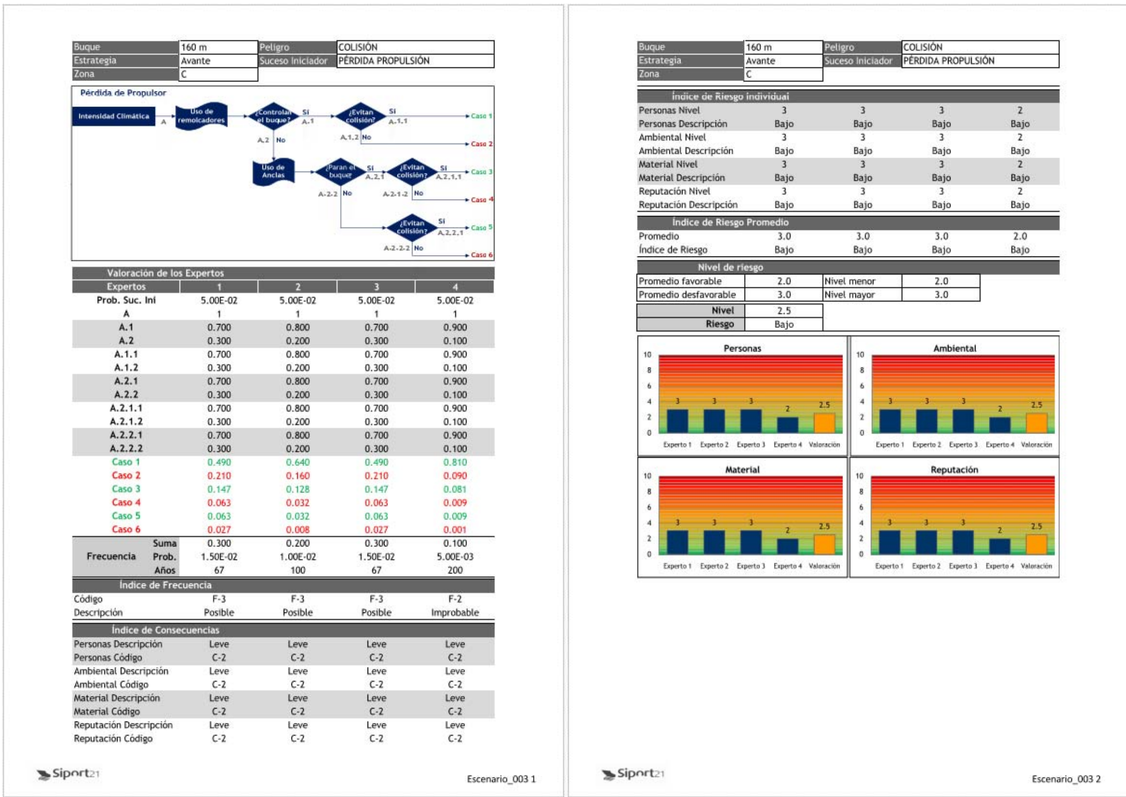
7. NAUTICAL RISK ASSESSMENT

All possible risk scenarios (grounding, collision, …) have to be assessed as well, emphasizing those cases when transport of dangerous goods is involved. The consequences of these types of events can be estimated by using the abovementioned tools, which will allow defining adequate preventive and corrective measures.

Once all navigation and manoeuvring conditions have been defined, the possible consequences of extraordinary incidents should be assessed, such as propulsion or steering systems failure, tugs failure (breakage of towing line), reduced visibility, positioning errors, sudden increase of wind speed, breakage of mooring lines, … The assessment of these events has to be done independently if these incidents are caused by the vessel itself or vessels operating nearby the project vessel. These types of events are beyond the usual difficulties in steering the vessel under normal manoeuvres.

Figure 13: LNG carrier manoeuvre in a FSRU Terminal

Therefore, the objective of these studies is the identification, analysis and evaluation of the different risk assumptions that might be expected during the development of the access and loading/unloading operations. As a result, actions and preventive and corrective measures will be defined and their effectiveness evaluated. The starting point is IMO (International Maritime Organization) recommendations related to risk scenarios. This information will be used as a starting point for the definition of the restricted navigable areas as well as the elaboration of contingency plans. It will be a critical aspect in all HAZID/HAZOP processes, that will be developed under a global view and coordinating the information with all the stakeholders (Terminals, Port Authorities, Operators, ...). Clear criteria to be adopted for operations, both for normal and emergency operations, will thus be defined.



Buque	160 m	Peligro	COLISIÓN
Estrategia	Avante	Suceso Iniciador	PÉRDIDA PROPULSIÓN
Zona	C		

Valoración de los Expertos				
Expertos	1	2	3	4
Prob. Suc. Ini	5.00E-02	5.00E-02	5.00E-02	5.00E-02
A	1	1	1	1
A.1	0.700	0.800	0.700	0.900
A.2	0.300	0.200	0.300	0.100
A.1.1	0.700	0.800	0.700	0.900
A.1.2	0.300	0.200	0.300	0.100
A.2.1	0.700	0.800	0.700	0.900
A.2.2	0.300	0.200	0.300	0.100
A.2.1.1	0.700	0.800	0.700	0.900
A.2.1.2	0.300	0.200	0.300	0.100
A.2.2.1	0.700	0.800	0.700	0.900
A.2.2.2	0.300	0.200	0.300	0.100
Caso 1	0.490	0.640	0.490	0.810
Caso 2	0.210	0.160	0.210	0.090
Caso 3	0.147	0.128	0.147	0.081
Caso 4	0.063	0.032	0.063	0.009
Caso 5	0.063	0.032	0.063	0.009
Caso 6	0.027	0.008	0.027	0.001
Frecuencia Suma	0.300	0.200	0.300	0.100
Frecuencia Prob.	1.50E-02	1.00E-02	1.50E-02	5.00E-03
Frecuencia Años	67	100	67	200
Índice de Frecuencia				
Código	F-3	F-3	F-3	F-2
Descripción	Posible	Posible	Posible	Improbable
Índice de Consecuencias				
Personas Descripción	Leve	Leve	Leve	Leve
Personas Código	C-2	C-2	C-2	C-2
Ambiental Descripción	Leve	Leve	Leve	Leve
Ambiental Código	C-2	C-2	C-2	C-2
Material Descripción	Leve	Leve	Leve	Leve
Material Código	C-2	C-2	C-2	C-2
Reputación Descripción	Leve	Leve	Leve	Leve
Reputación Código	C-2	C-2	C-2	C-2

Buque	160 m	Peligro	COLISIÓN
Estrategia	Avante	Suceso Iniciador	PÉRDIDA PROPULSIÓN
Zona	C		

Índice de Riesgo individual				
Personas Nivel	3	3	3	2
Personas Descripción	Bajo	Bajo	Bajo	Bajo
Ambiental Nivel	3	3	3	2
Ambiental Descripción	Bajo	Bajo	Bajo	Bajo
Material Nivel	3	3	3	2
Material Descripción	Bajo	Bajo	Bajo	Bajo
Reputación Nivel	3	3	3	2
Reputación Descripción	Bajo	Bajo	Bajo	Bajo
Índice de Riesgo Promedio				
Promedio	3.0	3.0	3.0	2.0
Índice de Riesgo	Bajo	Bajo	Bajo	Bajo

Nivel de riesgo			
Promedio favorable	2.0	Nivel menor	2.0
Promedio desfavorable	3.0	Nivel mayor	3.0
Nivel	2.5		
Riesgo	Bajo		

Figure 14: Risk evaluation sheet (FSA Methodology)

8. EDUCATION AND TRAINING

Familiarization with the new vessels and the new manoeuvring areas (meteorological scenarios, bathymetry, manoeuvre strategies, AtoN, and other relevant aspects) is an essential activity. In order to end up with familiarization and training processes it is very important to perform a detailed assessment of all the available data in the preliminary stages of the study, the selection and modeling of the main representative scenarios as well as the definition of an adequate simulation program to cover the objectives of the project.

This type of training sessions will allow the participants (Master, Officers, …) to have a better knowledge of the local conditions and the manoeuvre strategies (new in most cases), as well as better communication procedures with the rest of the technicians involved (Pilots, Tug Masters, Harbour Masters, …).

Figure 15: Masters/Officers and Pilots in the real time Simulator Bridge during training sessions

9. CONCLUSIONS

This paper describes the different simulation tools and techniques used for port planning, design and optimization, from the establishment of the operational rules to the transfer of this information to the stakeholders based on education and training.

Several simulation tools with different objectives have been assessed for the evaluation of port design. Among them there are moored ship dynamic models, ship to ship interaction models, traffic flow simulation models, and fast-time and real-time manoeuvring simulators.

Some of these tools can be used in combination with other simulation tools in order to increase the accuracy and reliability of the results, by including more complex parameters in the simulations. As an example, results of some simulation tools such as ship to ship interaction can be used as input parameters for moored ship dynamic models (to take into account passing effects over the mooring arrangements of vessels) or real-time manoeuvre simulations (to take into account bank suction and blockage effects, of the interaction between two meeting vessels).

Nevertheless, there is a relevant fact to be taken into account: operations of vessels at ports are the result of the interaction of three main factors:

1. The vessel (with her propulsion and steering characteristics, capacity, onboard equipment ...)
2. The physical environment (vertical and horizontal dimensions of fairways and basins, meteorological and maritime conditions)
3. The human factor (Masters and Officers, Pilots, Tug Masters, Vessel Traffic Systems...)

In the design process of port infrastructures or in the definition of operational conditions all three elements must be carefully taken into account. It will only be possible to reach an adequate safety and operability level if all three factors are integrated. This integration is made possible by the available advanced simulation tools that allow for a precise assessment of these aspects.

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