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**Guideline (Manual) on a minimum comprehensive mix of AtoN
in fairways/waterways including dredged channels and canals**

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1 Introduction

Until recently, mariners have used the radio aids to navigation systems (also referred as electronic aids to navigation) and the short range systems in two distinct geographic areas. The short range system was mostly used close to shore and in restricted waterways. On the opposite, offshore vessels were able to navigate safely using less accurate radio aids system. However, considering the availability, reliability and relative low cost of high precision electronic aids systems (e.g. GPS/DGPS and electronic charting programs) available today, these two areas of navigation are beginning to overlap. This is especially true in those transitional areas where mariners shift from the low accuracy requirements of ocean navigation to the high accuracy needs of coastal and inshore piloting. As electronic aids continue to improve, their use will increase in areas where previously only short range aids provided the necessary accuracy. This evolutionary change must be recognized and accounted for when conducting waterway analyses.

However, safe navigation by electronic means, does require a certain level of accuracy, availability and integrity in order to accurately portray the fairway/waterway, dredged channel or canal. There should also be an adequate level of integration with the control of the ship either automatically or through the navigator. As there are uncertainties connected with this, visual navigation eventually combined with the use of radar is in principle either a primary or a secondary means of navigation.

So, despite the technical changes there remains a significant need to provide mariners with navigational information when piloting within restricted waters. The best manner in which to provide information to this level of precision is through the use of a short range aids to navigation system consisting of buoys, beacons, sound signals, and electronic systems such as RADAR beacons (RACONS) , Automated Information System (AIS) devices and GNSS.

This guideline cater for this and provide guidance for Aids to Navigation Design regarding fairways/waterways including dredged channels and canals which should be both relevant to the mariner and cost effective to the National Authorities. In order to cover different situations, the guideline is quite broad.

Aids to navigation systems may be provided for the safety of navigation in various kind of waters such as:

- Waters adjacent to the coast
- Archipelagic waters
- Straits

- Estuarine rivers
- River systems
- Canals through narrow stretches of land.
- Fairways with natural navigation channel
- Dredged channels and canals
- Open Sea with Ship Routeing Systems

Different users are considered, as there are ships, vessels, boats etc. facilitating commerce, fishing, leisure and a number of other activities that can typically be found in marine environments

Aids to navigation systems may be established to:

- a) assist landfall,
- b) mark approaches to harbours, ports and waterways
- c) mark channels or tracks
- d) mark hazards
- e) identify positions or courses
- f) indicate preferred routes
- g) separate traffic (e.g. to mark traffic separation schemes noted by specialized symbols on Hydrographic charts and/or IMO Routeing Systems)
- h) indicate special areas such as anchorages

2 Minimum requirements

2.1 General

The primary goal of the design of waterway aids to navigation systems is to facilitate safe, economic and efficient movement of vessels. Aid to navigation systems are designed to assist navigation and not to replace normal prudent navigational practices or the use of onboard navigational equipment.

The aids to navigation provided are normally intended to function in systems and therefore mariners should make use of the full information provided. These systems are intended to be used by the prudent mariner who knows and understands the functioning of aids to navigation, uses them in conjunction with charts and other published information, and conforms to the applicable Rules of the Road.

Whether designing a new waterway system or evaluating an existing one, there are many factors that must be considered. The identification of these factors allows National Authorities to develop a greater understanding of the risks and threats that are present within a particular waterway. Section 5 of this manual provides guidance for completing this analysis. Recognizing that waterways are different, the *site analysis, needs analysis, simulation, and operational analysis* provide the necessary frameworks to generically evaluate the overall risks that may be present and provide mitigation measures..

These factors include the consideration of

- user “needs”,

- shoreside characteristics,
- physical and environmental condition of the waterway and
- significant traffic types and density using the waterway.

Once the evaluation has been completed, National Authorities should use this information to design the aids to navigation system that mitigates the risk to safe transit or reduces it to an acceptable level. In completing the design it is important to note that the entire waterway must be viewed using a systematic approach, recognizing that each individual element of the waterway design by itself will not reduce transit risk. So while individual regions of the waterway must be considered, the overall aids to navigation system must support a smooth transit of the waterway as a whole. This way, the waterway must be examined “end-to-end” to ensure that an acceptable and uniform level of risk is present throughout the waterway. While the analysis process is a tool for the assessment of risk, it should be the National Authorities objective to design an aid to navigation system best able to manage those risks.

The specific aids to navigation system implemented should enable waterway users to transit an area safely and efficiently, while avoiding groundings, obstructions to navigation, and collisions with other vessels. Therefore, in order to satisfy the information requirement of the user, a system of aids to navigation must:

- Be available at the time it is needed
- Provide timely warning of danger from channel limits and fixed obstructions to navigation
- To quickly enable the mariner to determine their location within the channel, relative to fixed obstructions to navigation, and relative to other vessels
- Enable a safe course for the vessel to be determined

Once the system has been established, maintaining the availability of this system is critical to controlling overall risks. Please refer to IALA Recommendation O-130 on short range AtoNs for additional information related to the categorization of individual aids to navigation, the calculation of availability targets, and recommended availability objectives.

3 Types and principles of Marking

3.1 Purpose of Marking

The purpose of marking is to:

- a) assist landfall, mark approaches to harbours, ports and waterways
- b) mark channels or tracks
- c) mark hazards
- d) identify positions or courses
- e) indicate preferred routes
- f) separate traffic (e.g. to mark traffic separation schemes noted by specialized symbols on Hydrographic charts and/or IMO Routeing Systems)
- g) indicate special areas such as anchorage

The responsible provision of aids to navigation systems requires that systems be designed to meet the essential minimum requirements for safe and expeditious navigation through specific waters in accordance with the type and volume of traffic. In general, redundancy within, and between systems is to be avoided. Notwithstanding, duplication in function may be appropriate and necessary to provide a degree of safety in the event of a discrepancy and to avoid excessive costs of emergency repairs. Moreover temporary duplication may be provided when new or alternative types of aids are being introduced in order to allow a safe transitional period.

3.2 General Principles of Marking

It is essential, that the Aids to Navigation be identified and located on charts (ENC, paper chart, synthetic radar screen).

In narrow or winding passages where the mariner has no time to correlate the vessel's position with chart information, the navigational marks should be explicit and clear so that navigational decisions can be made directly using visual and/or radar information.

Short Range Aids to Navigation, especially buoys, should be designed regarding their visual information, radar information (active or passive) and other modes of information (Radionavigation, AIS).

In designing and redesigning systems, past incidents such as groundings, collisions or near-misses must be carefully considered. Such incidents should be well documented to ensure accuracy of the information used for a decision to change or not to change the configuration of aids in a system.

Aids to navigation systems should be designed to assist mariners under various weather, sea and ice conditions found during the local navigation season for the various types of vessels. Design elements must take into account the visibility and radar availability implications where buoys are removed for part of the navigation season and may be replaced with ice spars.

Designing for worst case visibility is not practical. Reduced visibility due to haze and fog must be considered.

During the design phase the required level of availability should be considered. The level of availability is dependent upon the threats and risks that are mitigated through the use of a particular aid to navigation. In those areas in which the level of risk has been determined to be high, the use of certain types of aids to navigation may prove to provide greater risk mitigations. However, the planner must also consider the higher availability objectives that may also be required.

Reliance upon a single aid to navigation may result in a higher availability requirement which may prove difficult for the National Authority to meet. If this is the case, then the implementation of multiple aids may be used to provide redundancy during periods of unavailability by certain aids.

3.3 Principles for different Types of Marking

The fairway area can be marked in different ways, using the right mix of conventional short range aids to navigation and electronic aids to navigation:

- Lateral Fairway Marking
- Marking the critical points
- Marking the (middle) line(s)
- Start of the fairway

Each of these types of marking can use

- leading marks, which are not physically in that place they indicate,
- especially leading lines along the centre line of the fairway, which act as powerful tool for lateral positioning but poor for longitudinal positioning,
- leading lines crossing the fairways for longitudinal positioning
- lateral, cardinal or safewater marks, which are physically in or very close to that place they indicate,
- especially single markers for warning purposes, curve turning points and longitudinal positioning and
- paired markers for both longitudinal and lateral positioning.
- Other aids to navigation including radio aids
- AIS

One advantage of the edge marks is that they are well visible with shipbourne radar. One disadvantage of edge marks is that they can be damaged by ice, current, collision.

3.3.1 Buoys and beacons

The principles for buoyage can be also used for beacons if the beacons are situated directly on the fairway.

The types of buoys are described in the IALA Maritime Buoyage System, which should be consulted for mandatory toolbox for buoyage. Thus the systematic, consistent and clear use of floating Aids to Navigation should be ensured.

If high navigation accuracy or a very clear and continuous buoyage is required paired or “gated” buoys should be preferred.

The design of a continuous buoyage of a fairway which is formed by straight lines and bends can be done in three steps:

1. Select a conspicuous buoy or pair of buoys for the point where the fairway starts.
2. Place buoys on points
 - a. where ships have to divert their course or
 - b. where the fairway boundary line or the middle line has a bend or
 - c. where critical shallows and rocks or other hazards form the boundary of the fairway and at
 - d. Fairway intersections
2. Distribute buoys between these points according to their observation distance. If a certain buoy separation distance is desired, the right size

and shape of buoys and nominal range of their light has to be determined. If a certain type, size and shape of buoys and lanterns is desired, the separation distance has to be determined. This is an iterative process. More than one option should be examined and assessed from the nautical, economical and technical point of view.

The buoy separation distance should be chosen in such way, that the next one or two buoys are recognized ca. 100 ore more before the nearest one has been passed or in other cases some 100 m before the last buoy is no longer visible.

In general the more fairway or channel markers are there the easier and more accurate is navigation. However, there is a saturation point where adding A to Ns odes not help positioning further. Too many markers may be confusing and weaken the result. To find this point, usually simulation have to be done in the detailed design phase.

Edge Marking (drawings from Finland input ANM 9/6/6 and 9/6/7) including more of it here?

Safewater Marks indicate navigable water all around. They can be used to indicate the start of a fairway or to indicate the fairway line.

3.3.2 *Leading lines*

Leading lines (lighted or unlighted) can be established if there are stretches that form a straight line. Leading lines should be established

- if the buoyage could be affected by ice,
- if there is a channel inside the fairway, which has to be used by ships with big draft

3.3.3 *Sector lights*

3.3.4 *Electronic aids to navigation*

54 Procedures for determining the requirements for short-range marine aids

Procedures for determining the requirements for aids to navigation at any site are based upon four types of analysis.

5.14.1 Types of analysis and steps for each analysis

The design methodology can be described as a step by step procedures organized in a logical sequence in order to justify the conclusion and recommendations in determining the requirements for short-range aids to navigation. These procedures consist of the following four analyses:

Site Analysis (5.1.1)

An analysis of users, traffic patterns, weather and possible navigational threats at the site.

The physical and environmental condition of a waterway, as well as the size of the vessels using the waterway, must be considered.

Needs Analysis (5.1.2)

An analysis of user needs for navigational markers and signals at the site (needs analysis) to help mariners cope with navigational threats.

Operational Analysis (5.1.3)

An analysis of outputs of various combinations of short-range aids that could be provided at the site (operational analysis) to identify feasible means of meeting user needs

Simulation and GIS may be used (5.1.5).

Cost-Benefit Analysis (5.1.4)

A comparative analysis of cost of effective combinations of aids (cost-effectiveness analysis) to select between viable alternatives.

In brief, the steps to be followed in each of these procedures are:

1. Specify the navigation site to be analyzed by identifying the user's traffic patterns and plotting the track or tracks on the chart. Gather all user and site information such as size, type and number of vessels, type, size, output and characteristics of all established aids to navigation, weather and sea conditions, previous reviews, marine incidents, requests, etc.
2. Identify and classify the size and number of users according to the three basic categories.
3. Rate the threats at each site for each type of user, using guidelines and professional judgement.
4. Identify any local means, other than short-range aids to navigation, that may meet any of the needs identified.
5. For each of the threats in the waterway, identify the related navigation needs and the aid or aids which address these needs.
6. Identify any threats that are not adequately reduced and the recommended aids or other means that could meet the navigational need.
7. Identify any aids to navigation that are provided where the threats are not significant or service is redundant and recommend action to reduce or discontinue aids.

8. Calculate the coverage and hazard marking requirements at any open water landfall situation, for each user group.
9. Calculate the equipment output required to achieve the required visual, aural and radar coverage at the specified level of availability. Identify where the requirements are not being met with established equipment and propose viable options.
10. Calculate the size and output requirements for each aid to navigation established or proposed, in the confined section of the waterway, to meet the proposed availability for each user group. Identify where the proposed levels are not being met and propose viable options.
11. Establish the comparative direct costs of each proposed alternative, to assist in determining the most cost-effective system of aids to navigation.

5.1.14.1.1 Site analysis

The purpose of this first analysis is to gather site specific data for the review work. In this phase, the following steps should be followed:

- Identify & classify the size, types & number of users
- Assess the volume of traffic and identify traffic patterns including navigation seasons and or trends for each users category.
- Obtain weather & sea conditions including tidal and current information, wind and reduced visibility
- Obtain information on the physical geography of the river, waterway or shoreline such as silting, distinctive shore features, existing charted landmarks etc.
- Retrieve related historical information such as previous reviews, marine incidents, requests for aids to navigation, etc.
- Prepare an inventory of all aids provided by the authority at the site if applicable. This may include also private aids to navigation.
- Identify and rate specific threats to identify potential hazards for each type of users. This initial rating considers each of the following threats individually:
 - Minimum depth allowance (considering the vessel draft, wave height and under keel clearance)
 - Distance from hazards and from other vessels when passing
 - Minimum channel width and angle of turn in channel
 - Wind speed, wave height, current along and across track and restricted visibility.

5.1.24.1.2 *Needs analysis*

Once the site analysis has been completed, the authority should proceed with the analysis of the mariners needs. This is where the authority establishes user requirements for safe and accurate navigation. It is at this stage of the process that the authority:

1. Consider the interactive effects and unique features of the site by rating the following composite threats according to a pre-determined scale:
 - a. Sea Conditions
 - b. Proximity of Hazards
 - c. Complexity of Channel
 - d. Diminished Room to Manoeuvre
 - e. Traffic Density / Mix / Crossing
 - f. Reduced Visibility
 - g. Darkness
 - h. Ice and Freezing Spray
 - i. Channel Siltation
 - j. Lack of Distinctive Feature for Positioning / Pilot Boarding Station
2. Identify related needs, noting the most appropriate generic types of aids to reduce the threats (e.g. visual marker on relevant hazards, lighted visual marker for lateral motion, visual boundary marker, Aural signal on relevant hazard, Radar target, etc...) as well as rate their relative effectiveness in reducing each type of threat for each category of users.
3. Note and assess to which extent local means and natural features (e.g. towers, spires, landmarks, etc.) can meet the needs,
4. Note the specific aids provided (if there is an aids system already in place) and assess against the threats and/or the generic needs.

A five point scale is used for the purpose of rating composite threats. Under this scale, threats are rated as follows: 1 - Overriding Importance; 2 - Highly Significant; 3 - Significant; 4 - Little Significance; and 5 - Not Applicable.

The generic types of markers and signals that serve to reduce the various categories of composite threats have been rated in consultation with users for their effectiveness in reducing these threats for each user category. These ratings are:

- A. Greatly reduces the threat.

- B. Significantly reduces the threat.
- C. Somewhat reduces the threat or reduces the threat for some vessels in the category (e.g., radar targets will assist those uncertified commercial vessels who are equipped with radar but do not qualify as Category I vessels because of their lack of other electronic navigation aids, etc.).

5.1.34.1.3 Operational analysis

Through the operational analysis, the authority is able to examine the outputs of various combinations of aids to navigation, compare the end results in relation to the needs of mariners for the specific waterway and consider the best possible option.

The operational analysis is conducted by performing a series of steps to:

- Determine the system requirements (landfall or confined waters)
- Determine the perception requirement (coverage)
- Compare the existing aids against the calculated requirements
- Determine the needs to meet design visibility (*Where is design visibility defined ?*)
- Examine and test options and or combination of aids to navigation
- Recommend final optimal system design.
- When reviewing an existing system, compare optimum design with existing system making appropriate observation and/or recommendations.

To complete the above steps, the following actions are also required:

- Calculation of the coverage and hazard marking requirements (perception requirement) for each type of users ensuring that said coverage is sufficient to allow the largest user time to complete an evasive manoeuvre.
- Calculation of the equipment output required to achieve the required visual, aural and radar coverage to meet the calculated perception requirement.
- Calculation of the size and output requirements for each aid to navigation established or proposed to meet the design availability for each user group.

4.1.4 Simulation and GIS

Prior to implementing a new AtoN system or changing an existing one, National Authorities can use simulation techniques to assess the overall safety and effectiveness of these changes. The use of Geographic Information System (GIS) technology can improve efficiency of AtoN deployment and waterway layout which, with volume of traffic overlaid (e.g taken from AIS data), can be used to assess risks and plan the disposition and type of AtoN to mitigate such risks and improve the provision of AtoN for all users. Having planned aids to navigation in this manner, the authority can use modern simulation tools where passage and combinations of various types of vessels can be simulated, in order to conduct a validation process, in

consultation with appropriate stakeholders. To achieve a high level of realism in the simulations, GIS data can be integrated to the waterway models used in the simulator.

One of the purposes of simulation in relation to waterway design is to evaluate planning of placement and design of AtoN in a specific waterway, channel or port area. Other purposes could be e.g. ensuring sufficient channel width, channel depth, and optimal orientation and design of breakwaters as well as ensuring that the lay-out of a channel and port is suitable seen from a manoeuvring point of view.

Simulation offers a method to help ensure that AtoN are appropriate and cost effective. Sophisticated computer simulation techniques are becoming increasingly available, and they provide an excellent mechanism for decision making as follows:

- generating 'what if' scenarios – feasibility studies
- obtain input to placement and design in consultation with stakeholders
- validation of final design and lay-out
- training in a variety of areas.

Simulating the placement and operation of AtoN by day and night, and under various conditions of visibility assists in ensuring that AtoN are effective and provided in a cost effective manner that suits the purpose of providing a predetermined level of safety. This is particularly important as aids to navigation become more sophisticated (synchronised and sequential lights, LED with flicker, and other new light characteristics).

Please see IALA Recommendation (O-138) for further discussion on the use of simulation in waterway design and placement of AtoN. The recommendation includes a reference to a guideline that amongst other outlines how to select the right simulation tool in relation to the objectives and expected outcome of the simulations.

4.1.5 Cost-benefit analysis

The last phase of the design methodology consists of a cost-benefit analysis which is a comparative analysis of costs of the various scenarios evaluated during the previous steps. This cost-benefit analysis should be done using values and cost factors as accurate as possible.

At the end of the process, the design methodology produces various options for aids system, various combinations of aids and associated costs ready for consultations with the affected mariners.

65 Conclusion

The art of navigation has evolved over many years, as well as ships, vessels and various other craft.

In principle navigation comprises:

- (1) to plan a track / passage for a ship by the use of a nautical chart,
- (2) to monitor or establish the ships position or advance along a predetermined track / passage, and

- (3) the control of the ship, e.g. that to secure that it follows a predetermined track / passage.

To navigate there are a number of "tools" available:

- clock
- log
- compass
 - magnetic compass
 - gyro compass
- radar
- nautical charts
 - paper chart
 - electronic navigational charts
- visual and radar aids to navigation
 - single point aids (lights and daymarks)
 - sector lights
 - ranges
 - racons and radar reflectors
- flood lightning of conspicuous objects
- Global Navigation Satellite Systems (GNSS)
- local and regional electronic navigation systems
- auto pilot

Of these "tools" some can be alternate to another tool while some can be complementary to another tool. That is the tools can be used in various numbers and combinations. Subsequently principally a primary and secondary method of navigation is often used. Depending on the situation the primary method could be either a visual/radar based method or a GNSS based method.

The appropriate nautical chart is of fundamental importance to find a safe track/passage and later as a reference during the ships movement. It is also fundamental to have a compass, clock and log to be able to follow and monitor the advance along the track. To establish a position visual or radar aids can be used either independently or in combination, although for instance a Global Navigation Satellite System can also be used.

The navigation process is normally performed by the navigator integrating the chart, navigational data and the control of the ship. In this case visual and radar aids normally play an important role. On some ships this process is fully automated, relying completely on electronic/digital "tools." This put a demand on accuracy on the chart, the navigation system and the control system, that cannot be fulfilled under all circumstances today. In general it is considered that proper marking of waterways/fairways, dredged channels and canals by visual and radar aids is important to reduce the risk posed by the waterway and the traffic.

The concept of accuracy differs between methods and is in general more developed for the nautical chart and the GNSS. That is the nautical chart is surveyed to a high accuracy and the ships position will be available throughout the voyage and with high accuracy by the use of GNSS. The aids to navigation will be surveyed with the same

accuracy as the nautical chart, but the position obtained by the use of visual and radar aids will not remain constant along the track. The concept of accuracy will in this case be the ability to keep the intended track and to know the advance along this track, leading to the provision of the right mix of conventional and electronic aids to navigation by the National Authorities to the mariners.