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| IALA Guideline |

1058

The Use of Simulation as a Tool for Waterway Design and AtoN Planning

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|  |  |  |
|  |  |  |

1. INTRODUCTION 4

2. SCOPE 4

3. USER REQUIREMENTS 4

3.1. Scoping of simulation study 5

4. SIMULATION PLANNING 5

4.1. The role of the participants 6

5. SIMULATOR SOFTWARE CAPABILITIES 6

6. SIMULATION TOOLS AND THEIR USE AND LIMITATIONS 7

7. REQUIREMENTS FOR ANALYSIS, REPORTING AND DOCUMENTATION 7

8. ACCURACY AND REALISM CONSIDERATIONS 8

9. DEFINITIONS 9

10. ACRONYMS 9

11. REFERENCES 9

ANNEX A SIMULATION TOOLS 10

List of Figures

Figure 1 Schematic overview of the components that can be included in fast-time simulations (Hollnagel, 1998) 10

Figure 2 An illustration of fast time simulation 11

Figure 3 Single display system 12

Figure 4 Multi-display system outside view and external handle box 12

Figure 5 Part task simulator 13

Figure 6 Tug cubicle 13

Figure 7 Single full mission simulator 15

Figure 8 Full mission simulator system with several coupled simulators 16

# INTRODUCTION

*Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system.*

(R.E. Shannon, 1975)

Simulation tools are capable of providing realistic and accurate results as input to the investigation and evaluation of channel and port design. The purpose of simulation for AtoN design, planning and evaluation is to identify and mitigate the risks (quantitatively) for the mariner operating in a specific waterway, channel and port area. It also includes evaluation (qualitatively) of channel layout, placement and technical specification of AtoN and manoeuvring aspects.

Simulation offers a relatively low-cost method to help ensure that the AtoN solution provided meets the users’ requirements in an effective and efficient manner.

By providing a simulation tool to the user, an overall improvement in safe and efficient operation can be realised by assisting in demonstrating the operation of the waterway, channel design and associated AtoN, before the reality of navigating a vessel in the area. As such, the simulator can be used to make a general assessment of the most appropriate mitigation measure that may be required in a particular waterway.

Simulations can provide a high level of realism as long as the purpose of the simulation is matched by the accuracy of the models. Hence, accuracy of models of vessels, environments and associated Aids to Navigation, together with appropriate planning and setup of simulated scenarios, should be carefully considered by the end user.

User consultation should be an integral part of all AtoN planning and simulation processes. Accurate simulation tools can potentially improve the usefulness of the feedback obtained from users.

# SCOPE

This Guideline covers:

* the range of user requirements that need to be taken into account to ensure the accuracy and relevance of the simulation design;
* some of the simulation tools that are available and the circumstances in which they can be used to good effect;
* analysis, reporting and documentation of results.
* It is noted that the requirement for training is outside the scope of this guideline

# USER REQUIREMENTS

The primary user of simulation in the context of this guideline is the aids to navigation and waterway authority. Other users that should be consulted may include:

* mariners;
* maritime authorities;
* AtoN service providers;
* port authorities;
* pilot organisations;
* maritime institutes and universities.
* other marine stakeholders

There may be a need for tools such as simulation tools and methods supplementing the existing qualitative (e.g. PAWSA, SIRA) and quantitative (e.g. IWRAP ) IALA risk assessment models.

In this context, the purpose of simulation in AtoN planning and waterway design is to test, demonstrate and document various scenarios for deployment of various AtoN and waterway design under different conditions with the aim of identifying optimal operational safety and efficiency.

The AtoN and waterway authority should be able to identify possibilities using simulation in terms of realism versus costs. Various simulation systems and concepts are currently in use world-wide, and their use and limitations are further described in detail in ANNEX A.

The basic user requirement from a simulation system is to have a multi-level simulation programme that delivers a cost effective and efficient means of assessing, repositioning and designing safe waterways, channels and associated AtoN.

## Scoping of simulation study

Prior to the simulation being commenced, there may be a need for aids to navigation and waterway authorities, service providers and/or other organisations to undertake an initial analysis incorporating step 1 in the risk assessment process (Reference is made to G1018). This analysis could provide the essential inputs and parameters for the simulation and is therefore critical to ensuring accurate results from the simulation. The suggested minimum scope of this initial analysis phase would include:

* identifying the objectives of the AtoN project;
* identifying the geographic boundaries, results of a site visit, timing constraints and broad funding constraints as appropriate;
* confirming the operational requirements including vessel types, routes, traffic density, prevailing met-ocean conditions, interaction with other vessels, minimum visibility required;
* define the scope of feasible channel marking options (e.g. boundary markers, hazard markers, leading lines, AtoN types).

# SIMULATION PLANNING

Listed below are a number of issues that should be carefully considered when planning a simulation study:

specific aims and objectives of simulation in regard to the aids to navigation (placement, positions, type, characteristics, number etc.);

determination of present and future lay-out of channel/waterway/port area to be studied. If the construction phase will affect the safety or efficiency of a fairway, this phase may also require evaluation by use of simulation;

environmental conditions to be evaluated (e.g. wind, current, tide, waves, swell, bathymetry, bank effects, lee effects, visibility and day/night-time operations (including background lighting));

* consider type of users, ships and traffic pattern;
* consider quality level of data should be aligned with the objectives of the risk assessment
* emergency conditions to be considered in the simulations;
* determine simulator equipment to be used;
* determine participation of stakeholders during the simulations;
* determine if the study should include recommendations for pilot/tug master/ship master training;
* determine design ship(s) and/or design tugs to be used for the simulation.

Many other factors can also affect the study. These include:

* any exemptions from pilotage in the area;
* any vessel traffic management measures in place;
* the need for specific decision support systems to be evaluated, such as portable pilot support systems.

## The role of the participants

Aids to navigation and waterway authorities should involve local pilots and mariners in the entire placement of aids to navigation in the waterway/port study process, including planning of the simulation program, the simulation scenarios and production of conclusions and recommendations, to ensure ‘buy-in’ or acceptance. In this manner, subjective and individual opinions on operational margins can be avoided and a working environment of mutual trust can be created.

If a simulation service provider is being involved, it is important that such providers are capable of managing the simulation studies. The simulation provider should be able to source experienced mariners and engineers. Their input should be based on professional experience whilst maintaining the neutrality of the simulation provider. In summary, the simulation provider should be able to provide an unbiased third-party expert opinion on the subject matter.

# SIMULATOR SOFTWARE CAPABILITIES

When assessing simulation systems, aids to navigation and waterway authorities should consider the following list of capabilities:

* allow the user to understand the spatial situation prior to deploying any physical changes to AtoN or channel design;
* allow cost benefit analysis of different types of AtoN, including colour and light characteristics; (optional)
* highest quality source data from surveys, terrain and port information;
* allow an assessment of conspicuity and light pollution on the provision of AtoN;
* allow assessment of radar picture;
* assessment of different types of AtoN including lights, daymarks, buoys, beacons, racons, AIS and VTS;
* allow assessment of different vessel manoeuvring characteristics;
* assessment of vessel speed, particularly regarding high speed craft, in consideration of light and racon characteristics required;
* night, day and different visibility simulations;
* use of different simulation tools from the basic desktop study to full mission simulation;
* need to simulate met-ocean conditions;
* assessment of horizontal and vertical visibility for vessels and of AtoN;
* ability to overlay historic traffic information including AIS and radar data;
* link to ENC and sometimes RNC;
* allow different stakeholder participation, ranging from pilots to full bridge teams;
* allow multi vessel simulations and show effect of interacting traffic with all types of vessels involved;
* allow simulation of manoeuvring behaviour of tugs and operational conditions related to the control of tugs and the manoeuvring space required;
* allow assessment of accuracy and performance of different positioning systems (e.g. DGNSS).

# SIMULATION TOOLS AND THEIR USE AND LIMITATIONS

A number of different simulation tools are available for design studies and have different capabilities, functionalities and applications. The following simulation tools will be described:

* fast-time simulation;
* desktop simulation;
* part-task simulation;
* full-mission simulation;
* traffic scenario simulation.

It is important to emphasise that it is normally the same simulator software, mathematical ship models, geographical databases including AtoN, and replay tool that are used for simulation including use for desktop, part-task and full-mission systems.

The highest accuracy of the mathematical ship models can be achieved if the models are based on tank tests, wind tunnel tests and fine-tuned with trial test data or other full-scale data. However, it is also possible to produce models based on drawings and formerly produced models of similar type of ships.

The geographical database describes the area where the simulations take place. The fidelity of representation depends on the available terrain data, which can influence the hydrodynamic elements and the visual scene.

The environmental conditions (e.g. waves, current and wind) depend on local conditions. Depending on the complexity of the local environmental conditions, separate hydrodynamic modelling tools may be required to generate data for the environmental conditions as input to the simulations.

The transition between desktop, part-task and full-mission simulators is easy and basically involves the addition of an expanded field of vision and integration of real instrumentation, communication, and manoeuvring equipment.

A detailed description of the simulation methods listed above is described in ANNEX A.

# REQUIREMENTS FOR ANALYSIS, REPORTING AND DOCUMENTATION

Since the margins investigated are often very small, there is a need for the simulation providers to be able to deliver an in-depth analysis of the simulations in order to provide proper conclusions and recommendations.

The report should consider the following:

* purpose of the simulation / study;
* methodology for the simulation / study;
* description of craft involved;
* description of modelling of craft;
* description of waterway and/or port area, for example:
* environmental conditions;
* aids to navigation;
* complicated parts of the evaluated area.
* description of modelling of environmental conditions, weather, sea and ice conditions including depth information;
* description of simulator set-up;
* description of runs performed (track plots of the performed simulations should be available);
* observations and manoeuvring considerations;
* results and in-depth analysis of the results;
* conclusions and applicable recommendations and restrictions concerning, for example:
* ship size;
* pitch, roll, yaw and heave effects on vessel and AtoN;
* speed (with regard to the squat effect);
* environmental limitations for wind, current, waves and tide as applicable;
* visibility;
* bank and interaction effects;
* daylight/darkness considerations;
* positioning and performance of aids to navigation;
* width and depth of waterway.
* description and evaluation of emergency scenarios;

The report should further include the following, when applicable:

* conclusions and recommendations for tug assistance, for example:
* description of simulation model
* type of tug (ASD, VSP, etc.);
* configuration recommendations and handling strategies;
* bollard pull and, if relevant, winch considerations;
* .
* other applicable recommendations such as:
* portable pilot system;
* education and/or training of pilots/tug masters;
* passages.
* comparison with PIANC recommendations, if relevant.

The report, should, as mentioned above, include conclusions and recommendations on the proposed placement of AtoN for the studied area, as well as its effectiveness in coordination with the rules and procedures of navigation, scope and service levels, including the possible installation of some AtoN whose use could be devoted specifically to any ship or manoeuvre.

The comments, conclusions and recommendations from participating local pilots or captains should be documented.

The data should preferably be presented in a digital form that can be used for post processing.

# ACCURACY AND REALISM CONSIDERATIONS

A simulator study is seeking to establish an acceptable level combining safety and efficiency considerations. Specific requirements, for example under keel clearances, use of AtoN and needs for dredging of specific areas affect both safety and efficiency. There is a need to be able to provide a basis for decisions that match these requirements. This is the fundamental argument for having high demands to accuracy and realism as well as transparency in the processes and for the models used for simulation.

The input data must match the current levels of accuracy within the local environment being considered.

Items that are important and are among those which must be considered when addressing accuracy and realism are:

* hydrographic data;
* cartographic data;
* vessel proportions and relationship with other craft and terrain;
* navigation and position systems;
* sea and weather variables (met-ocean data);
* visual scene and AtoN portrayal including both daytime and night.

It is clear that many variables can be used to produce an accurate simulated scenario for test and demonstration to the user(s). It is most important that to achieve an acceptable level of realism the data used must be as accurate as possible. For example, the size of the vessel in relation to the available depth of water must reflect real parameters.

In general, it is important that survey data, CAD data and met-ocean data (wind, current, tide, waves, swell, ice) can be integrated directly to the geographical databases for accuracy and integrity reasons.

# DEFINITIONS

The definition of terms used in this Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at <http://www.iala-aism.org/wiki/dictionary>.

# ACRONYMS

AIS Automatic Identification System

AtoN Aid(s) to Navigation

ASD Azimuth Stern Drive (tug)

CAD Computer-Aided Design

DGNSS Differential Global Navigation Satellite System

ENC Electronic Navigation Chart

IALA International Association of Marine Aids to Navigation and Lighthouse Authorities - AIS

IMO International Maritime Organization

IWRAP IALA Waterway Risk Assessment Program

PAWSA Ports and Waterways Safety Assessment (IALA)

PC Personal Computer

PIANC The World Association for Waterborne Transport Infrastructure

RNC Raster Navigation Chart

SOLAS International Convention for the Safety of Life at Sea (IMO 1974 as amended)

S44 Standards for Hydrographic Surveys (IHO)

VSP Voith Schneider Propeller (tug)

VTS Vessel Traffic Services

2-D Two dimensional

3-D Three dimensional

# REFERENCES

1. SIMULATION TOOLS
2. FAST TIME SIMULATION

Fast time simulation can be used during the initial planning for the general placement of aids to navigation in waterways and in the approach and access to ports, especially when evaluating several proposed designs and lay-outs.

As opposed to the following described simulation tools, this tool is a two-dimensional tool operating with a speed up factor and does not have a person in the loop. The input parameters include one or more specific design vessels, detailed data covering bathymetry, proposed waterway dimensions and restrictions and met-ocean data. The ship models used are usually fully modelled (6 degrees of freedom), thus providing realistic behaviour of the ships used. Less capable models may be used, but care should be taken that these models meet the objectives and the purpose of the risk assessment.

The tool may be used for an initial evaluation of the dimensions and design of a given waterway where one or more possible options are proposed.

The tool is also useful in selecting suitable scenarios for full-mission simulator investigation. The tool can provide information about physical feasibility of a scenario, i.e. whether it is possible to steer the vessel along a desired track within the physical and environmental limits.



1. Schematic overview of the components that can be included in fast-time simulations (Hollnagel, 1998)

The tool can be applied in a deterministic manner where the helmsman is replaced by an advanced autopilot which reacts with a determined response to deviations from the track. As this autopilot is fed with perfect knowledge of the state of the vessel and the environmental influences, it is not certain that a human operator will be able to produce the same results. A subsequent real-time simulator-based investigation with a man-in-the-loop meets this requirement.

Another way to apply the tool is in a probabilistic manner. In this setup the uncertain knowledge of the helmsman and variations in his behaviour are represented by stochastic functions sometimes referred to as a virtual navigator. Hence, the virtual navigator represents the behaviour of various Masters’ ways of manoeuvring the vessel. By repeating the simulation many times with new stochastic deviations (a so-called Monte Carlo process), a number of different tracks are obtained forming a swept path, which can be analysed statistically. The width of swept path significantly depends on the choice of stochastic parameters.

The system can provide distances to AtoN, the waterway boundaries and under-keel clearance.

The system does not consider the presence of other traffic.



*This figure shows the result of a fast time simulation where a specific vessel has been undertaking several passages into a port under the same weather conditions. Particularly in the bend, you can see that there is a difference in the position of the ship during the entries. The collective presentation of all the runs indicates a swept path which in this case shows that the vessel may come very close to the side of the waterway in the bend.*

1. An illustration of fast time simulation
   1. Advantages

* can provide appreciation of problem as part of an initial quantitative feasibility study;
* can evaluate multiple scenarios effectively;
* the tool is readily accessible by an individual or can be used in consultation with organisations that have the appropriate facility ready for use;
* the system provides a probable distribution of tracks in a relatively short time;
* enables appropriate user input to simulate design without the need to have users on-site;
* allows incremental changes to scenarios based on feedback;
* facilitates cost benefit analysis (Step 4 in the risk management process).
  1. Disadvantages
* the time required for completion of one batch of simulations depends on the capacity of the computer since the system will attempt to process the simulations as fast as possible;
* the vessel’s track to be followed must be specified as input to the model
* preparation and setup of many scenarios can be time consuming
* does not allow dynamic changes during the simulation;
* does not provide a platform for assessing human factor;
* no human navigator in the control loop. Autopilots do not replicate human behaviour and computer models of human behaviour may have limitations.
* caution should be taken in relation to assumptions introduced in the models of either advanced autopilot or virtual navigator by requesting documentation of the underlying autopilot or virtual navigator.

1. Desktop simulation



1. Single display system



1. Multi-display system outside view and external handle box

Desktop simulation can be used for initial feasibility studies in the early stages of a design phase, to evaluate the efficiency of the aids to navigation mix and any new AtoN placement proposals in waterways or port approaches.

The simulation is typically executed on a single PC and the user interacts with ship and area models through a mouse or as shown above through an external handle box.

Functionality of this system needs to be adequate to give the user a realistic experience, fulfilling the objectives of a particular task. As an example, it would be sufficient to use vector tugs as a tool for the initial studies of preliminary design proposals. As the simulations normally involve a single person, communication with other ships, port and VTS facilities is not simulated. Other traffic may be in the simulation but will just follow pre-programmed tracks.

Figure 3 shows a single PC solution where the ship is controlled via a handle box with simple handles. On the screen is shown a limited field of view and on the top bar, e.g. course, speed and rate of turn is indicated.

Figure 4 is an expanded version of the system illustrated in Figure 3. The system in Figure 4 is expanded with three more screens so that the operator can, at all times, see the out-of-the-window view, conning display, electronic chart and radar picture.

The desk top simulation system is rarely used in two-dimensional mode alone, without use of three-dimensional visualisation.

* 1. Advantages
* opportunity to achieve interactivity at lower cost;
* simple to simulate different scenarios;
* system can be portable enabling users to more easily be involved in simulation process;
* relatively low-cost and short timeframe to establish the simulations compared to other tools;
* can be used as a visualisation tool for non-mariners.
  1. Disadvantages
* the level of realism is reduced compared to the full mission and part task simulator; therefore, this system is problematic for pilots and mariners to use since they miss essential cues that they normally have (e.g. full field of view and the sensing of vibrations and sounds);
* the very degraded man-machine interface restricts information search and processing of information and will affect response time. This is particularly the case if a mouse is used to control the ship;
* insufficient realism available for the mariner to provide appropriate feedback on human factors issues;
* it is difficult for mariners for example, to assess distances, speed and drift compared to the real situation;
* great care should be taken in relation to the size of the visual image displayed on small number of monitors, which may provide an overly simplistic view for decision making.
* above mentioned disadvantages are even more profound when the system is used with 2D (bird’s eye view) systems without the 3D out-of-the window visual view.

1. PART TASK SIMULATION

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1. Part task simulator



1. Tug cubicle

Part task simulation can be used for the evaluation of the effectiveness of the mix of aids to navigation, channel design and procedures, with a view to specific ships or specific manoeuvres characterising the present or future anticipated vessel types sailing in a specific waterway.

Part task simulations have a higher level of fidelity in certain tasks and operations that the simulator is designed for compared to desktop simulation and can be seen as an intermediate tool between desktop and full-mission simulations. A part-task simulator (Figure 5) is characterised by having an extended three-dimensional visual system projecting images onto one or several screens. Also the model of the simulated area might be more detailed with more accurate met-ocean data implemented. Instruments, handles and operational functionality from simple generic types to more specific applications, for example:

* ships with special propulsion systems (e.g. podded propulsion);
* ships with special instrumentation;
* dynamic positioning systems;
* use of various types of tugs and towing concepts:
* fundamental waterway design can be ascertained by simulating tug usage at various levels of realism;
* vector tugs or the use of real tug simulators in conjunction with the core ship simulator may be considered, emphasising that the level of realism rises significantly with the various types that are possible;
* when using the fully modelled tugs it is possible to assess human factors issues such as communication and manoeuvring difficulties.
* Use for testing various MASS related applications

Often an instructor or operator is involved in the simulations assisting in controlling the scenarios. Modification of model parameters such as AtoN positions and characteristics can be changed from one simulation to the next.

* 1. Advantages
* takes up less space and is more economical than a full-mission simulator;
* can be linked to other simulators for more interactive experience;
* more realistic with better characteristics and controls compared to desktop;
* sufficient realism available to ensure understanding on part of user and therefore better user feedback;
* lower cost than full mission simulation and shorter timeframe to establish;
* higher level of fidelity compared to desktop simulation;
* mariners are included in the simulation process, making it possible to execute the passage or operation in a realistic manner;
* may be made transportable (e.g., built into a standard container or air freight boxes).
  1. Disadvantages
* participant involvement may be less than in the full-mission simulation;
* lower level of inputs available so users’ feedback may be less comprehensive compared to full-mission simulation;
* high establishment and maintenance costs compared to desk top simulation
* there may still be missing cues, due to rudimentary instrumentation (soft instruments) or limited field of view that makes the simulator system inadequate to validate a final design or position of AtoN in a proposed waterway.

In general terms, it is important for a final validation that the realism of the simulated scenarios is sufficiently high for mariners to manoeuvre the vessel in the simulator as in real life. This is typically obtained in a full-mission simulator.

1. Full Mission Simulator



1. Single full mission simulator

Full mission simulation validates the effectiveness of the mix of aids to navigation in combination with specific manoeuvring aspects and definition of Standard Operating Procedures. Figure 7 illustrates a single full mission simulator. The full mission simulator is characterised by having typically a 240-degree field of view (or more) projected onto screens or monitors. Instrumentation, handles and communication equipment are real. The level of realism is increased by introducing sound and vibrations. With this set-up it is possible to execute emergency response scenarios such as loss of propulsion or rudder failure and to indicate failures via alarm panels.

It is also possible to couple two or more simulators for investigation of two-way traffic or more complex traffic scenarios or use of tugs.

The full-mission concept is characterised by a wide visual field for the simulators that play a vital role in the evaluation process. The use of real instrumentation and handles provide the mariners with as realistic cues as possible. In this way the conclusions and recommendations are based on a thorough review of technical aspects as well as the important human factors (such as response times and communication).

In general, fast time simulations, desktop and part task simulations are used for evaluations in the initial design phases and the results are used as input for further fine tuning of the design. Full mission simulations, including full mission tug simulation systems, are used as part of the final validation of a lay-out or operational conditions.

Tug bridge, 360-degree HFOV360

Instructor station.

Auxiliary tugs cubicles.

LNG Bridge120-degree HFOV



1. Full mission simulator system with several coupled simulators

The use of escort towing (indirect towing) in waterways is increasingly used to assist the constantly increasing size of vessels in both manoeuvring and navigation. Placement of AtoN and the width of the waterway should take such operations into account and requires a realistic simulation tool for validation.

During full-mission simulations in particular the design ship(s) and tug(s) should be manoeuvred by professional mariners, so that the outcome of the simulations would be based on professional judgements and accepted best practice.

Verification of a final layout of a channel, port area or port modification may be studied by the use of a full-mission simulation system. Thus, compared to the smaller desktop simulators or part task simulators, the full-mission concept is preferred for validation. The full-mission simulations may have participation by local pilots, tug masters, port authorities and other relevant subject matter experts that can contribute with expertise and practical experience in order to establish a viable basis for decision making.

The fundamental reason for emphasizing the use of a full-mission system in combination with the above mentioned participation of relevant experts is that this is the only way to ensure that technical ship handlings as well as the important human factor elements are sufficiently highlighted providing for the highest level of realism possible. Also, bearing in mind that the safety margins are constantly being challenged, for instance to reduce the required channel width and under-keel clearance for larger and larger ships calling the ports.

* 1. Advantages
* as near to true to real life as possible and Human/machine interface more realistic;
* allows accurate and realistic assessment of different scenarios;
* sufficient realism available to ensure understanding on part of user and therefore optimal feedback;
* dynamic modification to model possible at all times;
* this system provides the highest level of fidelity and provides the participating mariners with realistic and relevant cues comparable with a real operation.
  1. Disadvantages
* very expensive compared to desktop studies and requires dedicated facilities;
* may not be suitable for initial evaluation due to cost implications;
* not portable;
* the cost of these systems means that the availability is restricted to certain organisations offering this service;
* even though modern full-mission simulation systems provide realistic and accurate models the systems do not fully model the real world situation and all cues;
* the effect of the relatively short simulation time (compared to real life operation on a bridge), allowing for a sustained high attention level, is unknown.

1. TRAFFIC scenarios

The simulation of traffic scenarios in a specific area is sometimes simulated to obtain a picture of present and future density and to determine risk of congestion, collision and grounding.

This type of simulation can be carried out using the same simulation tools addressed above requiring the same amount of accuracy in the modelling of ships and areas. Notwithstanding the overall traffic situation being evaluated the safety margins for specific vessels operating in the waterways will still be in focus which allows for careful consideration of particular scenarios.

Actual marine traffic data such as AIS data can be used as input data in the simulated scenarios as traffic vessels each on their planned route.

These simulations can be used for an overall evaluation of AtoN placement, routeing and needs for modifications in present conditions in combination with review of recorded AIS tracks. Recorded AIS tracks provide a very important basis for the evaluation of present conditions and are today already used as a decision-making tool for planning the placement and modification of AtoN.

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