IALA GUIDELINE

G1058
THE USE OF SIMULATION AS A TOOL FOR WATERWAY DESIGN AND ATON PLANNING

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10, rue des Gaudines - 78100 Saint Germain en Laye, France
Tél. +33 (0)1 34 51 70 01- Fax +33 (0)1 34 51 82 05 - contact@iala-aism.org
www.iala-aism.org

International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

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1. 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 realized 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 Marine 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.

2. 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; and
- analysis, reporting and documentation of results.

It is noted that the requirement for training is outside the scope of this guideline

3. 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 organizations
- Maritime institutes and universities
- Other marine stakeholders

Users of simulator systems are encouraged to understand to what extent a given simulator system is providing the required quality and fidelity to suit the purpose of simulation studies and investigations. A guideline on technical features and the technology used is given in Annex B.

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.

3.1. SCOPING OF SIMULATION STUDY

Prior to the simulation being commenced, there may be a need for Marine Aids to Navigation and waterway authorities, service providers and/or other organizations 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; and
- defining the scope of feasible channel marking options (e.g., boundary markers, hazard markers, leading lines, AtoN types).

4. 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.

4.1. THE ROLE OF THE PARTICIPANTS

Marine Aids to Navigation and waterway authorities should involve local pilots and mariners in the entire placement of Marine 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.

5. 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 historical 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; and
- allow assessment of accuracy and performance of different positioning systems (e.g., DGNSS).

6. 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

It is important to emphasize 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 models may undergo a final validation by experienced navigators familiar with the specific ship type and size.

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.

7. 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 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; and
  - 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 (Azimuth Stern Drive, Voith Schneider Propeller, 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.

8. ACCURACY AND REALISM CONSIDERATIONS

A simulator study seeks 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 accurately 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.

9. DEFINITIONS

The definition of terms and acronyms used in this Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary).

ANNEX A SIMULATION TOOLS

A.1. 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.

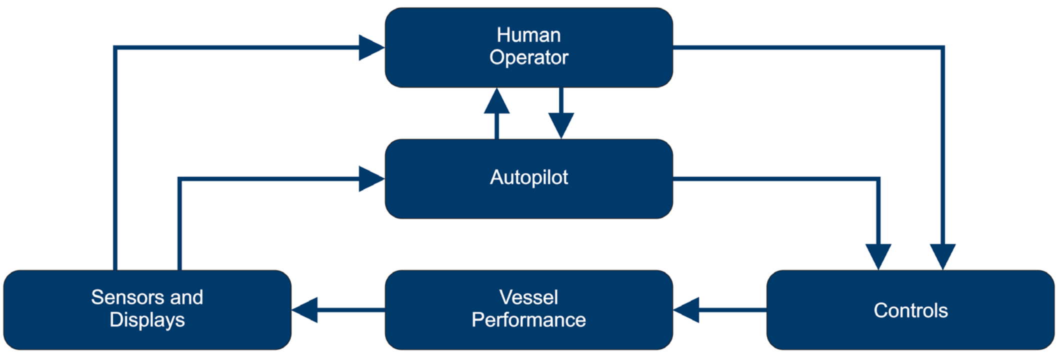


Figure 1 Schematic overview of the components that can be included in fast-time simulations (Hollnagel, 1998)

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 cruise vessel has been undertaking several passages leaving a port. One actual track is shown on top of the swept area for all simulations.

Particularly after the bend the vessel experiences a large drift angle and care must be taken to stabilise the vessel on course.

Figure 2 An illustration of fast time simulation

A.1.1. 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 organizations 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).

A.1.2. 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.

A.2. DESKTOP SIMULATION

Figure 3 Example of a VR headset

Figure 4 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 design and any new AtoN placement proposals in waterways or port approaches.

The simulation can be executed on a single PC where 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 an example of the use of virtual reality (VR). The VR display provides 360 degrees field of view.

The lower part of figure 3 shows a display system with two additional monitors so that the operator can, at all times, see the out-of-the-window view, conning display, electronic chart and radar picture.

Figure 4 is an example where the ship is controlled via a handle box with simple handles.

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

A.2.1. 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 visualization tool for non-mariners.

A.2.2. 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.

A.3. PART TASK SIMULATION

Figure 5 Part task simulator

Figure 6 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 characterized 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 (Figure 6):
  - 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.

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.

A.3.1. 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).

A.3.2. 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.

A.4. FULL MISSION SIMULATOR

Figure 7 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 characterized 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 characterized 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.

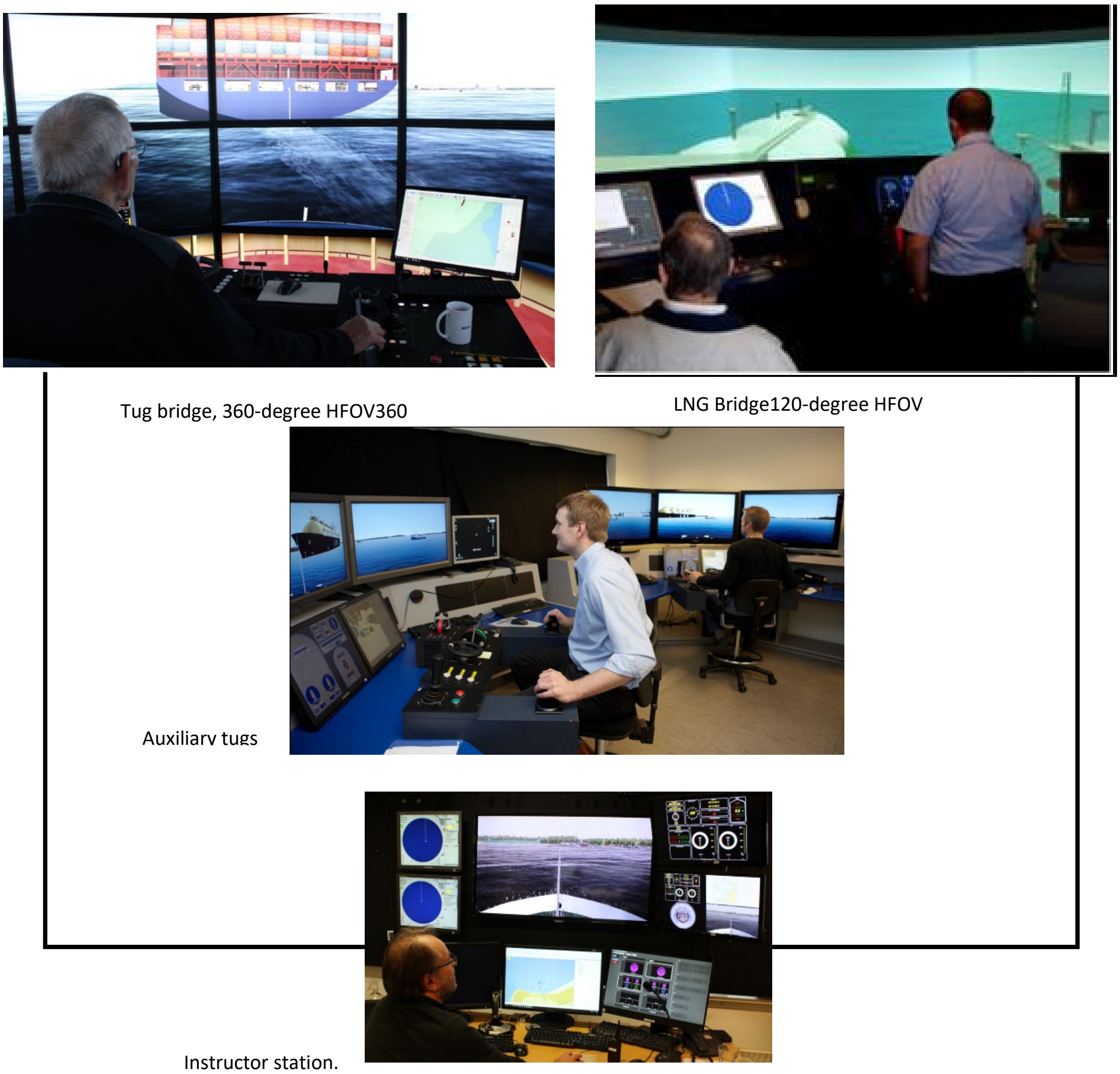


Figure 8 Full mission simulator system with several coupled simulators

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.

A.4.1. 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.

A.4.2. 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 organizations 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.

* *IALA gratefully acknowledges the use of material in the form of photographs and illustrations provided by FORCE Technology, Kgs. Lyngby, Denmark.*

ANNEX B TECHNICAL FEATURES AND TECHNOLOGY RELEVANT FOR SIMULATION OF ATON

B.1. INTRODUCTION

IALA's Guideline *G1058* On the use of simulation as a tool for waterway design and AtoN planning is intended to be a high level, strategic document to assist Competent Authorities in understanding how simulation tools can assist in planning and implementing AtoN. This Annex should be seen to provide generic technical guidance, supplementing the IALA Guideline *G1058*.

Reference is made to the NAVGUIDE [9] for a definition of an AtoN.

The rapidly developing technology for computer-based simulation provides users with an increasing level of fidelity and realism; on the other hand, this technology will always have its inherent limitations. This Annex provides generic considerations on the use of available simulation technology thereby providing an overview and awareness of capabilities and limitations of simulation software, visual systems, visualization media and other relevant systems. It also identifies a collection of features that are important to consider, to meet the objectives of a simulation study for planning, research and testing of potential risk mitigation measures including AtoN.

This Annex is based on the technological status at the time of publication. As maritime simulation tools include several elements of particular types of technology that are under constant and rapid development, users should be aware that the technology described in certain parts of this Annex may have advanced further at the time of reading. Thus, it is recommended that users consult simulator system producers for information on latest developments.

B.2. SCOPE

This Annex covers:

- User needs and requirements
- Modelling and simulation of AtoN
- Visual simulation and display technology
- Display technology
  - Projection theatres
  - Video walls
  - VR displays
- Radar simulation
- Sound simulation
- Simulation of ship navigation systems

B.3. USER NEEDS AND REQUIREMENTS

This Annex is based on user needs and requirements identified by members of the ARM Committee. In determining the needs of the user, the following classification should be considered.

Table 1 Classification of user needs

Applications/Users	Mariners	Engineers/Scientists
Research	Vessel behaviour, such as turning point, under-keel clearance, impact of bridge systems on navigation	Visual comparison of colour, intensity, flash characteristics
Development		Comparison of light sources, evaluation of surface colours
System design and Testing	Fairways/channel, Marking schemes	Buoy design, movement, vertical divergence

In addition to the user requirements identified, relevant and detailed information can be found in existing IALA recommendations and guidelines.

B.4. MODELLING AND SIMULATION OF ATON

Simulation provides a cost-efficient and flexible tool that can support activities discussed in Section B.3. Simulation is considered the next best thing to observing real AtoN in operation. It allows the user to study the AtoN when it is not possible or too costly to experiment directly with the real AtoN.

Major advantages of simulation are: new designs can be tested without committing resources to their implementation; it allows insight into how AtoN works in operation; to experiment with unfamiliar situations; and, answer "what if" questions. The simulation must provide adequate levels of accuracy and thus credibility. The more the simulation resembles real world situations, the easier it is for end users and decision makers to relate to it. Characteristics of AtoN should be captured as closely as possible to enable well-founded decisions.

Even though simulation has many advantages, users should understand the capabilities and limitations of the individual elements of a simulation system. The quality of the result of a simulation study is dependent on the quality of the model, the skill of the user, and the quality of the input data.

Guideline *G1058* highlights the importance of careful consideration of when, and to what extent, the end-users/mariners shall be involved in the simulation for planning, execution, and evaluation of the results of a simulation study.

Ideally, the conspicuity for a simulated and real world an AtoN should ideally be identical. Despite a high accuracy of the simulated model, it is not possible to generate a like-for-like situation. The user should understand the gap between the real and the simulated world to maximise the benefits of simulation.

Figure 9 depicts the four channels through which information can be transferred from AtoN to the user. For each channel the media, model and data required are illustrated. Each channel requires individual means of modelling and presentation and is discussed in the following sections.

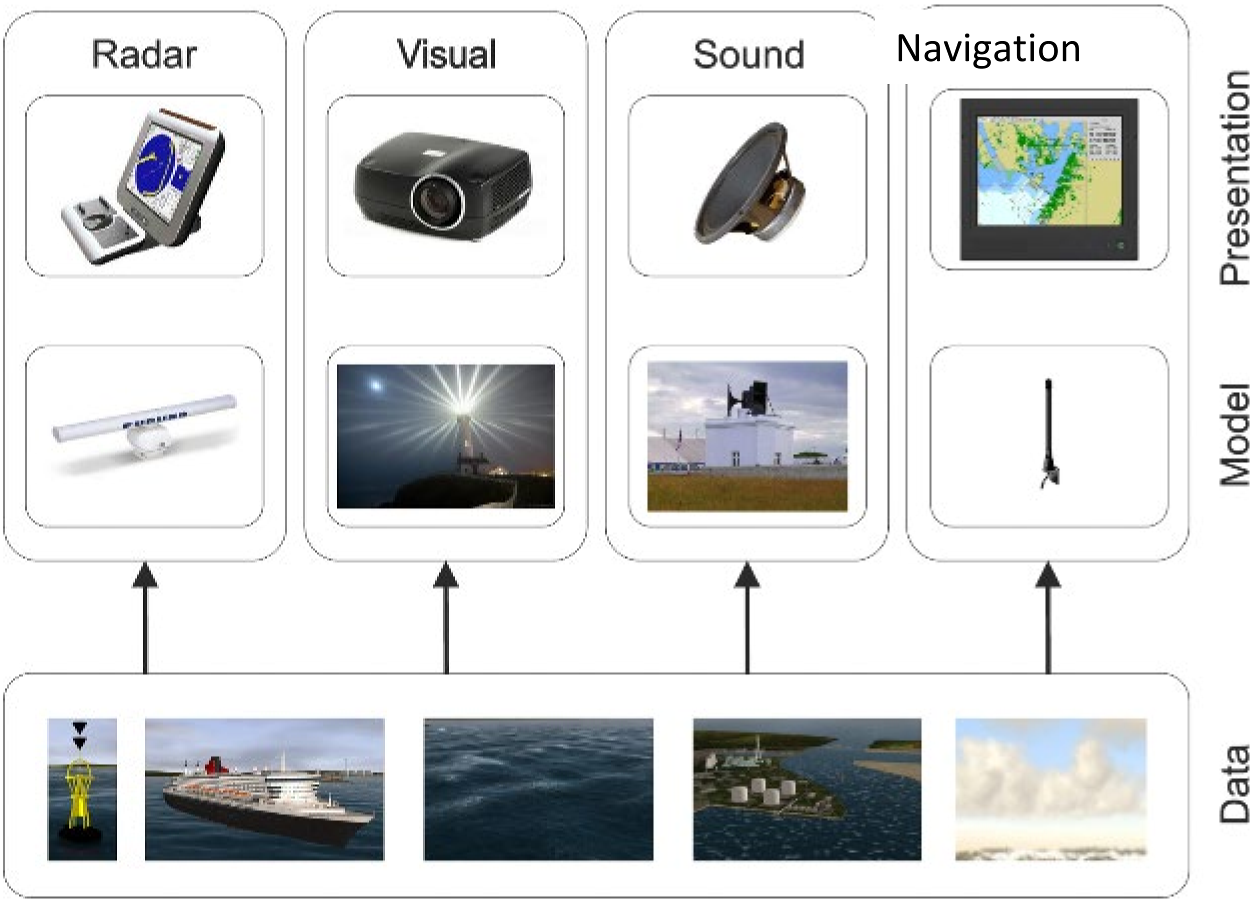


Figure 9 AtoN modelling and presentation

Table 2 Presentation media comparison

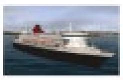
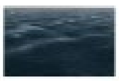
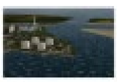
Channel		**Presentation media**	
		Reality	**Simulated**
	Radar	Monitor / PPI	Monitor, VR display
	Visual	Sun, lamps, etc.	Projector, monitor, VR display, etc.
	Sound	Fog horns, bells, etc.	Loud speakers
	Radio	Monitor	Monitor, VR display

Table 3 Simulation model

Channel		Simulation model
	Radar	Simulates how the radar transceiver, transmit pulses and receives echoes in the data model of the 3-D world.
	Visual	Simulates how light in the scene, either direct or reflected, scatters and enters the eye before visual perception. The visual scene
	Sound	Simulates how sound is received from sound emitters, like fog horns, sound from weather phenomena, sound on board ships, etc. are received before the “presentation” by the sound speaker.
	Radio	Simulates how radio waves from radio stations are received, interpreted by the receiver and finally displayed on the ECDIS or other navigation information display.

A single representation of the simulated world is used by all 4 channels, although each channel focuses on specific aspects of the data model.

Table 4 Data Models

Channel		Data Model
	AtoN	Positions, motion characteristics colour, flashing characteristics, buoy geometry, etc. are part of the data model for AtoN.
	Ships	Ship manoeuvring characteristics, visual appearance, navigation lights are part of the data model for ships.
	Ocean	The ocean wave climate, currents, tide, wind, and bathymetry are examples of elements in the data model of the ocean.
	Terrain	The terrain model includes the landscape, vegetation, buildings, and emissive light sources providing background lighting.
	Atmosphere	Reflected sun light and light from navigation lights are scattered by the actual weather, such as fog, haze, clouds, etc. Background sky colours changing over the day affects the conspicuity. Correct data for these effects is part of the total data model.

B.5. SIMULATION OF VISUAL CUES

B.5.1. PRESENTATION TECHNOLOGY

The presentation technology is the system responsible for the transmission of visual cues to the mariner on the simulator's bridge.

A number of presentation technologies are available, ranging from a single monitor or VR display to a LED video wall or projected view on a circular wall. All have their specific strengths and limitations.

For a simulation to be effective, the user must be able to derive all relevant visual information from the stimuli – thus the resolution of the display may be more important than its luminance, although there may be some interaction due to the physical characteristics of the human eye.

The first question to be answered before choosing a presentation technology is what the aforementioned "relevant visual information" will be. Then, from the available technologies, the most cost-effective alternative may be chosen. In the simulation models, the limitations of the presentation technology can be compensated to some extent. If the visual information cannot be sufficiently transferred by any of the available technologies, an additional, not necessarily visual feedback to the user could be provided.

All the technologies discussed in the following sections use digital technology, which has a finite resolution. As the number of pixels available is an inherent part of the hardware used, it must be considered carefully.

The typical setup of visual systems for marine simulators is:

- Projectors for large bridge spaces; or
- Monitors for smaller facilities; or
- VR displays

Projectors

A projection system involves a light source from which an image is projected onto a screen. The user observes the screen and as such the image transfer is indirect. The projection screen is usually at a distance of several metres from the observer position, which enhances the sense of reality through perspective. A drawback is that the radiation and reflection losses limit the luminance of the image such that the simulated conditions may resemble dusk lighting.

The projector techniques used determine the light output at the source, contrast and colour accuracy, response speed, etc. Continuing developments are stimulated mainly by the gaming industry and digital cinema and supported by the constant increase of computer power. Probably the most important parameter for simulation of visual AtoN is the resolution – and as all this is about digital imagery, this is determined by the number of pixels per minute of arc seen from the user's position.

On a full-mission bridge simulator, a large viewing angle is typical 210-degree field of view projected onto screens. (preferably 360-degree). A frequently applied setup is a circular projection screen with a number of projectors underneath or on top of the simulator bridge, each one being responsible for a sector of the outside view. Besides the characteristics of the projectors, some specific issues relate to the composition of the image in such a theatre.

The projected image of each projector should ideally be a perfect cylindrical section, all colours sharp and aligned throughout the entire image. As the projectors cannot all be in the centre of the cylinder section, for example due to obstructions such as a wheelhouse, the image generation system must compensate for this. In addition, the projection of a flat image source would lead to a flat projected image, so the focus must be corrected for the cylindrical image. These corrections are fairly standard, although many hours of adjustment may be involved to setup and maintain an optimal image.

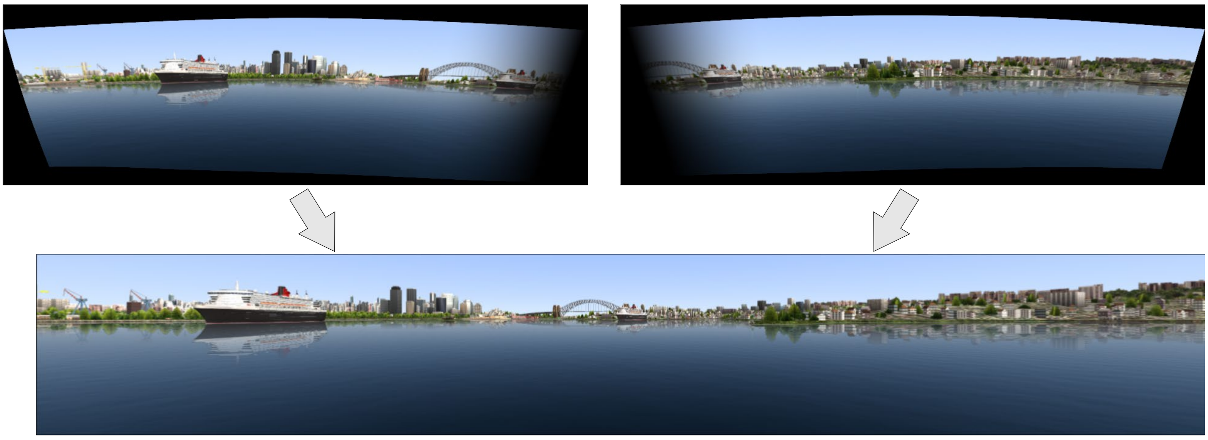


Figure 10 Warping and blending two visual channel images making it correct at the projection screen

Monitors

A monitor-based setup is less expensive compared to a projector based, providing the same image quality. However, the feel of being immersed is higher for a projector-based system with a seamless field of view image having no blind areas due to the obstruction by bezels. Head move inside a real wheel-house mock-up.

When a simulated image is presented on one or more monitors, the radiation and reflection losses associated with projection are avoided. The monitors can replace bridge windows, the window frames giving a natural separation from the adjacent monitors. Having the displays at close range decreases the impression of perspective. The user's position on the bridge should be fixed, otherwise the absence of parallax would be apparent from the window frames.

A video wall consists of several video monitors positioned side by side or on top of each other. It is important that the frames of adjacent monitors must not be noticeable. The powering and control of the displays may be a technical challenge which are illustrated in Figure 11 below.

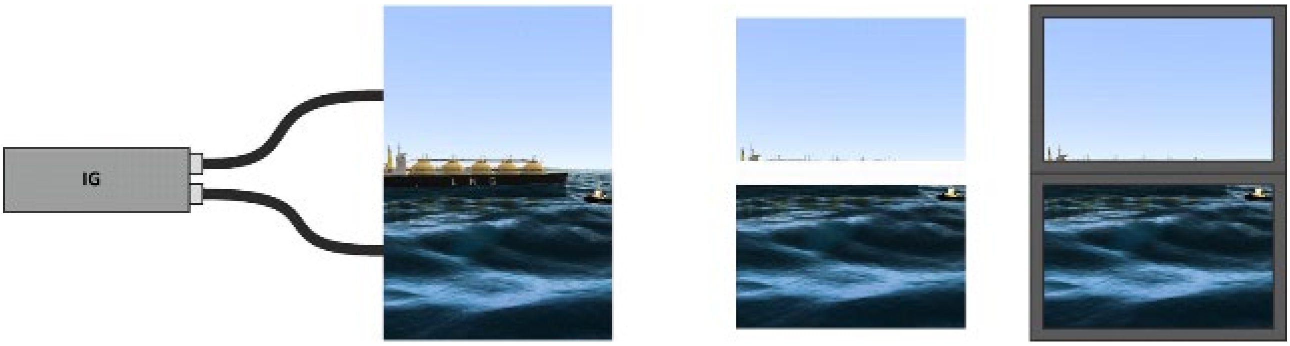


Figure 11 Bezel correction for video walls

Figure 11 illustrates the "Bezel correction" process of removing pixels behind the frame of multiple monitors. The Bezel correction needs to be carried out if the visual images are rendered by one IG (Image Generator) channel and displayed on several monitors.

A simulation may use a combination of the techniques described above. As an example, a separate monitor could be used to fill in the rear view on a projected 270-degree view bridge. Furthermore, the lights of AtoN could be superimposed on a projected view with separate laser beams, giving high contrast and high resolution.

When a projected view is combined with additional monitors for rear view, or a bridge wing view, the difference in luminance and contrast of the displays should be considered.

An advantage of monitors over projection systems is that pixels are not distorted by optical aberrations, so that the resolution is not reduced by blurring of the pixel images. Moreover, the usually very laborious adjustment process to get the best possible projected image is avoided. Depending on the distance between the user and the monitors, the number of monitors needed to provide a reasonable field of view could become rather large and the adjustment of display colours is still a significant task.

The larger the distance between the user and the monitors, the better the sense of reality gets (approaching that of a projected image). The distance and the pixel pitch of the screen together determine the maximum displayable resolution. As an example, if we have a monitor with 0.25 mm pixel pitch and need a resolution of 1' the distance must be at least 86 cm. To get a field of view of 30 degrees for one screen the size of the screen has to be 46 cm. A monitor with the same resolution but twice as large (thus having pixel pitch of 0.5mm) may be placed at double the distance to get the same visual representation. The options are illustrated in Figure 12.

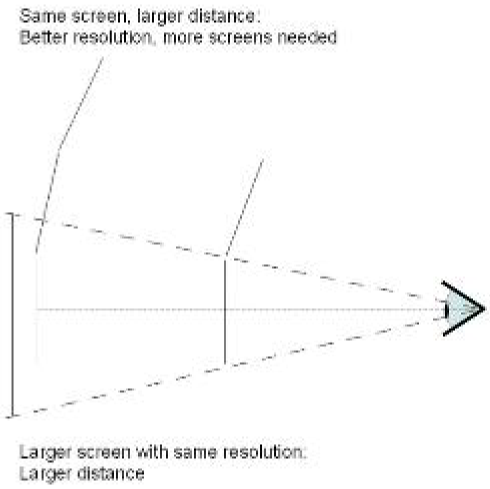


Figure 12 Screen configurations

VR Displays

The same rationale and techniques can be applied with VR (Virtual Reality). Instead of creating a very large projection wall for the image, the user may be provided with small displays showing everything that he should be able to see. The displays are built into a VR display that the user wears, excluding his real surroundings. The VR display must sense the position of the user's head and the direction of his eyesight. This information must lead to very fast adaptation of the image, as the latency (the time the image lags behind) must be rather small for the user to keep the illusion that he is really looking around. The resolution in VR Displays is quite good for simulation purposes, thus making the VR Displays a rather attractive display solution in terms of cost. The VR Displays provide as good an image quality in comparison to the monitor-based setup and the seamless field of view image as the projector-based solution. In addition to this a simulator system using VR Displays can rather easily be moved to another physical location. Hence, the user is not linked to a specific simulation centre.

Regardless, the choice of display system, the following quality indicators to observe in order of importance are:

- Contrast
- Resolution
- Brightness
- Colour space
- Quality certification
- Image generator system

It is of great importance that the provider of the simulator system can verify that the software supports the display system for its intended purpose.

B.5.2. MODELLING

When considering the presentation of AtoN, a number of models should be taken into account. Many of these models cannot be considered in isolation because changes in one model may affect the conditions of another model. Each of these models is shown in Table 5 and is grouped into categories. The following paragraphs will describe some of these models, or combinations of models where they affect one another.

Table 5 Conceptual models relevant to simulation

Observer	AtoN	Environment
		 

• Illuminance
• Angular subtense
• Colour
	• Fixed AtoN
	  • Lights
	    ○ Point
	    ○ Line
	    ○ Surface
	  • Construction
	    ○ Geometry
	    ○ Surface materials
	    ○ Local illumination
	• Floating AtoN
	  • Motions
	    ○ Mooring system
	    ○ Environmental forces
	  • Construction
	    ○ Geometry
	    ○ Surface materials
	    ○ Local illumination
	  • Lights
	    ○ Point
	    ○ Line
	    ○ Surface
		• Terrain and man-made constructions
		  • Geometry
		  • Surface material
		  • Lights
		• Ships
		  • Geometry
		  • Surface material
		  • Lights
		• Ocean
		• Weather
		• Atmosphere
		• Celestial

For each of the conceptual models the phenomena described below should be considered.

B.5.2.1. Observer

Some understanding of human vision is required if models are to compensate for limitations in the presentation of an AtoN.

Illuminance

The amount of illuminance an AtoN light casts upon the eye of the observer depends upon its intensity, the distance of the AtoN from the observer and the state of the atmosphere. The illuminance level for an AtoN light should be at a level where the colour and the rhythmic character of the AtoN can be recognized with confidence both night and day.

It should, however be noted that with high levels of background lighting, a higher value of illuminance is required in order to see an AtoN light. At these higher levels, human vision behaves quite differently than at low illuminance levels. Phenomena such as short flashes (strobes), fast repeating flashes and flickers become more conspicuous as illuminance levels increase.

Angular Subtense

The subtense angle of the target object is not considered a human factor, but a property of the geometry of size and distance. However, the visual acuity of the eye determines the degree of detection and recognition of an object that has a particular subtense angle.

Viewed from far away, most AtoN lights are point sources and therefore have no discernible size. As the observer gets closer to an AtoN light, the size increases so that the size and shape of the light source become noticeable.

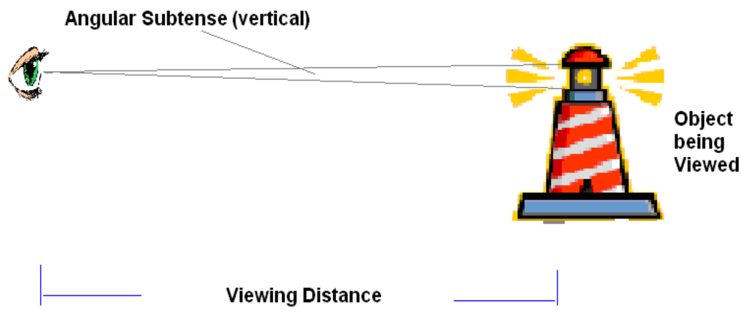


Figure 13 Diagram explaining Angular Subtense

B.5.2.2. Aids to Navigation

Extended Lights Sources

For close-range observations, the physical size of an AtoN light may be of importance, and it must be modelled such that the size of the light emitter is represented

Geometry

The physical appearance of daymarks shall be modelled as realistically as possible. For many simulation studies, generic buoys scaled to the correct size may be feasible. However, it is recommended that the conceptual model include the possibility of having the exact appearance of the buoy itself represented.

Surface Materials

The surface colours of AtoN shall be modelled as closely as possible to real-world colours. Bands of reflective material assisting in the identification of the floating AtoN when illuminated at close range are not considered of major importance. Reflection from glossy surfaces, such as large glass surfaces, may have a significant influence on the overall contrast and, therefore, of major importance for conspicuity day and night. The surface material shall also reflect indirect lighting from spotlights providing floodlighting.

Local illumination

Additional light sources may illuminate part of the supporting structure or daymark, improving conspicuity. This is also known as floodlighting. Indirect illumination of daymarks during night time may be pre-calculated, achieving good realism at a low computational cost.

Floating AtoN

A floating AtoN will be influenced by:

- Wind
- Waves
- Current
- Tide

- Its mooring system

The motions of a floating AtoN influenced by the above effects, may modulate the flashing characteristics significantly influencing the identification of the AtoN and may also have an impact on the AtoN swing radius (leave distance).

A real-time ship simulator is traditionally not used for the design of a specific buoy and the required mooring system. However, generic or specific motion response data models, for example, Response Amplitude Operator (RAO)[1] may be imported into a ship simulator in order to assess the suitability of the floating platform as a stable carrier of an AtoN light and as a daymark in the required environmental conditions.

B.5.2.3. Environment

Terrain and Man-made constructions

Cultural lights may be considered as rivals to the conspicuity of AtoN lights. Hence, cultural lights should be included. Cultural light sources include:

- Housing
- Greenhouses, public lighting
- Large flashing screens and advertisements
- Moving cars, aircraft, cranes, etc.
- Offshore structures
- Wind turbines

Wind turbines should be modelled with rotating blades when considered relevant for the study, as they may interfere with lights at longer distance.

Objects shall appear with the correct perspective. Flat background models (billboards) may be used for objects in the far distance for which the perspective does not change significantly.

Ships

Other ships navigating the waters to be studied also play a significant role for the conspicuity of AtoN lights and for studying the safe passage and safe distances.

Conspicuity is influenced by:

- The above water structure of moving ships obstructing the visual observation of the AtoN.
- Navigation lights, search lights, etc.
- Illumination onboard ships, such as in the accommodation and deck-lighting

For spatial planning studies where ships operate at close range to each other, the manoeuvring characteristics may be important. In this case the other ships' dynamics should be modelled as own ships. Otherwise, other ships can be modelled as traffic ships.

Ocean

A model for the ocean shall be included when assessing floating AtoN in realistic conditions.

The model should include the effect of:

- Tide;

  The tide may have a significant influence on relative height of fixed AtoN.

1 Response Amplitude Operator. An RAO is a transfer function useful for a linearized system. When the RAO is convoluted with the wave field spectrum, this yields the motions spectrum of the object in that wavefield, cf. [5].

- Sea state;

  The sea influences how floating AtoN are moving and thereby observed both at day and night, as also described above for floating AtoN. The sea state shall include both wind-driven waves and swell for developed and non-developed sea states.

- Current;

  The current, both tidal and storm surge, may influence the heel of floating AtoN thereby changing the relative vertical divergence of lights, including characteristics and nominal range. The current may also influence the swing radius of a floating AtoN.

- Reflection in calm water surface.

In particular, in night scenes the reflected background lights on the water surface may interfere with AtoN or other lights.

Weather

Wind influencing floating AtoN is considered to have a minor effect compared to that of current and sea state.

Clouds scatter light from the celestial objects, influencing global lighting in the environment. In addition, precipitation and fog scatter light from man-made lighting including reflected light. A glare effect will appear from light emitters.

Fog and various types of precipitation such as rain and snow should be available for simulating various weather situations.

Feasibility studies of AtoN should be made for various expected weather conditions.

Celestial objects

The Sun and the Moon are important light sources during day and night providing illumination of the scene.

The scattering of light passing through the atmosphere is of paramount importance for these light sources and should not be neglected. The high intensity light emitted by the Sun, reduces the relative intensity of AtoN lights.

The simulation should have a correct model of the azimuth and inclination based on time and day for these objects that feed into the scattering equation of light through the atmosphere.

Atmosphere

Whereas weather phenomena such as precipitation and fog may be considered as low altitude atmospheric phenomena, the light from celestial and man-made objects is also scattered by atmospheric phenomena. This may include:

- Humidity and pollutants,

  Particles in the atmosphere scatter light, both sunlight and local light emissions and reflection in the scene. The scattering is modelled using two supplementary models. The rayleigh model applies for particles smaller than the wavelength and the mie model for larger particles. The scattering of light causes the sky to have its gradual shading from white to blue. The aerial perspective makes objects in the distance less saturated and a little bluer. The ångström model combines both mie and rayleigh and includes other factors for aerosols present in the atmosphere close to the sea, further described in IALA Guideline *G1073.*

- Temperature.

  Local temperature variations might diffract the emitted light making the scene a little blurred, reducing visual acuity.

B.6. SIMULATION OF RADARS

As in the real world, the simulated radar system includes two elements:

- radar display; and
- radar transceiver.

If proper radar simulation design is applied, the same model for the radar antenna can be used for driving either an emulated or a stimulated radar display.

Several standards, guidelines and recommendations cover radar equipment and radar simulation, such as references [6], [7] and [8].

B.6.1. RADAR DISPLAYS

The presentation of the radar return is made using a radar display.

In a ships bridge simulator this may be done using:

- a stimulated real radar display; or
- an emulated radar display.

It should be noted that some manufacturers of radar systems place part of the signal processing in the radar antenna unit and that the model of the radar antenna must replicate this signal processing.

Stimulated radar display

If stimulated radar displays are used, no modelling of the real display system is required. Features like ARPA, trial manoeuvres, overlays and to some extent signal processing, that can influence the realism provided to the user, are made using the exact and approved equipment as found onboard real ships. This provides a very realistic setup at the expense of installing real equipment.

Emulated radar display

If emulated radar displays are used, real signal processing features must be re-engineered to facilitate realistic operation, replicating a real radar display.

The performance standard for Radar / ARPA displays includes a number of features which are given in [7]. If an emulated radar display is used for AtoN simulation it is important to make sure that features are made available to the user, which are deemed necessary for reaching the purpose of the simulation study.

B.6.2. MODELLING OF RADAR TRANSCEIVERS

For certain features to be displayed by the radar some effects have to be modelled in the antenna/transceiver model. The required effects are given in[6].

Radar Display Interface

It is possible to use the same model of the radar transceiver for both an emulated and a stimulated radar display. However, a piece of additional hardware, similar to a graphic adapter, is required to convert the radar return representation into a radar video signal which are different amongst radar manufacturers.

Terrain modelling

For the outside view to be generated during the simulation, a 3-D model of the real-world terrain has to be specified. This 3-D model can be the basis for the radar image but some extra information should be added. This mainly pertains to the radar reflectivity of the faces of 3-D objects. The same algorithms as used to generate the outside visual view can be used for the radar image, as this is also governed by line of sight, using the scanner position. Instead of colours and shading, radar reflection, scattering and diffraction properties should be used.

Alternatively, separate scenery for the radar image may be defined (spatially matched to the outside view scenery). This could be simplified because not everything in the visible scenery will show up on radar or be relevant for the simulation.

Modern computers are capable of using 3-D models of terrain and other objects. It is strongly advised to use a 3-D database. This ensures that masking of AtoN by ships, terrain or seaway is included in the simulation, when compared to a simplified 2-D representation.

Ships

Other ships may be regarded as a composition of a number of objects, i.e., superstructure, hull, cargo (especially containers), masts and cranes. Each of those objects has specific radar characteristics and the shape of the radar image of a “target” ship will depend on distance and aspect.

AtoN

Normally, AtoN will have a specified radar performance that will be used in the simulation. A radar reflector is specified by its radar cross section.

Racons

The response of a racon is shown as a radial Morse code pattern extending beyond the position of the racon. The starting position can vary due to a small time delay in triggering. The length of the pattern represents a fixed object size (usually a few nautical miles) and thus changes proportionally with the radar display range setting.

Models of racons should include:

- Frequency response
- Pulse length (equivalent to range on display)
- Trigger delay
- Polarization
- Sweep mode:
  - Slow
  - Fast
  - Frequency agile

Wind farms

The influence of offshore wind farms on radar performance has been studied extensively for the UK Maritime and Coastguard Agency (MCA) in 2004[2]. At smaller ranges, the turbine towers produce very strong echoes due to their height. In contrast to the horizontal beam width, the vertical beam width of marine radar is quite large. Thus the full height of a turbine tower is illuminated by the radar beam, and despite the usually round form, there is a large amount of reflected energy. The turbine blades also produce strong echoes, which are dependent upon the orientation of the nacelle. Because of this massive reflection, even the much weaker side lobes of the radar beam may produce echoes. These will appear on a P.P.I. (Plan Position Indicator) as objects at the same range but at shifted bearings. Reflections between turbine towers (multipath) can cause spurious echoes at larger ranges.

Weak objects behind a wind farm could be masked because the radar gain is set at a low value to avoid spurious echoes, while the object echo is further attenuated by the wind farm. A small vessel sailing through a wind farm will frequently be “swamped” by the echo of a turbine. The limitations of beam width also apply, but because of the strong reflection of the turbine outside the nominal beam width (half-power points), the beam width is effectively extended.

B.7. SIMULATION OF SOUND

2 See http://www.dft.gov.uk/mca/effects_of_offshore_wind_farms_on_marine_systems-2.pdf

This section is limited to the possibilities of simulating the sounds of AtoN and not sounds from own ship, environment and other ships.

B.7.1. PRESENTATION

Speaker systems

Modern full mission bridge simulator systems are normally fitted with quadraphonic speaker systems. These are of high quality providing good realism in the representation of AtoN sound and support the perception of distance and direction.

Sound Reception Systems

On vessels with enclosed bridges, typically cruise vessels, a sound reception system is used to attenuate the sounds encountered by a vessel. By using four microphones the sound reception system detects the direction of the incoming signal and a panel on the bridge indicates the direction as well as providing the attenuated sound through speakers. Such sound reception systems are available for simulators, providing the same functionality as in the real world.

B.7.2. MODELLING

Gongs, bells, horns and sirens are typical audible signals emitted by AtoN. The user's perception of sound will depend on several factors:

- The sound level emitted by an AtoN
- The distance and direction to the sound emitting AtoN
- The ambient noise level at the position where the user is listening to the sound – typically on the ship's bridge;

  Elements such as engine noise, weather noise, radio noise and other noise from devices positioned on the bridge, or close to the user's position on the bridge, will affect the reception of AtoN sound signals. Reception is also affected if the user is located inside a fully enclosed bridge, or on an open bridge:
- Environmental conditions affecting the speed of sound such as air humidity, damping elements, reflecting elements, presence of snow, rain or fog, icebergs with snow, cliffs covered with vegetation, etc.

Sounds from AtoN are recorded digitally and reproduced with the correct time pattern through speaker systems in the simulator. The sound level, its degradation and direction, can be part of the simulator model.

Various algorithms are used to ensure a high level of realism, including the effect of environmental conditions. If such algorithms are not used; the speaker system is not providing sufficient quality supporting the input; or, only one or two speakers are provided, the directional element will be missing.

Refer to IALA Guideline *G1087* on the use of Audible Signals for details that should be considered when simulating sound signals and IALA Recommendation *E-109* for the calculation of the range of sound signals.

B.8. SIMULATION OF OTHER SHIPBOURNE NAVIGATION INSTRUMENTS

B.8.1. ECDIS

The Electronic Chart Display and Information System (ECDIS) is a system that shows a digitized version of a nautical chart (an ENC) with extra information superimposed on it – most notably own ship's position and heading. The fitting of ECDIS is mandatory for (nearly all) new ships and will be mandatory on all SOLAS ships after 2014.

The information is organized in layers and users may switch layers on and off to adjust the information presented to their needs.

The IMO document outlining the model course for ECDIS training [8], illustrates the relevant interfaces with other bridge equipment. Not all capabilities will apply to every simulator setup.

ECDIS simulation equipment should be capable of simulating operational ECDIS and should meet all performance standards adopted by the IMO.

An ECDIS must comply with the requirements of the IMO Performance Standards, Resolution A.817(19), otherwise it should be indicated as being an ECS (Electronic Chart System).

B.8.2. PORTABLE PILOT UNIT

A Portable Pilot Unit (PPU) can be described as a portable version of an ECDIS, with its own accurate position sensors. Using two separately spaced GPS receivers, heading can also be determined accurately. The ideal track and channel boundaries are indicated on the display and parameters like cross-track error, rate of turn, transverse speed fore and aft, can be continuously updated and visualized. Additionally, track prediction can be displayed based on current velocity field, rudder angle and rpm, etc.

The system provides the pilot with all relevant information to advise on navigation. It is even possible to send VTS traffic images to the PPU, providing the pilot with the same traffic information as the VTS.

B.8.3. AIS AS VIRTUAL ATON

Virtual AtoN should be supported in simulation. This allows for testing such virtual aids as it does for physical aids, although these will only be observable on radars, ECDIS, etc.

B.8.4. E-NAVIGATION SERVICES

IMO has developed a strategic vision for e-Navigation, which integrates existing and new navigational tools.

Future e-Navigation services will include the representation of AtoN and it will be possible to integrate these into marine bridge simulators like other navigational instruments. This could serve to test the representation of AtoN.

A few prototypes of e-Navigation systems are currently being produced and could be integrated into simulators. The systems are, by their nature, complex and involve the interaction between several systems, including data transfer systems. The integration of a fully operational and working e-navigation system depends on the simulator's ability to provide input from all sensors and systems connected to the e-Navigation system. A simulator should normally be able to simulate errors and malfunctioning systems.

As the e-Navigation concept is just at the start of its development, large changes may still be expected. Simulation must be set up in a flexible manner to be able to accommodate these future developments.

B.9. REFERENCES

[1] Shannon, R.E. (1975). '*System Simulation: the art and science'.* Prentice Hall.

[2] Shannon, R.E. (1998). 'Introduction to the Art and Science of Simulation'. Proceedings of the 1998 Winter Simulation Conference.

[3] J. Banks, J. Carson, B. Nelson, D. Nicol (2001). 'Discrete-Event System Simulation'. Prentice Hall. p.3. ISBN 0-13-088702-1.

[4] Faltinsen, O. M. (1990). *'Sea Loads on Ships and Offshore Structures.'* Cambridge University Press. ISBN 0-521-45870-6.

[5] IEC 62388: 'Maritime navigation and radiocommunication equipment and systems – Shipborne radar – Performance requirements, methods of testing and required test results'

[6] IMO MSC 192 (79) '*Adoption of the Revised Performance Standards for Radar Equipment'*

[7] DNV standard for certification no. 2.14 'Maritime Simulator Systems

[8] IMO STW Operational use of Electronic Chart Display and Information Systems (ECDIS) STW 43/3/1, 2011

[9] NAVGUIDE 2018 Marine Aids to Navigation Manual

APPENDIX 1 TERMS AND DEFINITIONS

The definition of terms and acronyms used in this Annex can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary. However, there are other terms and abbreviations, which are not defined in the IALA Dictionary. Those are:

- **Stimulation** is used when a real radar video signal is produced in a simulator model and feeds, as in real life, into a real radar display identical to those used onboard real ships;
- **Emulation** is the replication of a real-world system using software and hardware;

  For example, the whole radar sub-system, both antenna and display is modelled and appears identical to a real onboard system.
- **Simulation**. In IALA Guideline 1058 the following definition has been used:

  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 [1].

  Thus the model must be designed to mimic the response behaviour of the real system to events that take place over time [2]. Therefore, for the purposes of this Guideline, a more accurate definition is as follows:

  Simulation is the imitation of the operation of a real-world process or system over time [3]. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviours of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.
- **Modelling** is the process of developing a schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics.
- **Conceptual models** aim to provide a mental breakdown of a system into smaller subsystems that are easier to understand. The primary objective of a conceptual model is to convey the fundamental principles and basic functionality of the system which it represents. Also, a conceptual model must be developed in such a way as to provide an easily understood system interpretation for the model users.
- **Presentation** is the continuous state of the simulation model presented to the system user with realistic and relevant stimuli as used in real world operations.
- **Brightness** is an attribute of visual perception in which a source appears to be radiating or reflecting light [1]. In other words, brightness is the perception elicited by the luminance of a visual target. This is a subjective attribute/property of an object being observed. “Brightness” was formerly used as a synonym for the photometric term luminance.
- **Own ships** are in ships bridge simulators identified by the ships steered by users at the ships bridges, having a working environment as close as possible to reality. Motions are modelled using 6 degree-of-freedom equations.
- **Traffic ships** are ships not steered from a ship’s bridge. They are mainly controlled by the simulator operator or running autonomously by computers. Traffic ships are modelled using simplified equations of motions compared to own ship models and are used to get a proper traffic density in the scenario.