OPERATIONAL FRAME WORK AND SAFETY STUDIES FOR LNG OPERATIONS

JESÚS LOSADA MASEDA
REGANOSA, MUGARDOS, SPAIN
J. VAN DOORN
MARIN, WAGENINGEN, THE NETHERLANDS

ABSTRACT

The paper addresses the use of simulation in the design phase and during operations for the determination of the safety of LNG operation offshore and onshore (jetty).

In the design phase the following questions are addressed:

- *How is the operation executed (procedures)*
- *What is needed (equipment)*
- *Limiting conditions (downtime)*
- *What in case of emergencies*
- *Safety level*

And concluded through a verification based upon full mission simulations (Familiarization and training).

To address these questions the following tools are used:

During the Design phase:

- *Static computations*
- *Fast-time simulations of normal operations*
- *Fast-time simulations of emergencies*
- *Risk Assessment models (QRA)*

During verification and implementation:

- *Real-time simulators*

Typical outcomes of these operational simulation studies are using, engine use, rudder use, ship speed and tug use to assess the weather downtime, the required tug power and type, nautical procedures and VTS requirements.

In the design phase more attention is paid to a risk assessment based upon large number of fast time simulations of pre-defined emergency scenarios.

INTRODUCTION

The design of port layouts and (offshore) terminals suitable for LNG-carriers has to meet exceptionally high safety standards. All responsible parties aim at the design of an inherently safe offloading system either on-shore or offshore.

In a port area a careful selection of the terminal location is combined with the definition of strict nautical procedures. Offshore all the focus is on the operational procedures and the interfacing connections.

The two-way approach of the design of a nautically safe LNG offloading system comprises:

The design of operations; this covers the layout of the infrastructure (onshore and offshore), the mooring system and the navigation procedures. Aspects that are addressed are:

- *Terminal location or offshore facility, orientation and surrounding infrastructure,*
- *Mooring lines/fender configuration or hawser length and positioning system,*
- *Procedures on the approach, berthing, tug*

use, weather windows and emergency response.

Many of these aspects can be addresses through (full-mission) manoeuvring simulations using expert opinion.

The Quantitative Risk Assessment; such an assessment identifies hazards, quantifies the total risks and defines measures to reduce the risks. Typical hazards are collision, contact, foundering and grounding, fire and explosions. The most important associated risk is the loss of containment leading to life threatening gas clouds. Typical measures are slow speed tug assisted manoeuvring, single ship operation, standby tug, and proper terminal site selection.

In this paper we like to discuss two typical examples of a safety study combined with a design of operations. The design of the operation aims at obtaining a safety level that is equal or higher than predicted in the safety study. Especially when dealing with LNG this is an important goal. One study discussed in this paper is related to offshore operations (Case 1) and one for a typical port (Case 2).

CASE 1: OFFSHORE OPERATION

Different design solutions are available for the offshore export or import of gas (or oil). The most common solution is a floater (barge or vessel shaped), transferring cargo either side-by-side or in tandem. The floater will be moored to the sea bottom by using a turret or a spread mooring.

The most favourable design solution will depend on a large number of factors like water depth, environment, distance to shore etc.

An important aspect in the design and operation of offshore facilities is the definition of procedures for the approach and berthing manoeuvre of large carriers. The following tools are available for the evaluation of manoeuvres:

- Static computations;
- Fast-time simulations of normal manoeuvres;
- Fast-time simulations of emergencies;
- Risk assessment models;
- Real-time simulations.

In this paper the different tools will be discussed shortly.

Static computations

When the critical environmental conditions are available static load computations can be used for a first analysis of the feasibility of operations and the need for tug assistance in an early design stage. Starting point of such an analysis can be the OCIMF coefficients or dedicated wind tunnel tests regarding the current and wind loads on vessels.

Fast-time simulations

The set-up and mathematical content of a fast-time or real-time simulation model can be equal. The main difference between the two models is that the real-time model is steered by a human being and the fast-time model controlled by an autopilot. The principle set-up of a fast-time model is shown in Figure 1.

In the previous picture the following blocks can be distinguished:

- Input parameters (Environment, Vessels, Tugs, Lines);
- Simulation model (Pilot and (Fast-time) Simulator);
- Simulation control (Manager and Scenario handler).

Different to the real-time simulation model are the autopilot, replacing the mooring master and tug masters, and simulation control normally done by the simulator instructor.

This autopilot controls the ship, responds on casualties and orders the tugboats. As one might expect, human decisions and performance are not necessarily consistent from person tot person, situation-to-situation, or day to day. Human response, like wind and waves, is probabilistic in nature and is included in a real-time simulator. However it is only possible to quantify them after a relatively large amount of simulations. Such a complex and huge study is unpractical and expensive within the context of the design of an offloading system. A more practical solution is to use a (fast-time) simulation model that is steered by an autopilot. It has the advantage that the autopilot always reacts in the same way, which makes the results of the simulations comparable. On the other hand the system is in general performing better than a human navigator. Consequently the result of the simulation can be regarded as the best you can get. This means that in the analyses of the results safety margins have to build in to make sure that the human is capable of doing the manoeuvre.

On a higher level in the fast-time simulator the scenario handler/simulation manager controls the simulation of a full scenario. It starts the simulation, controls the ship speed and gives orders for the connection of lines (hook-up). It initiates events and emergency responses and sets time delays. The

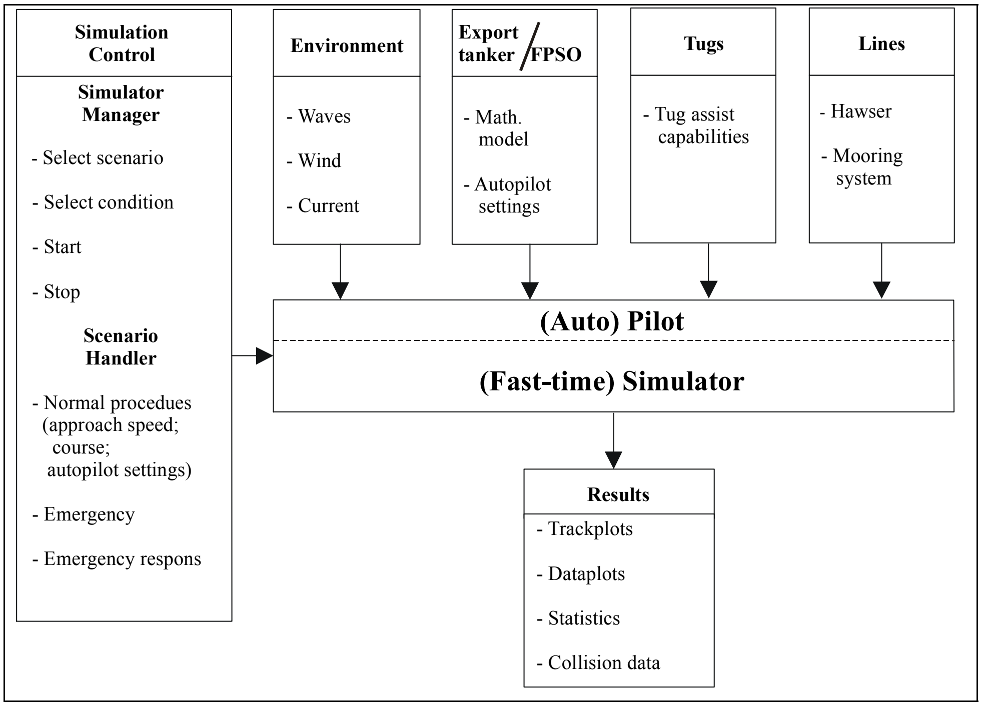


Figure 1. Set-up of a (fast-time) simulation model

simulation stops after a collision or when the tanker reaches a predefined stable state. Possible events during the manoeuvre are system failures (engine, rudder, lines, tugs) or explicit human failures.

The autopilot and the scenario handler introduce effects that normally result from human behaviour; it gives a good insight in the execution of normal manoeuvres and the effect of emergencies. However a final check of the outcome of the fast-time simulations should be done in a real-time simulator (see below).

MODELLING

Before simulations can be executed the input parameters like the environmental conditions, ship characteristics, tugs and line dynamics have to be modelled.

The ship manoeuvring behaviour is an important aspect in the simulation. The technique to develop mathematical manoeuvring models is based on a combination of model tests and full-scale sea trials. Often an existing mathematical model, based on model test results, is tuned using the results of full-scale trials. Added to the manoeuvring model are the environmental forces resulting from waves and wind and engine characteristics. When the vessels are working in close proximity the local shielding effects, especially on wind and currents have to be taken into account.

One of the aims of the nautical study is to define the required tugboat power and type. In the end the tugs are required to provide a certain force to keep the vessel under control. In the fast-time simulation model tugs are modelled as tug capability diagrams. These diagrams show the effective pulling or pushing force as a function of:

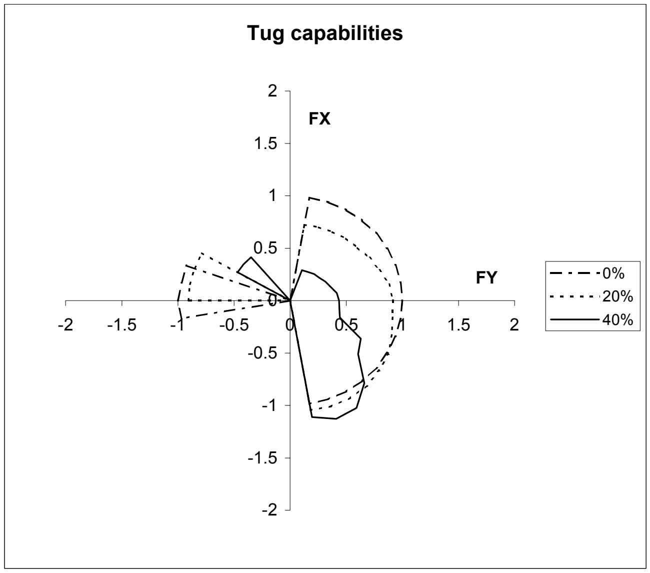
Bollard position on the tanker, pulling or pushing angle, ship speed and wave height.

Furthermore, the modelling of the tugs has to take into account the maximum speed for tugs to change position while assisting a large tanker. The speed of the tug when changing position is depending on the line length and the tug type. An example of a tug capability diagram is shown in Figure 2.

RESULTS OF SIMULATIONS

The results of (individual) simulations are presented as track plots showing the track of the vessel. Furthermore a number of data plots is prepared showing the ship speed, rudder use, engine use and tug forces as function of the sailed track.

In Figures 3 and 4 an example is presented of a LPG carrier approaching a turret moored FPSO, preparing for berthing alongside. Whether a run is acceptable is depending on the ship speed at critical distances, the amount of engine power used, the rudder use and tug use.



Bollard: bow starboard and aft starboard
TugType: ASD
Assist: push/pull
Max. vel 12 knts

Assist force contours defined as fraction of the maximum effective bollard pull, depending on the forward velocity of the tanker. The velocity contours are related to the maximum tug velocity (e.g. 40% = 4.8 kts).

Figure 2. Example of a tug capability diagram

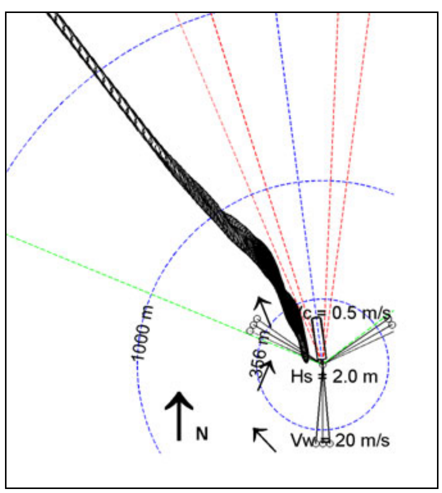


Figure 3. Track plot of an approach to a turret moored FPSO (side-by-side mooring)

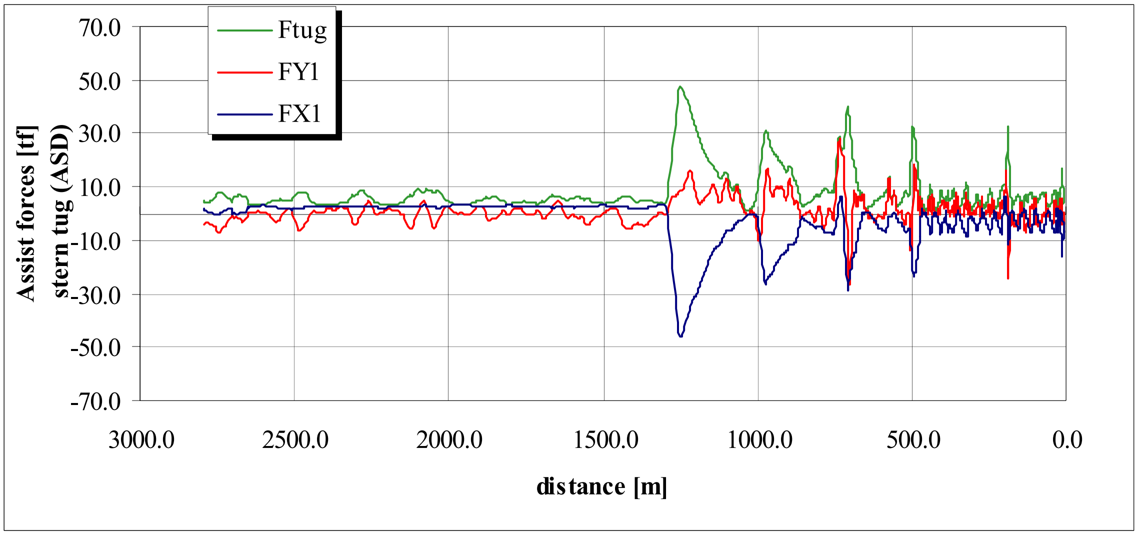


Figure 4. Tug forces as function of the sailed track (stern tug)

In general it is required that there is sufficient spare manoeuvring power available to be able to respond in case of emergencies. Consequently rudder, engine and tug power should not be used to the maximum. The final result of a series of fast-time simulations is a matrix of environmental conditions under which manoeuvres can be allowed; this can be used to compute the downtime of the facility.

Emergencies

When the rules for normal conditions are defined attention should be given to the responses on emergency situations, like rudder failures, engine failures and tug failures. With the scenario handler it is possible to include these effects in the simulations. It is also required to define an emergency response strategy, so the reaction of the vessel after the emergency. In many cases it will be required to abort the manoeuvre (or offloading operation) and bring the vessel to a safe distance from the offshore facility.

A limited number of emergency runs give insight in the redundancy in the operation. Furthermore these runs can be used to define the most effective emergency scenario.

Risk assessment: QRA approach

As the fast-time simulations are fully automated it is possible to execute a large number of simulations. This gives the possibility to combine different emergencies and different environmental conditions in one series of simulations. Also the analysis of such a large batch of simulations is automated. The criterion for the analysis of these manoeuvres is the occurrence of a collision and the corresponding impact energy. A distinction is made between a vessel coming very close to the offshore facility (near miss) and a vessel hitting the offshore facility, see also Figure 5. It is realized that with a small variation of parameters a near miss can turn into a collision, so in the final result the near misses and real collisions are combined.

The amount of simulations executed for such an analyses is in the order of 1000. Knowing the probability of a specific emergency and combining this with the frequency of occurrence of the environmental conditions, a relation between impact energy and the probability of occurrence can be established. An example of such a graph is shown in Figure 6. The collision energy is an indicator for the expected damage due to the collision.

Executing series of simulations for different situations, e.g. different hawser lengths, different tugs or different environmental windows give results that couples risks to these situations. This can be of great help during decision-making, support the evaluation of different solutions. In the past a comparison has been made between the number of collisions found following this methodology and the accident statistics from different offshore installations. It is concluded that this methodology gives a good estimate of the number of accidents; however the energy involved is more difficult to compare with accident statistics.

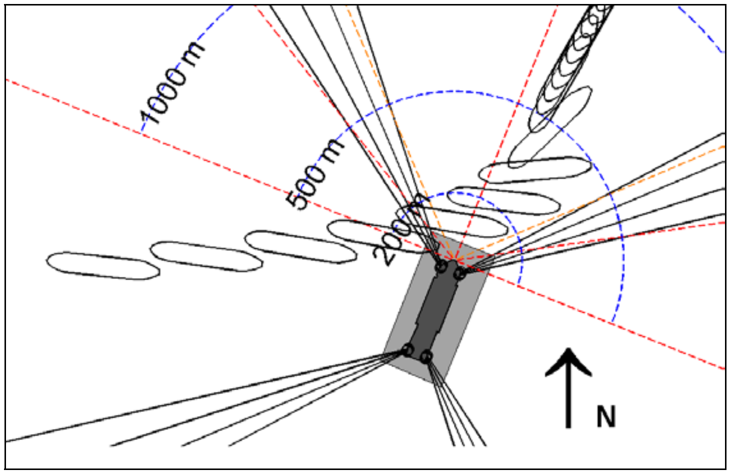


Figure 5. Example of an emergency manoeuvre

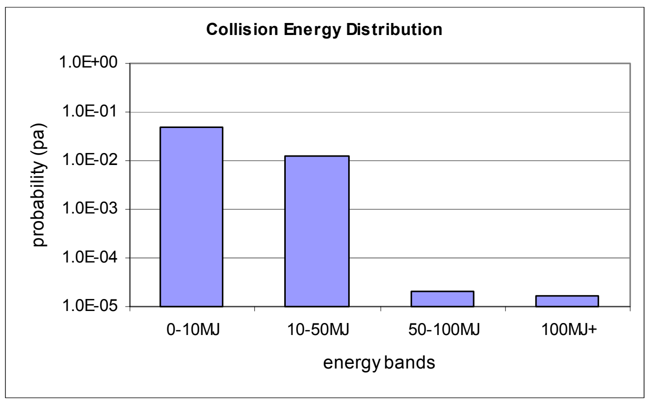


Figure 6. Collision energy distribution

Real-time simulations

After the procedures and the limiting environmental conditions are defined these should be verified and implemented in a real-time simulation session. The real-time simulator has the advantage that:

1. The 'human element' is included in the simulations;
2. It is possible for offshore personnel to verify and familiarize with the developed procedures and rules.

In a first session the procedures will be checked and finalized together with (senior) personnel. Not only the mooring masters should participate but also tug masters and offshore management personnel. The tug masters should participate actively in the simulations. This results in a multi-ship simulation with the tanker controlled from one simulator bridge and the tug(s) from other simulator bridges. The simulator bridges should be equipped with the instrumentation normally available during operations. For the tanker this is a display with the hawser loads and a display with an electronic chart. The tug should have the normal controls for the specific tug type, instruments showing the line length and line load and the possibility to control the winch. For management personnel this type of training is important to get insight in the risks and environmental limitations of offshore operations.

Conclusion

In this section it is shown that fast-time manoeuvring simulations can play an important role both in the determination of procedures, the weather window, and the need for tug power for offshore operations. Also a Risk Assessment can be executed with a fast-time simulation model. In the final stage, before a facility becomes operational, offshore personnel should be familiarized and trained on a real-time simulator.

CASE 2: TYPICAL PORT SAFETY STUDY: PORT OF FERROL

The second case is an example of a typical port safety study executed for the Port of Ferrol. Regasificadora del Noroeste, S.A. (REGANOSA) is planning to build a new facility for storage and handling of Liquid Natural Gas (LNG) at Punta Promontorio, at the south side of Ferrol river, opposite of the city of Ferrol. The site is situated in the North West of Spain close to La Coruna.

The approach to the proposed new terminal can be divided in three stretches:

1. Approach from open sea until the (new) breakwater;
2. Passage of the inner channel;
3. Manoeuvres on the river.

An overview of the area is shown in Figure 7.

The objectives of the study focused on three items:

1. Channel dimensions;
2. Risks involved in the handling of large carriers;
3. Determination of nautical procedures for the handling of large carriers.

The content of the study can be divided in the following main items:

- Collection and assessment of data;
- Determination of the required minimum channel dimensions;
- Risk studies;
- Moored ship study;
- Real-time simulations;
- Nautical procedures.

All these items are briefly discussed in this paper, except the moored ship study. This study was executed in close co-operation with WL | Delft Hydraulics and EQE International Limited.

Collection and assessment of data

The quality of this type of studies is largely depending on the quality of the available data. In the past various studies have been executed for the development of the new outer port at Ferrol. Data regarding wave climate, wind climate and wave penetration were obtained from these studies. The University of Santiago executed a dedicated study to determine the flow pattern in the inner channel. This is very important as the flow velocities can reach high values at this location.

Traffic data were received to compute traffic intensity for the present and future situation. Also the design vessel was selected together with the client: a 140,500 m^3 membrane carrier and a 126,500 m^3 Moss Rosenberg vessel.

Determination of the required minimum channel dimensions

This study was executed as one of the first items in the study. The available channel dimensions were checked against criteria published by PIANC and ROM3.1-99 [1, 2]. The PIANC rules for channel dimensioning have been programmed by MSCN. This program (freely available) has been used to make a first

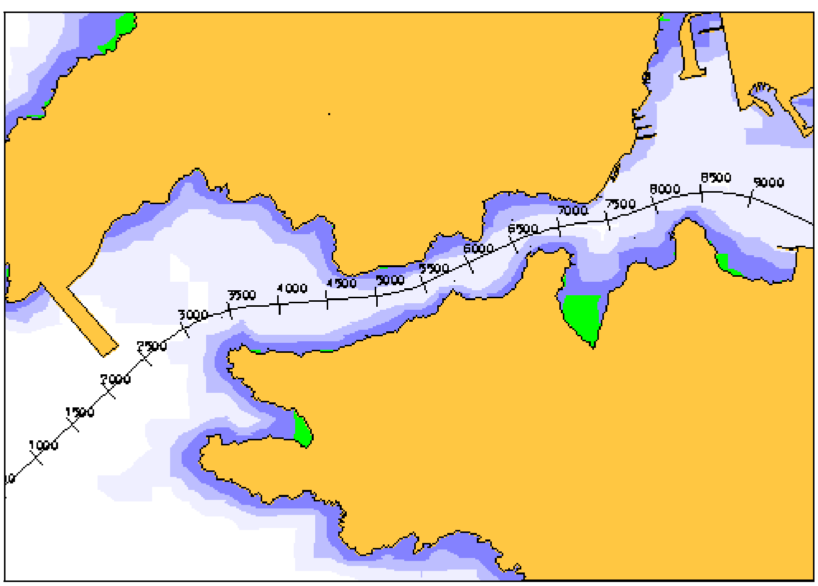


Figure 7. Entrance to the port of Ferrol

judgment of the required channel width. On basis of this first appreciation it was realized that at three locations in the inner channel the available width was just sufficient.

A first analysis was made of the controllability of the vessel in strong wind conditions using static computations, and it was concluded that tug assistance was required to maintain sufficient control of the vessel in extreme wind conditions and during emergencies.

These first findings were checked with a series of fast-time simulations. These simulations were executed with the fast-time simulation model SHIPMA. This fast-time simulation tool is identical to the tool described in the section regarding offshore simulations. These simulations confirmed the results of the ROM/PIANC study regarding the channel width. It also showed that the proposed tug assistance scenario is effective, especially for keeping the ship speed low in the inner channel.

An example of a simulation is shown in Figure 8.

Quantitative Risk Assessment studies

The risk study is divided in three elements:

1. Traffic forecast and traffic intensity;
2. Grounding and collision risks;
3. Risk analyses of LNG transportation and unloading.

The traffic forecast and intensity study provides input for the grounding and collision risk study but it also gives insight in the effect of increased traffic intensity on waiting times and the availability of tugs.

The traffic flows to the various locations inside the port are shown in Figure 9.

Computations were made for the present situation and a number of future scenario's, regarding the development of the LNG terminal and the new outer port.

The grounding and collision risk study is executed with the SAMSON model. SAMSON stands for Safety

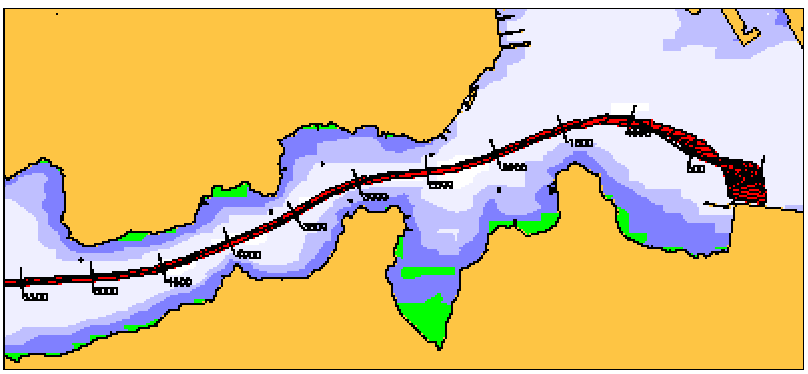


Figure 8. Example of a fast-time simulation

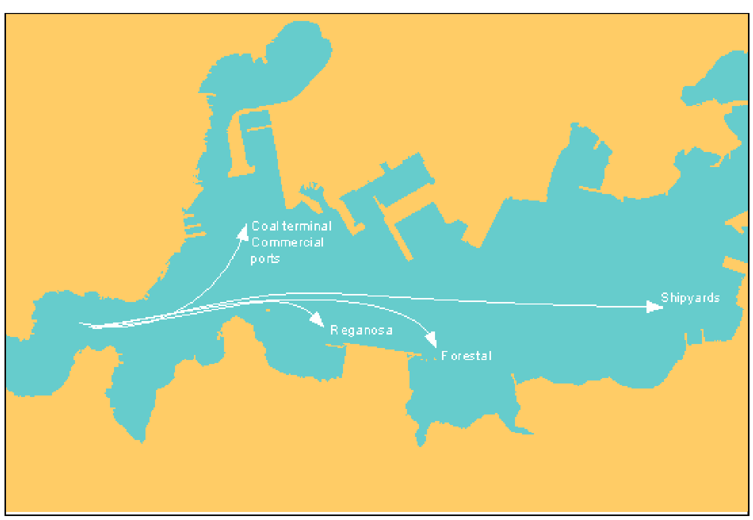


Figure 9. Traffic flows inside the port of Ferrol

Assessment Models for Shipping and Offshore in the North Sea. This model has been developed, extended, validated and improved during the last 20 years in studies performed for the Dutch Ministry of Transport and within many European projects. Although initially developed for the North Sea the model is built up modular and can be used for any location on the world [3].

Starting point for the computation is a schematization of the route and the grounding lines. This schematization is shown in Figure 10.

The result of the computation is the grounding probability per year for each section of the grounding line. Two classes of grounding are distinguished, the first is "ramming" resulting from a navigational error and the second is "drifting" resulting from a mechanical failure. A typical result is shown in Figure 11.

Finally a study was executed regarding the associated risks. On basis of the grounding risk computed with SAMSON the risk of damage to the carrier was computed, the possible development of a LNG cloud and finally the probability on fatalities.

The result of this study is shown in Figure 12.

This figure shows the effect of the ship speed on the probability of fatalities. The middle line (blue line) is the result for the basic speed scenario, the lowest line (orange line) for one knot slower and the highest line (green line) the result for one knot faster. This graph shows that reducing the ship speed with one knot results in an increase of the safety level with a factor 10!

Consequently the approach in the real-time simulations should be to develop procedures that make it possible to pass the inner channel at low ship speed

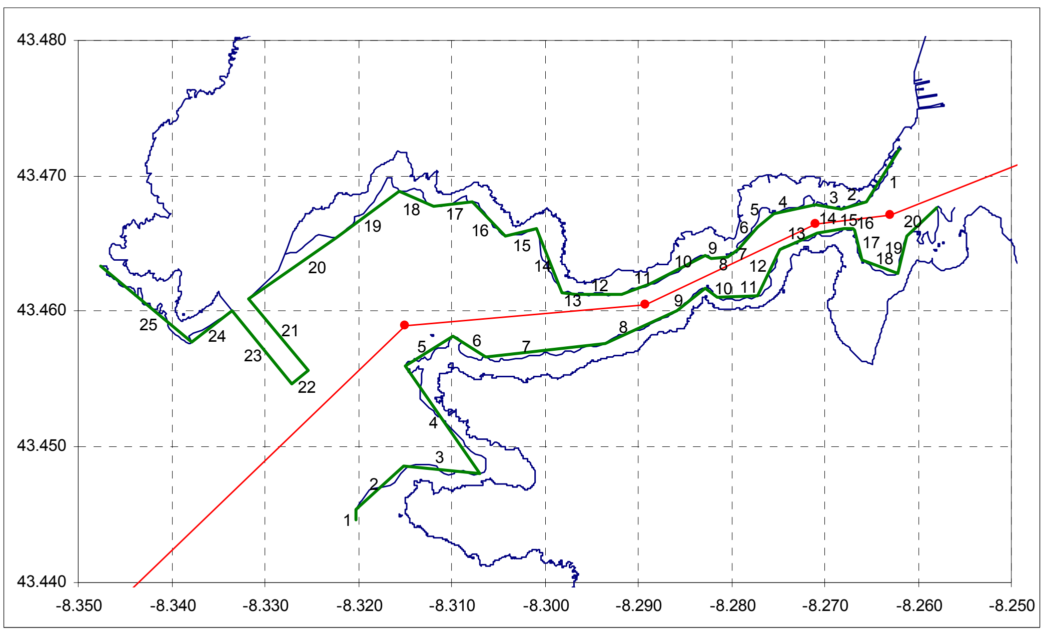


Figure 10. Schematisation of the SAMSON model

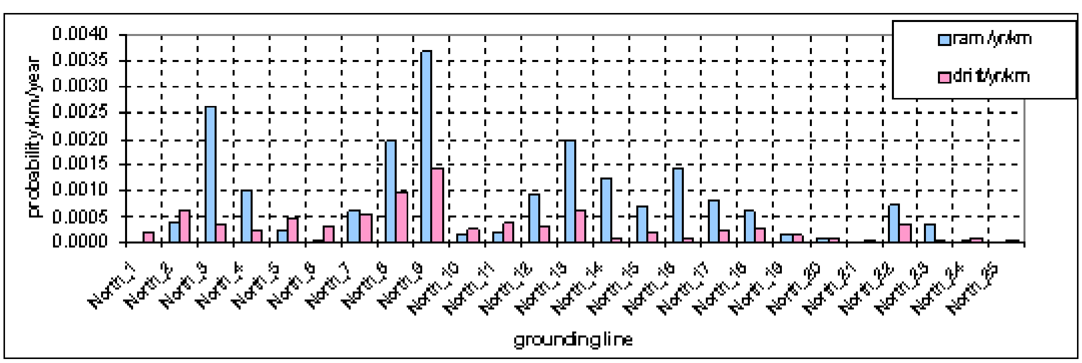


Figure 11. Grounding probability per year per km for the north side of the entrance channel

(5 to 6 knots). By reducing the ship speed the risks involved in the operation becomes much lower than the normally accepted standard.

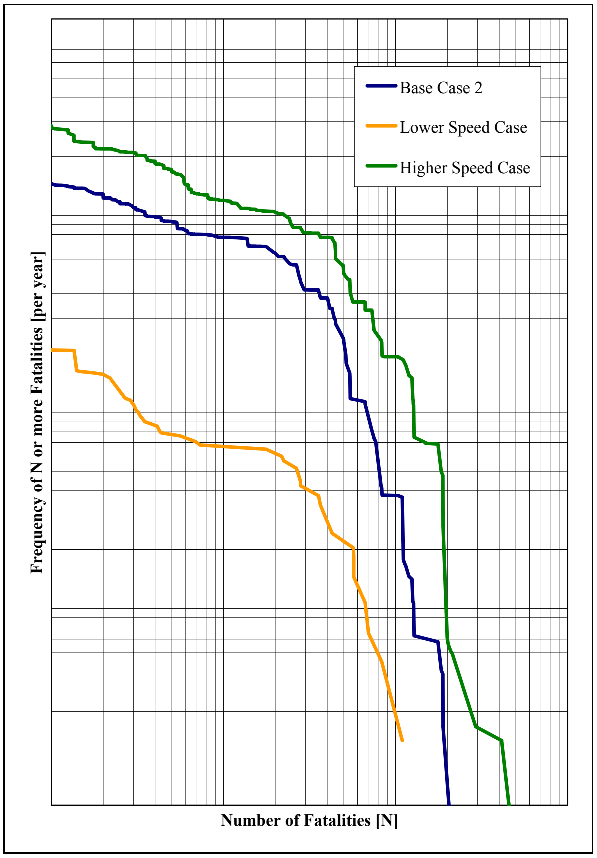


Figure 12. Effect of ship speed on the risk level

Real-time simulations

A simulator database of the port of Ferrol area was prepared for MARIN's nautical simulators. In total three simulation sessions were executed with pilots from Ferrol executing entry and departure manoeuvres. During the last session an experienced tug captain participated in the simulations sailing an ASD tug from a second simulator bridge.

Simulations were executed under extreme environmental conditions, e.g spring tide and strong winds.

From the results of the simulations the probability was computed that the channel boundaries are exceeded, during normal passages and during failures. It was found that the 1 per-cent exceedance probability line stays within the 10 meter depth contour line. It should be noted that this is not the grounding line. An example of such a result is shown in Figure 14.

The simulations showed that it is possible to transit the channel at a low ship speed of less than 6 knots. This means that the channel transit is much safer than normal safety criteria applied for this type of operations.

It was also concluded that it is essential to have two escort tugs assisting at the stern of the vessel during channel transit. The role of these tugs is to keep

Figure 13. Example of the simulator database (LNG carrier in the inner channel)

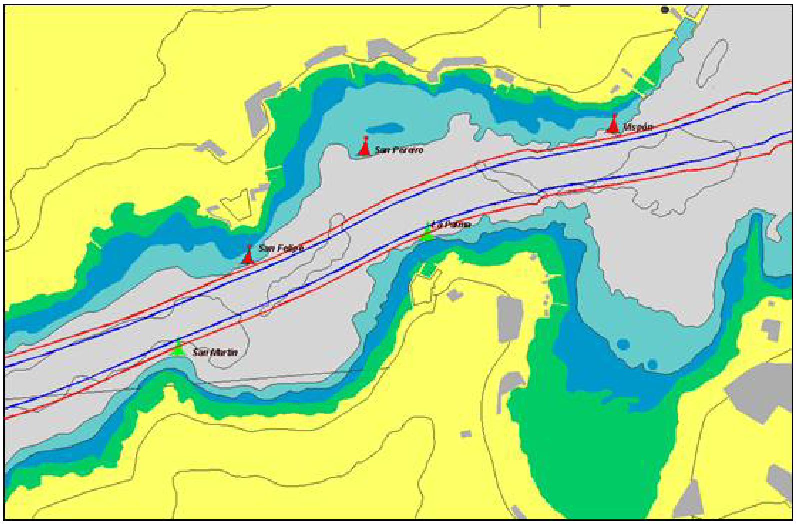


Figure 14. Exceedance probability lines for 10 (blue) and 1 per-cent, detail San Martin to Vispón

the ship speed low and to assist in case of an emergency. Two tugs are essential to control the vessel during specific failures and to remain under control when one tug fails or when a towing line brakes.

Procedures

On basis of the manoeuvring studies and the moored ship studies a detailed overview of nautical procedures, entrance rules and limiting environmental conditions was prepared. This was all summarized in a 'nautical summary' that is used to develop the port procedures.

CONCLUSIONS

For the port of Ferrol the two-way approach was followed for the design of the LNG offloading system:

A Quantitative Risk Assessment: was executed to quantify the risk involved in the import of LNG.

The design of operations: the study was executed to minimize the risks involved in the reception of large LNG carriers.

The result of both studies is a set of procedures that minimize the risk of LNG transport to Ferrol.

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About the authors …

Jesús Losada Maseda is Project Coordinator Engineer for Reganosa LNG plant. He is Energy efficiency advisor and preparing PhD in Barcelona Polytechnic University in risk assessment and evaluation area.

Jos van Doorn is Senior Project Manager at the nautical centre MSCN of the Maritime Research Institute Netherlands (MARIN). He has a MsC of Delft University of Technology. He is specialized in the subjects of nautical training and offloading studies.

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