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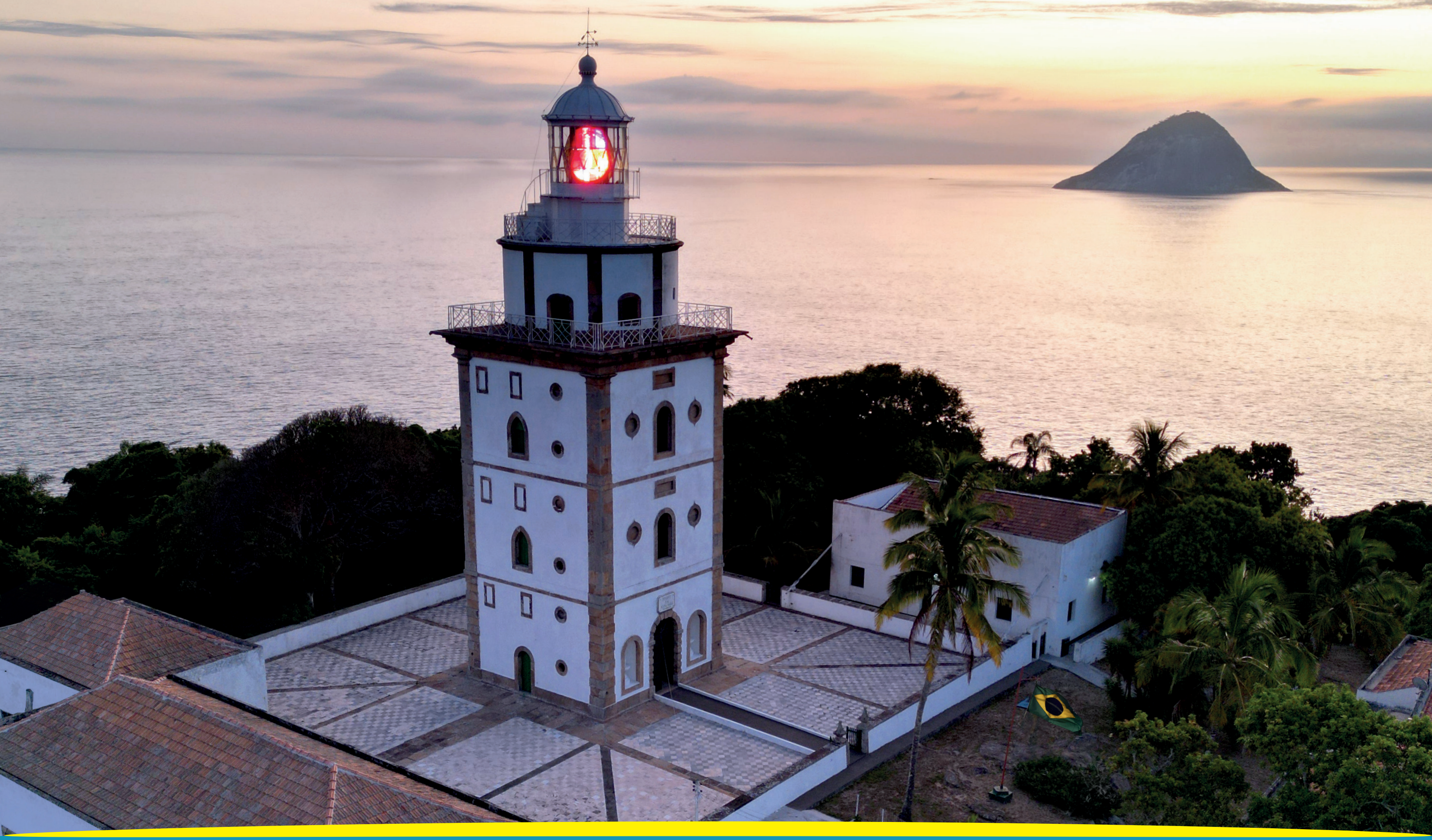

NAVGUIDE 2023

MARINE AIDS TO NAVIGATION MANUAL

9TH EDITION

INTERNATIONAL ASSOCIATION OF MARINE
AIDS TO NAVIGATION AND LIGHTHOUSE AUTHORITIES

NAVGUIDE 2023

Marine Aids to Navigation Manual

9th Edition

International Association of Marine Aids to Navigation
and Lighthouse Authorities

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FOREWORD

The NAVGUIDE has proven to be an invaluable resource for the maritime community, providing updated information on the latest advancements and developments in the field of Marine Aids to Navigation. The 2023 edition is no exception, bringing together the expertise of the world's leading experts in this area. This edition is not only an important resource for professionals in the field, but it is also a testament to the collaboration and commitment of the IALA membership to improving and harmonizing Marine Aids to Navigation practices worldwide.

The Guide is a product of five years of collaboration by the participants of the four primary Committees, AtoN Requirements and Management (ARM), AtoN Engineering and Sustainability (ENG), e-Navigation Information Services and Communications (ENAV) and Vessel Traffic Services (VTS).

The 2023 edition of the NAVGUIDE also sees its primary means of distribution being in a digital format which will be available on the website (www.iala-aism.org) along with all the other publications available to our members and users of Marine Aids to Navigation. I encourage readers of this NAVGUIDE to also consult the website for other documents, including standards, recommendations and guidelines that may assist you in your day-to-day work. As always, IALA is receptive to feedback on how the NAVGUIDE may further be developed for future editions and welcomes suggestions for improvements (contact@iala-aism.org).

It is important to note that the NAVGUIDE has been translated into multiple languages by our members to ensure that it is accessible to many users, regardless of their primary working language. The IALA World-Wide Academy has also included the NAVGUIDE as part of its Marine Aids to Navigation Management training syllabus, further demonstrating its significance in the Marine Aids to Navigation field.

In conclusion, the 2023 edition of the NAVGUIDE represents the hard work and dedication of the IALA membership to improving the safety and efficiency of Marine Aids to Navigation practices. I am proud to be a part of this organization and grateful for the contributions of all its members in producing this important publication.

Francis Zachariae
IALA Secretary-General
June 2023

CHAPTER 1

INTRODUCTION TO IALA-AISM

1.1 PURPOSE OF THE DOCUMENT

This manual is designed to help Marine Aids to Navigation (AtoN) authorities with the harmonization of AtoN services by providing a comprehensive reference guide on all aspects of the service. Additionally, it refers to more detailed guidance from other IALA documents and related international organizations on specific topics.

1.2 BACKGROUND

Shipping is a global industry that is regulated through various organisations. Nations have recognised that it is both effective and appropriate to regulate and manage shipping on an international basis.

IALA is a non-profit and non-political international technical association devoted to the harmonisation of Marine Aids to Navigation. IALA was formed in 1957 to provide a framework for Marine Aids to Navigation authorities, manufacturers and consultants from all parts of the world. A process has started to change IALA from that of a non-governmental organisation (NGO) to that of an international intergovernmental organisation (IGO). Elevating IALA's status to that of an IGO will make it a peer to organisations like the International Maritime Organization (IMO) and the International Hydrographic Organization (IHO), thereby strengthening existing cooperation. As well, it will allow for a broader participation in IALA by States, at government level. This will assist IALA's aim to promote the greatest possible uniformity in Marine Aids to Navigation.

The aim of IALA is to foster the safe, economic and efficient movement of vessels, through improvement and harmonisation of Marine Aids to Navigation worldwide and other appropriate means, for the benefit of the maritime community and the protection of the environment.

The Strategic Vision of IALA sets out two main goals:

Goal 1 Marine Aids to Navigation are developed and harmonised through international cooperation and the provision of standards.

Goal 2 All coastal states have contributed to a sustainable and efficient global network of Marine Aids to Navigation through capacity building and the sharing of expertise.

1.3 MEMBERSHIP

IALA has three main types of members:

National membership: Applicable to the national authority of any country or part of a country that is legally responsible for the provision, management, maintenance or operation of Marine Aids to Navigation.

Associate membership: Applicable to any other service, organisation or scientific agency concerned with Marine Aids to Navigation or related matters.

Industrial membership: Applicable to manufacturers and distributors of Marine Aids to Navigation equipment for sale, or organisations providing Marine Aids to Navigation services or technical advice under contract.

There is also a fourth type of membership: **Honorary membership** which may be conferred for life by the Council to any individual who is considered to have made an important contribution to the work of IALA.

IALA Membership in the world in 2022

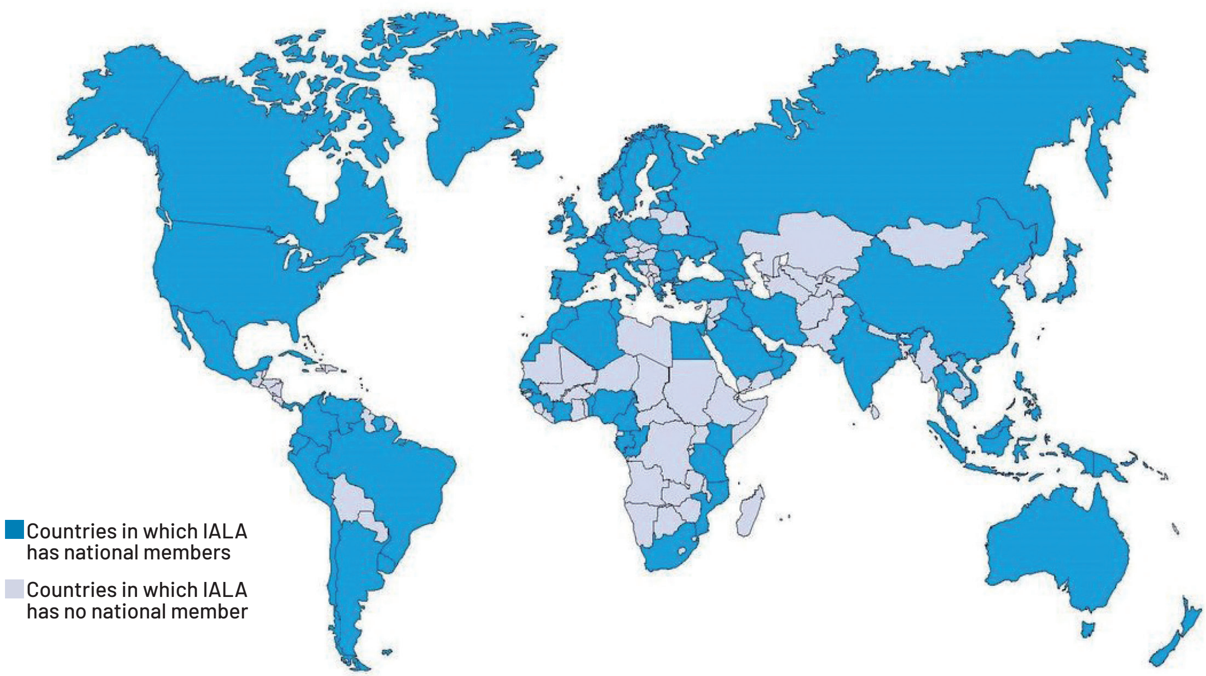


Figure 1. IALA National Members

1.4 GENERAL ASSEMBLY

The General Assembly is held every four years and brings together members from all categories. Usually, it convenes in conjunction with the four-yearly Conference.
During the General Assembly, national members are entitled to:

- determine the broad policy direction;
- elect members to the Council;
- decide upon changes to the Constitution; and
- approve Standards.

Associate and Industrial members are entitled to attend the General Assembly and take part in the discussions, but they do not have the right to vote.

1.5 THE COUNCIL

IALA is administered by a Council of up to twenty-one elected and three non-elected Councillors. The elected positions are determined by a ballot of all National members attending a General Assembly. Only one National member from any country may be elected to the Council and there is a general aim to draw Councillors from different parts of the world to achieve a broad representation on the Council.

The Council, among other things:

- implements the overall policy of IALA as defined by its aims or by the General Assembly;
- decides membership matters;
- establishes committees relevant to the aims of IALA and/or facilitates other such bodies as may be appropriate;
- determines rules of procedure for committees and other such bodies as may be appropriate and their terms of reference;
- approves recommendations, guidelines, manuals and other appropriate papers;
- approves submissions to other organisations;
- decides the venue and the year of the next IALA Conferences and symposiums;
- establishes rules for participation in IALA Conferences and Symposiums;
- convenes General Assemblies;
- approves the annual budget and accounts;
- determines the rate of contributions;
- decides upon the location of the Headquarters and registered office of IALA;
- may authorise the purchase, sale, renting or letting of property and the granting and obtaining of loans whether or not secured by mortgage, required for the running of the association; and
- may grant any power of attorney as required.

1.6 IALA SECRETARIAT

IALA has a permanent Secretariat based at their headquarters in France. The Secretary-General acts as the legal representative of IALA and oversees the operations of the Association. Staff are organised into three different divisions: Technical Operations, Administration and Finance, and the World-Wide Academy. Additionally, several experts and consultants assist the Secretariat in various areas.

1.7 COMMITTEES

Committees are established by the Council to study a range of issues, as determined by the General Assembly, including to prepare draft Recommendations and Guidelines, and draft submissions to other international organisations. A Committee may also be asked to provide continuous monitoring of topics that could influence decisions concerning the provision of Marine Aids to Navigation, including Vessel Traffic Services.

The committees bring together Marine Aids to Navigation authorities, subject matter experts, manufacturers and consultants from all parts of the world. Participation in Committee work offers the opportunity to:

- Contribute expertise and compare experiences with other IALA members;
- Share points of view within the international maritime community;
- Participate in the development of new systems and technologies;

- Enable the worldwide maritime community to speak with one voice in international forums at a time when maritime requirements run the risk of being lost within a fast developing technological context; and
- Meet with suppliers or customers and contribute to the design of "best practice" products.

The committees meet regularly, normally twice per year. The programmes for the Committees are for a four-year period, usually from one Conference to the next. Each Committee has a Chair and Vice-Chair, and normally comprises a number of working groups.

Draft Recommendations and Guidelines and other documents created by the Committees may address topics relating to management, operations, engineering, emerging technologies and training. They are forwarded to the Council for approval before being published on the website.

All members are eligible to participate in the Committees, which are presently:

- AtoN Requirements and Management Committee (ARM);
- AtoN Engineering and Sustainability Committee (ENG);
- e-Navigation, Information Services and Communications Committee (ENAV) Committee; and
- Vessel Traffic Services Committee (VTS).

Note that the ENAV committee will be renamed as the Digital Technology (DTEC) committee starting from the latter half of 2023.

1.8 POLICY ADVISORY PANEL

The Policy Advisory Panel (PAP) is a group that comprises the Secretary-General, Deputy Secretary-General, members of the Secretariat, the Chairs and Vice-Chairs of each Committee, the Chair of the Legal Advisory Panel, the Dean of the World-Wide Academy, a representative of the Industrial Members Committee and special advisors as necessary. The Panel meets at least once a year to review the work being done by the Committees.

The role of the PAP is to:

- consider and advise the Council and the Secretariat on policy and strategy matters concerning the development and harmonisation of Marine Aids to Navigation systems, with specific emphasis on the Strategic Vision;
- co-ordinate the work of the Committees and provide a forum for Committee Chairs to share progress, challenges and operations of the Committees as well as provide a coordinated delivery of the various work plans with the Secretariat; and
- carry out such other work as the Council may from time to time require.

1.9 LEGAL ADVISORY PANEL

The Legal Advisory Panel (LAP) comprises National members with interest in legal affairs, representatives of relevant international organisations, and experts.

Its scope includes:

- providing legal support to the Council as required;
- responding to issues and concerns that may be raised through the IALA Secretariat;
- responding to requests from IALA Committees and other IALA bodies for legal advice;
- providing IALA with information on legal issues that result, or may result from, providing guidance to the membership in the provision of Marine Aids to Navigation services;
- preparing draft documentation/guidelines on items of common concern;
- identifying where external legal advice may be needed and assisting with the preparation of requests/briefs for such advice, as appropriate; and
- reviewing, updating, advising and reporting to the Council on the IALA Risk Registers; and
- providing a forum to discuss legal matters of common interest.

1.10 IALA WORLD-WIDE ACADEMY

The IALA World-Wide Academy is the vehicle by which IALA delivers education, training and capacity building.

The Academy is an integral, but independently funded part of IALA. It focuses on the second goal of the Strategic Vision, namely that "All coastal states have contributed to a sustainable and efficient global network of Marine Aids to Navigation through capacity building and the sharing of expertise".

The functions of the Academy are:

- education and training;
- capacity-building; and
- research and development.

The Academy is dedicated to assisting coastal states with continuous and sustainable improvement of their AtoN services, including VTS. While its education and training activities are intended for all coastal states, capacity-building activities are aimed at those states which require assistance in fulfilling their international obligations related to Marine Aids to Navigation.

The research and development activities of the Academy are aimed at identifying topical knowledge gaps within the IALA domain, and encouraging research in these areas worldwide. The Academy maintains an overview of its activities in a Master Plan which can be found on the Academy website – www.academy.iala aism.org.

1.10.1 IALA ACCREDITATION SCHEME

IALA has developed a number of model courses covering the contents of its Standards, Recommendations and Guidelines.

The model courses, which may be found on the Academy website, are primarily intended for adoption by training organisations which have been accredited by a Competent Authority, normally an IALA national member.

These organisations are called Accredited Training Organisations (ATOs), and the accreditation scheme aims at ensuring the quality of their delivery of the model courses. There are now several ATOs around the world, delivering both AtoN and VTS related model courses.

Refer to IALA publications:

- Recommendation R0103(V-103) - Training and Certification of VTS Personnel
- Recommendation R0141 – Training and Certification of AtoN Personnel
- Recommendation R0149 - Accreditation of Training Organisations
- Guideline G1014 – Accreditation of VTS Training Organisations and Approval to deliver VTS model courses
- Guideline G1100 – The Accreditation and Approval Process for AtoN Personnel Training

1.11 CONFERENCES, SYMPOSIA AND EXHIBITIONS

IALA holds a general Marine Aids to Navigation Conference every four years. Conferences may be attended by members and also by non-member Marine Aids to Navigation authorities.

Papers, presentations and discussions address a wide range of Marine Aids to Navigation issues. The work of IALA over the previous four years is also presented. All members are invited to submit papers for discussion.

The Industrial Member's Committee traditionally organises an Industrial Exhibition in conjunction with the Conference.

Figure 2. 20th IALA Conference logo

In addition, IALA may hold a Symposium on a specific topic of interest to the members every four years, two years separated from the IALA Conference. The Symposium also hosts an industrial exhibition.

Figure 3. 19th IALA Conference 2018, Incheon Korea

1.12 WORKSHOPS AND SEMINARS

IALA convenes Workshops and Seminars to address topics that may arise during the work term between Conferences.

Workshops are special meetings convened for the purpose of making maximum use of the technical expertise of participants to further the work of IALA on a specified subject or topic. The workshops also enable skills and understanding of new techniques to be learned by detailed lectures combined with simulation or similar "hands on" methods.

Seminars are meetings of specialists on a specified subject or topic convened for the purpose of consultations by means of the presentation of papers followed by learned discussion.

1.13 IALA PUBLICATIONS

IALA produces a comprehensive set of guidance documents that have the objective of facilitating a uniform approach to Marine Aids to Navigation worldwide.

The publications cover various aspects related to ATONs, including their design, construction, placement, and maintenance, as well as the use of visual, audible, and electronic signals to assist mariners in navigation. The guidelines also address the use of new technologies, such as satellite-based positioning systems, to enhance the accuracy and reliability of navigation.

The IALA guidelines are widely recognized and followed by maritime authorities and organizations worldwide, and they play an important role in ensuring the safety and efficiency of maritime transportation. All the documents could be found in the documents catalogue https://www.iala-aism.org/guidance-publications/.

There are five such documents in a logical hierarchy, as follows.

1.13.1 STANDARDS

IALA Standards form a framework, implementation of which by all coastal states will harmonise Marine Aids to Navigation worldwide. IALA standards cover technology and services and are non-mandatory.

IALA Standards may contain normative and informative provisions. Normative provisions are those with which it is necessary to conform in order to claim compliance to the Standard. Informative provisions are those which specify additional desirable practices but with which it is not necessary to conform in order to claim compliance to the Standard. There are seven standards, covering topics as follows:

Figure 4. IALA Standards

Refer to IALA publications:

- S1010 Marine Aids to Navigation Planning And Service Requirements
- S1020 Marine Aids to Navigation Design and Delivery
- S1030 Radionavigation Services
- S1040 Vessel Traffic Services
- S1050 Training and Certification
- S1060 Digital Communication Technologies
- S1070 Information Services

1.13.2 RECOMMENDATIONS

IALA Recommendations specify and outline what practices shall be carried out in order to comply with that Recommendation and may be referenced, wholly or partially, in an IALA Standard.

These recommendations are accessible at the following link: https://www.iala-aism.org/product-category/publications/recommendations/

1.13.3 GUIDELINES

IALA Guidelines describe how to implement practices normally specified in a Recommendation. These guidelines are accessible at the following link: https://www.iala-aism.org/product-category/publications/guidelines/

1.13.4 MANUALS

IALA Manuals offer a comprehensive perspective on a broader range of topics, and the IALA Dictionary is considered a Manual.

1.13.5 MODEL COURSES

IALA Model Courses are training documents that define the level of training and knowledge needed to reach levels of competence defined by IALA.

1.13.6 TECHNICAL DOCUMENTS CATALOGUE

IALA has published a Technical Documents Catalogue which provides further information on the above publications as well as links to the appropriate documents. This is available on the IALA website – www.iala-aism.org.

IALA publications are governed by a set of principles including:

- Usability – The system should be as intuitive as possible, i.e. can be easily read and understood;
- Visibility - Publications conform to the IALA corporate image, with colour coding;
- Validity - The date of issue and date of amendment/edition should be clearly visible to ensure that users have the most up-to-date information; and
- Availability – Publications are available to download in electronic form from the IALA website at no charge.

All the above publications (Standards, Recommendations, Guidelines, Model courses etc.) are available to download from https://www.iala-aism.org/guidance-publications/

Other documents available from IALA on request include:

- Basic Documents, being Constitution, General Regulations, Policy & Procedures – Committees, and Constitution and Bye-Laws of the Industrial Members' Committee.
- Conference proceedings.
- Reports of symposia, seminars, committee meetings, workshops and other events.
- IALA Bulletin, the house magazine which appears twice per year.

1.14 RELATED ORGANISATIONS

IALA works in close cooperation with the International Maritime Organization (IMO), the International Hydrographic Organization (IHO), the International Telecommunication Union (ITU), the International Maritime Pilots' Association (IMPA), the Comite International Radio Maritime (CIRM), and the International Harbour Masters' Association (IHMA), and has cooperation agreements with a number of other international maritime organisations.

CHAPTER 2

CONCEPTS AND ACCURACY OF NAVIGATION

2.1 NAVIGATION METHODS

The IALA Dictionary defines Navigation as:

- The art or science of determining the position or course of a ship or aircraft by means of observations on board, whereby difficulties and dangers are avoided and a desired destination is reached as quickly and safely as possible.
- The process of planning, controlling and recording the movement of a craft from one place to another.

IMO Resolution A.915(22) defines navigation as "the process of planning, recording and controlling the movement of a craft from one place to another." The principal methods of marine navigation are briefly described as follows:

2.1.1 TERRESTRIAL NAVIGATION

Navigation using visual, radar and, (if appropriate) depth sounding observations of identifiable, conspicuous features, objects and marks to determine position.

2.1.2 CELESTIAL OR ASTRONOMICAL NAVIGATION

Navigation using observation of celestial bodies (i.e. sun, moon, planets and stars) to determine position.

2.1.3 DEAD RECKONING

Navigation based on speed, elapsed time and direction from a known position. The term was originally based on the course steered and the speed through the water, however, the expression may also refer to positions determined by the use of the course steered and speed *expected* to be made good over the ground, thus making an estimated allowance for disturbing elements such as current and wind. A position that is determined by this method is generally called an estimated position.

2.1.4 RADIONAVIGATION

Radionavigation is a method of determining a vessel's location or direction of travel using radio signals. There are various types of radionavigation systems available, including eLORAN, GNSS (Global Navigation Satellite System), DGNSS (Differential Global Navigation Satellite System), and others.

While radionavigation can be a reliable and efficient means of determining position, it is important to note that these systems can be vulnerable to interference or disruption from a variety of sources, such as solar flares, atmospheric conditions, or intentional jamming.

It is therefore recommended that mariners and pilots not rely solely on a single method of determining their position or course, but rather use multiple methods to cross-check and verify their position. In addition, regular testing and maintenance of the equipment is crucial to ensure it is functioning properly and providing accurate data.

2.2 PHASES OF NAVIGATION

Typically, navigation is divided into three phases: Ocean navigation, coastal navigation and restricted waters navigation. Some documents have introduced other phases, namely harbour approaches, port and inland waterways navigation.

The harbour approach phase is an aspect of the restricted waters phase, but will be treated separately in this manual as it is of particular relevance to IALA members.

Port and inland waterway navigation are two aspects of restricted waters navigation and will not be dealt with separately in this manual, as the precautions and measures required for restricted waters navigation also apply to these waters.

2.2.1 OCEAN NAVIGATION

In this phase, the vessel is typically:

- beyond the continental shelf (200 metres in depth) and more than 50NM (Nautical miles) from land;
- in waters where position fixing by visual reference to land, charted fixed offshore structures, or to fixed or floating Marine Aids to Navigation, is not practical; and
- sufficiently far from land masses and traffic areas that the hazards of shallow water and of collision are comparatively small.

Although the IMO has adopted stricter accuracy requirements (see Table 1) the minimum navigational requirements for the Ocean Phase are considered to be a predictable accuracy of 2 to 4NM, combined with a desired fix interval of 15 minutes or less (maximum 2 hour fix interval). The required accuracy in the Ocean Phase is based on providing the ship with the capability to correctly plan the approach to land or restricted waters.

The economic efficiency aspects of shipping (e.g. transit time and fuel consumption) are enhanced by the availability of a continuous and accurate position fixing system that enables a vessel to follow the shortest safe route with precision.

2.2.2 COASTAL NAVIGATION

In this phase, the vessel is typically:

- within 50NM from shore or the limit of the continental shelf (200 meters in depth); and
- in waters contiguous to major land masses or island groups, where transoceanic routes tend to converge towards destination areas and where inter-port traffic exists in patterns that are essentially parallel to coastlines.

The vessel may encounter:

- ship reporting systems (SRS) and coastal vessel traffic services (VTS);
- offshore exploitation and scientific activity on the continental shelf; and
- fishing and recreational boating activity.

The Coastal Phase is considered to exist when the distance from shore makes it feasible to navigate by means of visual observations, radar and, if appropriate, by depth (echo) sounder. As with the Ocean Phase, the distances from land can be varied to take account of the smaller vessels and local geographical characteristics.

Although the IMO has adopted stricter accuracy requirements (see Table 1), international studies have established that the minimum navigation requirements for commercial trading vessels operating in the Coastal Phase is a navigation system capable of providing fix positioning to an accuracy of 0.25NM (463m), combined with a desired fix interval of 2 minutes to a maximum of 15 minutes.

More specialised maritime operations within the Coastal Phase may require navigational systems capable of higher repeatable accuracy, either permanently or on an occasional basis. These operations can include marine scientific research, hydrographic surveying, commercial fishing, petroleum or mineral exploration, and Search and Rescue (SAR).

It is not always practical, given the manning of most vessels, to plot fixes at the desired interval of 2 minutes on a chart in the traditional way. GNSS (GPS, DGPS, GALILEO etc.) and also in the future in some areas, enhanced Loran (eLORAN) provide a means of exceeding the IMO Coastal Phase requirements for positional accuracy and fix rates when integrated with Electronic Chart Systems (ECS) or Electronic Chart Display Information System (ECDIS) technology.

2.2.3 HARBOUR APPROACH

This phase represents the transition from coastal to harbour navigation. In this phase the:

- vessel moves from the relatively unrestricted waters of the coastal phase into more restricted and more heavily used waters near and/or within the entrance to a bay, river, or harbour; and
- navigator is confronted with a requirement for more frequent position fixing and manoeuvring the vessel to avoid collision with other traffic and grounding dangers;

The vessel will generally be within:

- the coverage areas of Marine Aids to Navigation of varying complexity (including lights, Racons, leading lights and sector lights);
- pilotage areas; and
- the boundaries of SRS and VTS.

Safety of navigation issues that arise during the Harbour Approach Phase impose more stringent requirements on positional accuracy, fix rates and other real-time navigational information than those required during the Coastal Phase.

GNSS (GPS, DGPS, GALILEO etc.) and also in the future, in some areas, enhanced Loran (eLORAN) provide a means of achieving the Harbour Approach requirements for high positional accuracy and fix rates at better than 10-second intervals when integrated with Electronic Chart Systems (ECS) and the Electronic Chart Display Information System (ECDIS) technology.

2.2.4 RESTRICTED WATERS

While similar to the Harbour Approach Phase, in the proximity to dangers and the limitations on freedom of manoeuvre, a Restricted Waters Phase can also develop during a coastal navigation phase, such as in various straits around the world.

The Pilot or Master of a large vessel in restricted waters must direct its movement with great accuracy and precision to avoid grounding in shallow water, striking submerged dangers or colliding with other craft in a congested channel. If a large vessel finds itself in an emerging navigational situation with no options to alter course or stop, it may be forced to navigate to limits measured to within a few metres in order to avoid an accident.

Requirements for the safety of navigation in the Restricted Waters Phase make it desirable for navigation systems to provide:

- accurate verification of position almost continuously;
- information depicting any tendency for the vessel to deviate from its intended track; and
- instantaneous indication of the direction in which the ship should be steered to maintain the intended course.

• These requirements are not easily achievable through the use of visual aids and ships' radar alone, but as with Harbour Approach navigation, they can be achieved with a combination of GNSS (and in the future, enhanced Loran (eLORAN)) and Electronic Chart Systems (ECS) or Electronic Chart Display Information System (ECDIS) technology.

2.3 ACCURACY STANDARDS OF NAVIGATION

IMO Resolution A.915(22) refers to the IMO's resolution that outlines maritime policy and requirements for a future GNSS. It also invites governments and international organizations that are either providing or planning to provide services for the future GNSS to take into consideration the annexed tables.

Table 1 presents the relevant standards adopted in Appendices 2 and 3 of IMO Resolution A.915(22). Appendix 2 includes the requirement for an accuracy of 10 m on ocean navigation, while IMO Resolution A.1046(27) notes that "Where a radionavigation system is used to assist in the navigation of ships in ocean waters, the system should provide positional information with an error not greater than 100m with a probability of 95%."

Table 1. Minimum Maritime User Requirements

Application	Absolute Horizontal Accuracy (95%)/(m)
GENERAL NAVIGATION:	
Ocean	10-100
Coastal	10
Restricted waters	10
Port	1
Inland waterways	10
HYDROGRAPHY	1-2
OCEANOGRAPHY	10
AIDS TO NAVIGATION MANAGEMENT	1
PORT OPERATIONS:	
Local VTS	1
Container/cargo management	1
Law enforcement	1
Cargo handling	0.1

2.4 MEASUREMENT ERRORS AND ACCURACY

Good practice in both navigation and Marine Aids to Navigation design dictates that an indication of the error or uncertainty in measuring a parameter or in obtaining a position fix should be reported along with the derived result.

2.4.1 MEASUREMENT ERROR

The measurement error is defined as the difference between the true value and the measured value. In general, three types of errors are recognised:

Systematic Errors: Also known as fixed or bias errors. They are errors that persist and are related to the inherent accuracy of the equipment, or result from incorrectly calibrated equipment. This type of error can to some extent be foreseen and compensated for.

Random Errors: Cause readings to take random values either side of some mean value. They may be due to the observer/operator, or the equipment, and are revealed by taking repeated readings. This type of error can neither be foreseen, nor totally compensated for.

Faults and Mistakes: Errors of this type are categorised in many documents as "Human error" or "Blunders". These errors can be reduced by appropriate training and by following defined procedures.

2.4.2 ACCURACY

In a process where a number of measurements are taken, the term accuracy refers to the degree of conformity between the measured parameter at a given time and its true parameter at that time. The term parameter includes: position, coordinates, velocity, time, angle, etc.

For navigational purposes, four types of accuracy can be defined:

Absolute Accuracy (Geodetic or Geographic Accuracy): The accuracy of a position with respect to the geographic or geodetic coordinates of the Earth.

Predictable Accuracy: The accuracy with which a position can be defined when the predicted errors have been taken into account. It therefore depends on the state of knowledge of the error sources.

Relative or Relational Accuracy: The accuracy with which a user can determine position relative to that of another user of the same navigation system at the same time.

Repeatable Accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time using uncorrelated measurements from the same navigation system.

For general navigation, Absolute and Predictable Accuracy are the principal concerns. Repeatable Accuracy is of interest to fishermen, the offshore oil and gas industry, ships making regular trips into an area of restricted waters and authorities when positioning floating aids.

Accuracy of a Position Fix: A minimum of two lines of position (LOP) is necessary to determine a position at sea. Since there is an error associated with each LOP, the position fix has a two-dimensional error. There are many ways of analysing the error boundary; however, the radial position error relative to the true position, taken at the 95% probability level, is the preferred method.

Navigational Position Fixing Measurements: Table 2 shows the typical accuracy (95% probability) achieved using common navigational instruments or techniques.

Table 2. Position Fixing Processes and Systems

Process	Typical accuracy (95% probability)	Accuracy at 1 NM (metres)
Magnetic compass bearing on a light or landmark	±3° The accuracy may deteriorate in high latitudes	93
Gyro-compass bearing on a light or landmark	0.75° X secant latitude (below 60° of latitude)	< 62
Radio direction finder	±3° to ±10°	93-310
Radar bearing	±1° Assuming a stabilized presentation and a reasonably steady craft.	32
Radar distance measurement	1% of the maximum range of the scale in use or 30 metres, whichever is the greater	
LORAN-C / CHAYKA	Depends on conditions Loran C was hyperbolic and provided 477m at edge of coverage improving towards stations	
eLoran	8-10 m differential Loran accuracies experienced at port approach, typically available within 30-50km of a differential reference station	
GNSS	Generally 3-5m for GPS	
DGNSS (ITU-R M.823/1 Format)	1-3m	
Dead Reckoning (DR)	Approximatively 1 Nautical Mile for each hour of sailing	

2.5 HYDROGRAPHIC CONSIDERATIONS

2.5.1 CHARTS

The IMO definition[8] of a nautical chart or nautical publication is a special-purpose map or book, or a specially compiled database from which such a map or book is derived, that is issued officially by or on the authority of a Government, authorised Hydrographic

Office or other relevant government institution and is designed to meet the requirements of marine navigation.

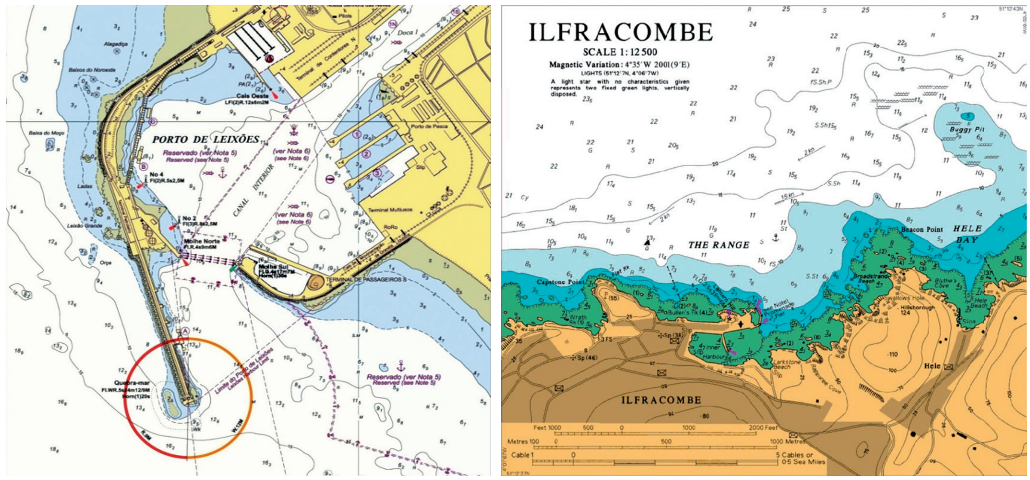


Figure 5. Nautical Chart examples

Nautical charts provide a graphical representation of a plane surface of a section of the Earth's sea surface constructed to include known dangers and Marine Aids to Navigation.

The principal international organisation on charting matters is the International Hydrographic Organization (IHO). A principal aim of the IHO is to ensure that all the world's seas, oceans and navigable waters are surveyed and charted.

The mission of the IHO is to create a global environment in which States provide adequate and timely hydrographic data, products and services and ensure their widest possible use. The vision of the IHO is to be the authoritative worldwide hydrographic body which actively engages all coastal and interested States to advance maritime safety and efficiency and which supports the protection and sustainable use of the marine environment. IMO is the body responsible for determining international standards for the quality of hydrographic surveys and chart production.

2.5.2 DATUM

In its simplest form, a datum is an assumed or defined starting point from which measurements are taken.

A more complex example of a datum is a Geodetic Datum used in the mathematical representation of the Earth's surface. Many different data (plural of datum) have been devised over time to define the size and shape of the Earth and the origin and orientation of coordinate systems for chart and mapping applications. These have evolved from the consideration of a spherical Earth, through to the geoid and ellipsoidal models, and also the planar projections used for charts and maps.

The geoid model considers the Earth's surface to be defined as the equipotential surface[9] that would be assumed by the sea level in the absence of tides, currents, water density variations and atmospheric effects.

A further approximation uses an ellipsoid, which is a smooth mathematical surface, to give a best-fit match of the geoid. Early ellipsoid models were developed to suit the mapping and charting of local regions or countries. However, they would not necessarily provide a satisfactory solution in other parts of the world. Some nautical charts still carry a legend referring to a local datum, for instance, Ellipsoid Hayford or International – Datum Potsdam, Paris or Lisbon.

2.5.3 CHART DATUM

Chart datum is defined as the datum or plane of reference to which all charted depths and drying heights are related. It is relevant to a localised area and is a level that the tide will not frequently fall below. It is usually defined in terms of Lowest Astronomical Tide (and in some cases by Indian Spring Low Water).

2.5.4 LEVELLING DATUM OR VERTICAL CONTROL DATUM

These are generic terms for levelling surfaces that are used to determine levels or elevations. Using nautical charts as an example:

- water depths are measured from Chart Datum to the seabed;
- elevations of land masses and man-made features are referenced to either Mean High Water Springs (where there are predominantly semi-diurnal tides) or Mean Higher High Water (where there are predominantly diurnal tides); and
- clearance heights for bridges are generally referenced to Highest Astronomical Tide.

2.5.5 CHART DATUM ISSUES

Until satellite navigation became commonly used, nautical charts were generally produced to the local and national datum.

The now widely used GNSS positioning uses an Earth centred datum referred to as World Geodetic System[11] 1984 (WGS-84) which is considered to be the best compromise for representing the whole of Earth's surface.

Generally, WGS-84 is the geodetic system associated with the differential correction information broadcast by maritime GNSS stations using the ITU-R M.823/1 signal format.

IHO S-4 Part B Section 200 recommends that all countries that issue national navigational charts should base these on the WGS-84 geodetic system. For many countries, this simple objective represents a formidable workload and will take a number of years to achieve. Consequently, many nautical charts will continue to refer to data other than WGS-84 and discrepancies of several hundred metres can exist between a GNSS derived position and the charted position.

During this transitional period, it is important for navigators and other persons using charts to:

- be aware of the datum applicable to the chart in use;

- include the applicable reference datum when communicating a measured position;
- determine whether or not a satellite derived position can be directly plotted onto a chart. In some cases, a chart will include information for adjusting a satellite derived position to align to the chart datum; and
- be aware that some GNSS receivers have the facility to automatically convert (and display) WGS-84 positions into other geodetic coordinate systems. The user should be aware of the settings that have been applied to the receiver.

Examples of the styles of note found on some charts are shown in Figure 7.

Table 3. Levels Relevant to Marine Aids to Navigation in Coastal and Restricted Waters

Level Description	Abbreviation
Highest Astronomical Tide: the highest tidal level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions (IHO Dictionary, S-32, 5th Edition, 2244)	HAT
Mean Higher High Water: the average height of higher high waters at a place over 19-year period. (IHO Dictionary, S-32, 5th Edition, 3140)	MHHW
Mean High Water Springs: the average height of the high waters of spring tides. Also called spring high water. (IHO, Dictionary, S-32, 5th Edition, 3144)	MSL
Mean Sea Level: the average height of the surface of the sea at a tide station for all stages of the tide over a 19-year period, usually determined from hourly height readings measured from a fixed predetermined reference level (CHART DATUM). (IHO Dictionary, S-32, 5th Edition, 3150)	MLWS
Mean Lower Low Water: the average height of the lower low waters at a place over a 19-year old period. (IHO Dictionary, S-32, 5th Edition, 3145)	MLLW
Indian Spring Low Water: a tidal datum approximating the level of the mean of the lower low water at spring tides. It was first used in waters surrounding India. Also called Indian tidal plane. (IHO Dictionary, S-32, 5th Edition, 2427) ISLW was defined by G.H. Darwin for the tides of India at a level below MSL and is found by subtracting the sum of the harmonic constituents M2, S2, K1 and O1 from Mean Sea Level	ISLW
Lowest Astronomical Tide: the lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. (IHO Dictionary, S-32,5th Edition, 2936)	LAT

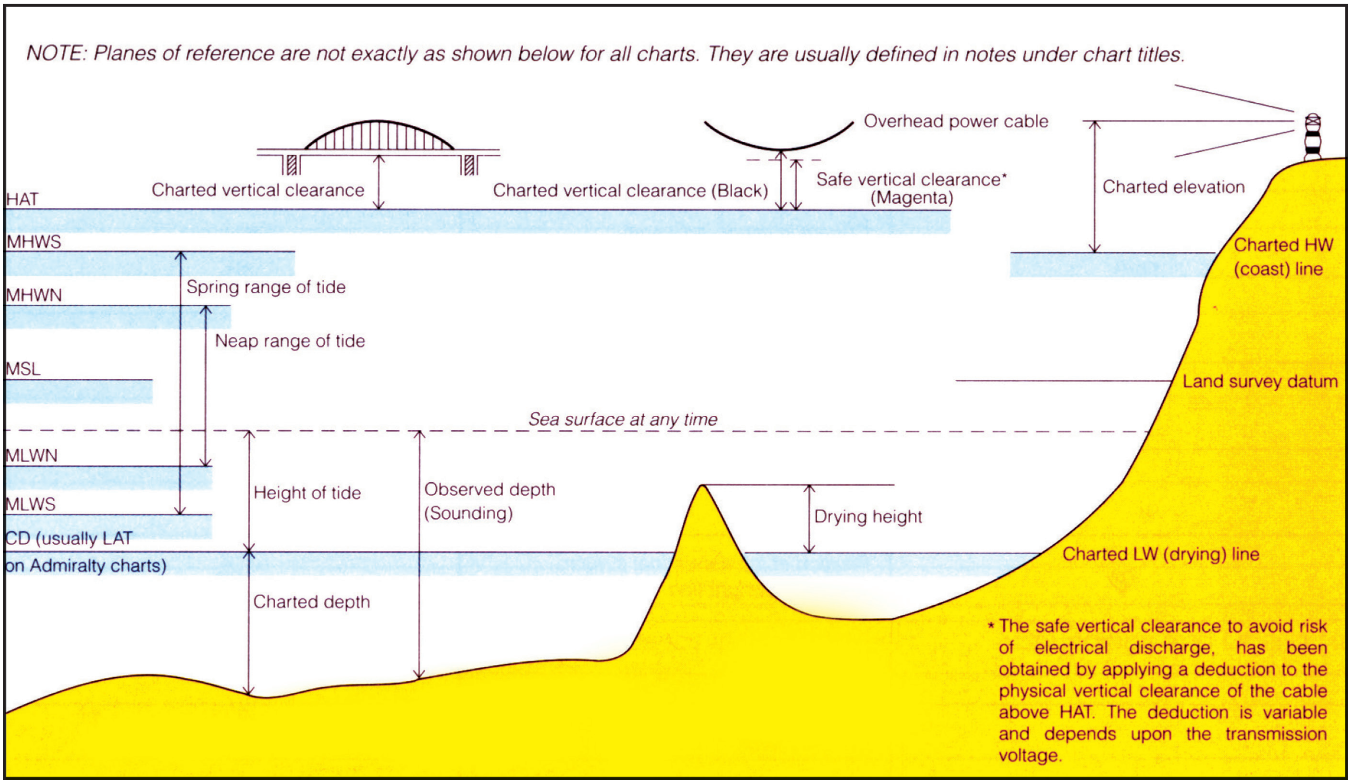


Figure 6. Levelling or Vertical Control Datum (IHO)

SATELLITE-DERIVED POSITIONS
Positions obtained from the Global Positioning System (GPS) in the WGS 1984 Datum must be moved 0.09 minutes SOUTHWARD and 0.06 minutes WESTWARD to agree with this chart.

SATELLITE-DERIVED POSITIONS
Positions obtained from the Global Positioning System (GPS) in the WGS 1984 Datum can be plotted directly onto this chart.

SATELLITE-DERIVED POSITIONS
Positions obtained from the Global Positioning System (GPS) in the WGS 1984 Datum cannot be plotted directly onto this chart. The difference between GPS positions and positions on this chart cannot be determined; mariners are warned that these differences may be significant and are advised to use alternative sources of positional information, particularly when closing the shore or navigating in the vicinity of dangers.

Figure 7. Examples of GNSS Notes on Charts

Table 4. Zones of Confidence (IHO)

1	2	3		4	5
ZOC[1]	Position Accuracy[2]	Depth Accuracy[3]		Seafloor Coverage	Typical Survey Characteristics[5]
A1	± 5m + 5% depth	=0.5 + 1%d		Full area search undertaken. Significant seafloor features detected[4] and depths measured.	Controlled, systematic survey[6] high position and depth accuracy achieved using DGPS or a minimum three high quality lines of position (LOP) and a multibeam, channel or mechanical sweep system.
		Depth (m)	Accuracy (m)		
		10	± 0.6		
		30	± 0.8		
		100	± 1.5		
		1000	± 10.5		
A2	± 20 m	= 1.00 + 2%d		Full area search undertaken. Significant seafloor features detected[4] and depths measured.	Controlled, systematic survey[6] achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder[7] and a sonar or mechanical sweep system.
		Depth (m)	Accuracy (m)		
		10	± 1.2		
		30	± 1.6		
		100	± 3.0		
		1000	± 21.0		
B	± 50 m	= 1.00 + 2%d		Full area search not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.	Controlled, systematic survey achieving similar depth but lesser position accuracies than ZOC A2, using a modern survey echosounder[5], but no sonar or mechanical sweep system.
		Depth (m)	Accuracy (m)		
		10	± 1.2		
		30	± 1.6		
		100	± 3.0		
		1000	± 21.0		
C	± 500 m	= 2.00 + 5%d		Full are search not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.
		Depth (m)	Accuracy (m)		
		10	± 2.5		
		30	± 3.5		
		100	± 7.0		
		1000	± 52.0		
D	Worse than ZOC C	Worse than ZOC C		Full area search not achieved, large depth anomalies may be expected.	Poor quality data or data that cannot be quality assessed due to lack of information.
U	Unassessed – The quality of the bathymetric data has yet to be assessed.				

2.5.6 ACCURACY OF CHARTS

At a national level, it is important that Authorities responsible for Marine Aids to Navigation and hydrographic services work together to ensure that both the network and the mix of Marine Aids to Navigation provided, and the available charts are appropriate for mariners to navigate safely.

Source quality indication is provided for official ENC charts (ZOC, zones of confidence). Source quality indication might also be indicated on the back of some national paper charts.

Mariners should always consider this information, as official charts (both electronic and paper) might be based on old measurements of poor or unknown quality.

The accuracy requirements for general navigation can be related to the scale of the chart necessary for each part of the passage which in turn will be determined by the local conditions and type of vessel.

Chart scales with the corresponding accuracy requirements recommended by IHO and the equivalent dimension of a 0.5 mm dot on a chart are found in Table 5.

Table 5. Chart Scales, Applications and Related Accuracy Considerations

Chart scale[13]	Corresponding need for accuracy	Approximate pencil Width (0.5 mm) Equivalence (metres)	Application[14]
1:10.000.000	10.000	5000	Ocean navigation
1:2.500.000	2.500	1250	Ocean navigation
1:750.000	750	375	Ocean navigation
1:300.000	300	150	Coastal navigation
1:100.000	100	50	Coastal navigation
1:50.000	50	25	Approach
1:15.000	15	7,5	Approach
1:10.000	10	5	Restricted waters
1:5.000	5	2,5	Harbour plans

2.5.7 CHARTED BUOY POSITIONS

No reliance can be placed on floating aids always maintaining their exact positions. Buoys should, therefore, be regarded with caution and not as infallible navigating marks, especially when in exposed positions. A ship should always, when possible, navigate by bearings of fixed objects or angles between them and not by buoys.

NOTES FOR CHAPTER 2

[1] The allocation of a ZOC indicates that particular data meets minimum criteria for position and depth accuracy and seafloor coverage defined in this Table. ZOC

categories reflect a charting standard and not just a hydrographic survey standard. Depth and position accuracies specified for each ZOC category refer to the errors of the final depicted soundings and include not only survey errors but also other errors introduced in the chart production process. [Note: the rest of footnote 1 does not apply to paper charts and is therefore omitted from S-4].

[2] Position Accuracy of depicted soundings at 95% CI (2.45 sigma) with respect to the given datum. It is the cumulative error and includes survey, transformation and digitizing errors etc. Position accuracy need not be rigorously computed for ZOCs B, C and D but may be estimated based on type of equipment, calibration regime, historical accuracy etc.

[3] Depth accuracy of depicted soundings = a + (bxd)/100 at 95% CI (2.00 sigma), where d = depth in metres at the critical depth. Depth accuracy need not be rigorously computed for ZOCs B, C and D but may be estimated based on type of equipment, calibration regime, historical accuracy etc.

[4] Significant seafloor features are defined as those rising above depicted depths by more than:

Depth	Significant Feature
a. <40 m	2 m
b. >40 m	10% depth

A full seafloor search indicates that a systematic survey was conducted using detection systems, depth measurement systems, procedures, and trained personnel designed to detect and measure depths on significant seafloor features. Significant features are included on the chart as scale allows. It is impossible to guarantee that no significant feature could remain undetected, and significant features may have become present in the area since the time of the survey.

[5] Typical Survey Characteristics - These descriptions should be seen as indicative examples only.

[6] Controlled, systematic surveys (ZOC A1, A2 and B) - surveys comprising planned survey lines, on a geodetic datum that can be transformed to WGS 84.

[7] Modern survey echo-sounder - a high precision single beam depth measuring equipment, generally including all survey echo-sounders designed post 1970.

[8] SOLAS Chapter V Regulation 2.

[9] These have the same potential gravity at each point.

[10] It should be noted that elevations of land features on maps are generally referenced to Mean Sea Level.

[11] The World geodetic system (WGS) is a consistent set of parameters for describing the size and shape of the earth, positions of a network of points with respect to the centre of mass of the Earth, transformations from major geodetic data and the potential of the Earth. (IMO Resolution A.860(20)).

[12] Examples taken from Australian Charts.

[13] The chart scale is generally referenced to a particular latitude e.g. 1:3000,000 at latitude 27° 15'S

[14] This information may be helpful in assessing the practical accuracy requirements for laying buoy moorings.

CHAPTER 3

MARINE AIDS TO NAVIGATION

3.1 INTRODUCTION

A **Marine Aid to Navigation (AtoN)** is a device, system or service, external to vessels, designed and operated to enhance safe and efficient navigation of individual vessels and/or vessel traffic. A marine Aid to Navigation should not be confused with a navigational aid. A **navigational aid** is an instrument, device, chart, etc., carried on board a vessel for the purpose of assisting navigation.

This chapter describes the major types of visual and other physical Aids to Navigation in current use and provides comments on the application and performance of the various technologies. Vessel Traffic Services (VTS), are also considered by IALA as satisfying the definition of an Aid to Navigation. VTS will be briefly covered in a separate chapter due to their increasingly significant role in contributing to navigation safety. The VTS Manual provides more detailed information.

The concept of e-Navigation has recently gained significant momentum and a framework is being developed under the auspices of the IMO. IALA has been requested by the IMO to develop the shore-based aspects of the conceptual framework and systems architecture for e-Navigation. A separate chapter of the NAVGUIDE covers e-Navigation. Radionavigation systems form a key element of the e-Navigation infrastructure and are therefore also covered in a separate chapter.

The context of Marine Aids to Navigation is initially covered with reference to International obligations, especially The International Convention for the Safety of Life at Sea (SOLAS).

3.2 OBLIGATION AND REGULATORY COMPLIANCE

AtoN providers must adhere to IMO and IALA standards, comply with national and regional regulations, ensure compatibility with global and regional navigation systems, minimize environmental impact, conduct regular maintenance and inspections for effectiveness and reliability, and report and investigate any incidents involving aids to navigation in order to implement corrective actions.

3.3 INTERNATIONAL CRITERIA

The International Convention for the Safety of Life at Sea, 1974 (as amended), or SOLAS is one of the oldest international conventions and originates from a conference held in London in 1914 to address aspects of safety at sea following the sinking of the White Star liner Titanic in 1912. Since then, there have been four other SOLAS Conventions, the latest being the 1974 version that came into force in 1980.

The SOLAS Convention is administered by the United Nations through the International Maritime Organization (IMO). The 1974 Convention (as amended) is divided into twelve chapters and within these are a series of regulations. The contents are outlined in Table 6.

Table 6. Contents of SOLAS Convention

Chapter	Contents
Chapter I	General Provisions
Chapter II-1	Construction - Structure, subdivision and stability, machinery and electrical installations
Chapter II-2	Construction - Fire protection, fire detection and fire extinction
Chapter III	Life-saving appliances and arrangements
Chapter IV	Radiocommunications
Chapter V	Safety of navigation
Chapter VI	Carriage of cargoes and oil fuels
Chapter VII	Carriage of dangerous goods
Chapter VIII	Nuclear ships
Chapter IX	Management for the safe operation of ships
Chapter X	Safety measures for high-speed craft

3.3.1 SOLAS CHAPTER V

SOLAS Chapter V, and Regulations 12 and 13 in particular, define the obligations on Contracting Governments to provide vessel traffic services and Aids to Navigation and related information. These Regulations define the primary roles of IALA National Members.

In December 2000, the 73rd session of the IMO Maritime Safety Committee (MSC) adopted a completely revised SOLAS Chapter V on Safety of Navigation that came into force on 1 July 2002.

In October 2005, IMO adopted IMO Resolution A.973(24) and A.974(24), outlining the IMO Member State Voluntary Audit Scheme which includes all aspects of SOLAS, including Chapter V, Regulations 12 and 13.

SOLAS Chapter V, Regulation 13 - Establishment and operation of Aids to Navigation states:

Each Contracting Government undertakes to provide, as it deems practical and necessary either individually or in co-operation with other Contracting Governments, such Aids to Navigation as the volume of traffic justifies and the degree of risk requires.

In order to obtain the greatest possible uniformity in Aids to Navigation, Contracting Governments undertake to take into account the international recommendations and guidelines (Reference is made to IALA) when establishing such aids.

Contracting Governments undertake to arrange for information relating to Aids to Navigation to be made available to all concerned. Changes in the transmissions of position-fixing systems which could adversely affect the performance of receivers fitted in ships shall be avoided as far as possible and only be effected after timely and adequate notice has been promulgated.

To satisfy the obligations of Regulation 13, the Contracting Government has to make assessments on:

- whether or not to provide particular types of Aids to Navigation;
- the type, number and location of Aids to Navigation; and
- what information services are necessary to adequately inform all concerned - principally mariners.

3.4 IALA MARITIME BUOYAGE SYSTEM AND OTHER AIDS TO NAVIGATION (MBS)

The IALA Maritime Buoyage System (MBS) represents one of IALA's major contributions to enhancing the safety of navigation. As recently as 1976 there were more than thirty buoyage systems in use worldwide and conflicting sets of rules applied. In 1980 Lighthouse Authorities from fifty countries and representatives from nine international organisations reached agreement on the rules for a single system, albeit with colour differences between Region A and Region B. In 2010 the MBS was revised. Key changes made included the introduction of an emergency wreck marking buoy and fixed marks. The full name of the revised system is therefore IALA Maritime Buoyage System and other Aids to Navigation, still being referred to as the MBS.

The MBS provides guidance on the application of AtoN systems used worldwide for all users. The MBS is comprised of fixed and floating visual marks and devices. This is primarily a physical system; however, all of the marks may be complemented by electronic means.

Within the MBS there are six types of marks, which may be used alone or in combination. Mariners can distinguish between these marks by identifiable characteristics. Lateral marks differ between Buoyage Regions A and B, whereas the other five types of marks are common to both regions.

3.4.1 MBS AtoN TYPES

The MBS uses different types of Aids to Navigation, which may be used in combination. The mariner can distinguish between these aids by identifiable characteristics. The system includes:

- Lateral Marks;
- Cardinal Marks;
- Isolated Danger Marks;
- Safe Water Marks;
- Special Marks;
- Emergency Wreck Marking Buoy;
- Mobile Marine Aids to Navigation; and
- Other Marks.

The more traditional marks are well covered in IALA documents. While the Emergency Wreck Marking Buoy and the Mobile Marine Aids to Navigation along with other marks are also covered in IALA documents, an overview of these types of AtoN is included in this Navguide.

Refer to IALA publication:

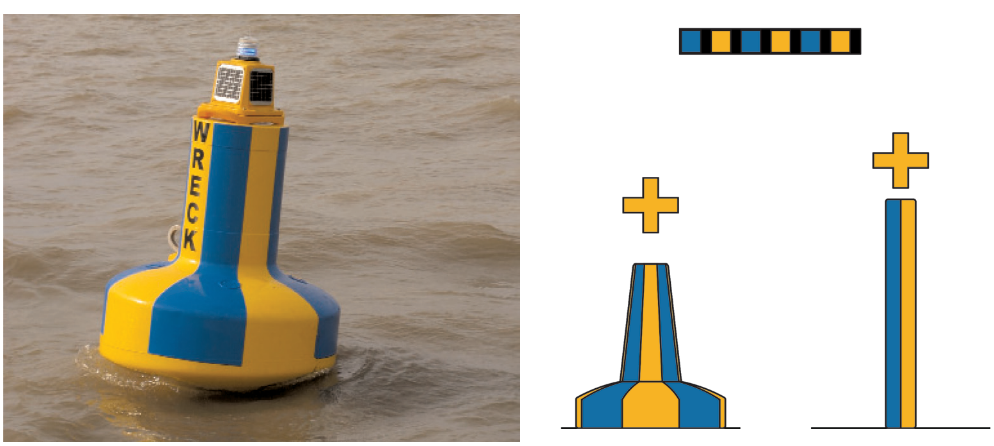
- Recommendation R1001 – IALA Maritime Buoyage System (with supporting guidelines)

3.4.2 EMERGENCY WRECK MARKING BUOY

The Emergency Wreck Marking Buoy (EWMB) is meant for prompt response to mark new dangers such as a wreck. It should therefore only be on station until the Competent Authority is satisfied that information concerning the new danger has been sufficiently promulgated or the danger is otherwise resolved. An appropriate risk assessment should be used to determine how long the EWMB should be deployed. If the new danger is expected to remain, the Competent Authority should mark it with a regular marking scheme.

The EWMB should be equipped and of a size that facilitates its detection under all sea conditions.

Upon a decision to use the EWMB, it should be deployed without unnecessary delay. This can be met by the use of EWMBs that are stored onboard a vessel ready for deployment. It should be taken into consideration that a smaller buoy, in some instances, may be deployed more rapidly. If necessary it could subsequently be replaced with a larger buoy.



Emergency Wreck Marking Buoy (EWMB)

Refer to IALA publications:

- Recommendation R1015 – Marking of Hazardous wrecks
- Guideline G1046 - Response Plan for the Marking of New Wrecks

IALA also has a consolidated recommendation and guideline for marking areas for specific navigational needs in relation to a variety of man-made structures including aquaculture facilities and offshore resource production and energy generation structures.

3.4.3 MOBILE AtoN

A MAtoN is defined as a non-fixed or un-moored AtoN; it does not include a normally fixed or moored buoy that is adrift from its station, temporarily or otherwise. A MAtoN can be fitted with an Automatic Identification System (AIS) device transmitting message 21.

Note: MAtoN should not be used for marking unmanned vessels; the lights exhibited by these vessels should comply with COLREGS, or other Competent Authority regulations.

Typical uses where MAtoN may be used, but not limited to, the following moving/ drifting applications:

- Ocean Data Acquisition System (ODAS) (e.g. to gather data on currents and weather);
- Wreckage (e.g. containers, debris);
- Water quality and pollution monitoring equipment;
- Dynamic guard zones and convoys;
- Underwater operations;
- Enhancing navigational safety during military operations (e.g. no sail zones during minesweeping, target exercises areas);
- Towed and deployed applications (e.g. cable laying);
- Search & Rescue applications; and
- Special events (e.g. swimming competitions).

3.4.3.1 TYPES OF MAtoN

MAtoN can be deployed either physically or virtually. Competent Authorities should determine the most appropriate type of MAtoN for each situation, based on the available equipment and assessment of risk.

Refer to IALA publications:

- Recommendation R1016 - Mobile Marine Aid to Navigation (MAtoN)
- Guideline G1154 - Use of Mobile Aids to Navigation

3.5 ATON PLANNING

IALA Standard S1010 applies to AtoN Planning and Service Requirements. This Standard references normative and informative provisions, detailed in the listed IALA Recommendations, covering the following scope.

- Obligations and regulatory
- Marine Aids to Navigation planning
- Virtual marking
- Levels of service
- Risk management
- Quality management

When planning AtoN, it is essential to conduct a comprehensive navigational risk assessment, taking into account factors such as local geography, shipping routes, and traffic density. AtoN providers should consult and collaborate with relevant stakeholders, including maritime authorities and local communities, to ensure the optimal placement and types of aids to navigation. These factors are part of Marine Spatial Planning (MSP), the main purpose of which is to achieve a balanced approach towards navigational safety, environmental protection, economic effects and communication (information management).

Additionally, AtoN managers must consider the compatibility of their systems with global and regional navigation systems, and ensure compliance with international guidelines and national regulations while minimizing environmental impact and maintaining system reliability.

An overview of AtoN planning in the context of overall organisational operational and strategic planning is covered in Chapter 5 of this publication.

Refer to IALA publications:

- Recommendation R1001 – IALA Maritime Buoyage System
- Recommendation R1010 – Involvement of maritime authorities in Marine Spatial Planning (MSP)
- Guideline G1078 – Use of AtoN in the design of fairways and channels
- Guideline G1033 – Provision of AtoN for different classes of vessels including high speed craft
- Guideline G1079 – Establishing and conducting user consultancy by AtoN authorities
- Guideline G1121- Navigational safety within Marine Spatial Planning

3.6 OPERATIONAL REQUIREMENTS

The primary objective of Marine Aids to Navigation is to mitigate transit risks and to promote the safe, economic, and efficient movement of vessels by assisting navigators with determining their position, a safe course, and warning them of dangers and obstructions, especially when used in conjunction with other aids within visual, audio, or radar range of the mariner.

3.7 VISUAL AIDS TO NAVIGATION DESIGN THEORY

IALA Standard 1020 applies to AtoN Design and Delivery. This Standard references normative and informative provisions, detailed in the listed IALA Recommendations, covering the following scope.

- Visual signalling
- Range and performance
- Design, implementation, and maintenance
- Power systems
- Floating aids to navigation
- Environment, sustainability, and legacy

Visual marks for navigation can be either natural or man-made objects. They include structures specifically designed as short range Aids to Navigation, as well as conspicuous features such as headlands, mountain-tops, rocks, trees, church-towers, minarets, monuments, chimneys, etc. Short range Aids to Navigation can be fitted with a light if navigation at night is required, or left unlighted if daytime navigation is sufficient.

Navigation at night is possible, to a limited extent, if the unlighted aids are provided with:

- a radar reflector, and the navigating vessel has a radar;
- retroreflecting material, and the vessel has a searchlight. This approach would generally only be acceptable for small boats operating in safe waterways and with the advantage of local knowledge.

Visual Aids to Navigation are purpose-built facilities that communicate information to a trained observer on a vessel for the purpose of assisting the task of navigation.

The communication process is referred to as marine signalling.

Common examples of visual Aids to Navigation include lighthouses, beacons, leading (range) lines, buoys (lighted or unlighted), lightvessels, daymarks (dayboards) and traffic signals.

The effectiveness of a visual Aid to Navigation is determined by factors such as:

- type and characteristics of the aid provided;
- location of the aid relative to typical routes taken by vessels;
- distance (range) of the aid from the observer;
- atmospheric conditions;
- contrast relative to background conditions (conspicuity); and
- the reliability and availability of the aid.

Visual Aids to Navigation can be distinguished by a wide range of characteristics such as:

- type, shape, size, colour, names, retroreflecting features, letters and numbers;
- lighted/unlighted, signal character, light intensity, sectors, inclusion of subsidiary aids;
- fixed structure, floating platform, construction materials; and
- location, elevation, relationship to other Aids to Navigation and observable features.

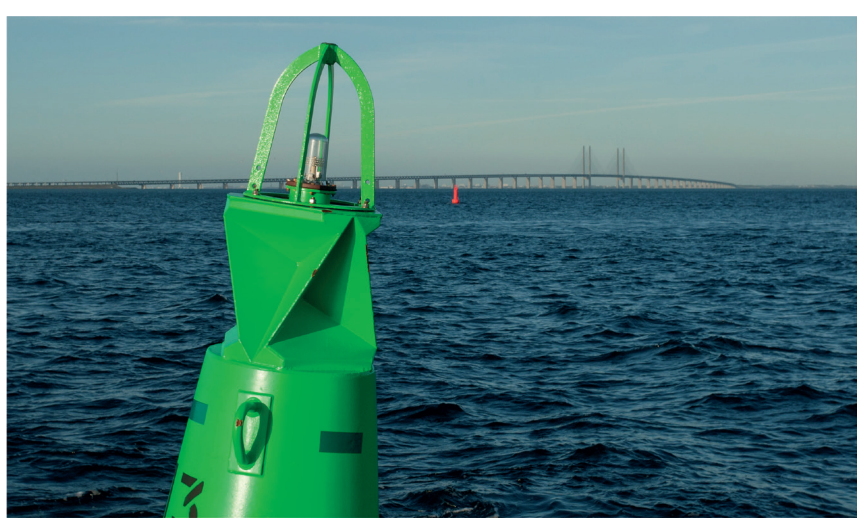


Figure 8. Floating AtoN (Photo - Courtesy of Danish Maritime Authority)

3.7.1 VISUAL PERCEPTION

When a navigator approaches a visual AtoN, for instance a buoy, the first thing the navigator will recognise is the shape or colour of the buoy, depending on the viewing conditions.

The navigator will subsequently recognise the topmark and finally its numbers or letters. Thus, the process of identifying a visual AtoN goes through three different stages of perception:

Detection - The observer is aware of an object. The navigator sees an object, but will usually not be able to deduce its shape or colour and will not know that it is an AtoN.

Recognition - The observer is aware that the object is an AtoN.

Identification - The observer is aware which AtoN the object is. At this distance, the navigator can perfectly discern the type of mark it is.

These three different stages of perception are often referred to as **DRI**.

Visual perception requires some understanding of a number of factors that impact the ability of an observer to see an AtoN. These factors are summarised below.

3.7.2 SIGNAL COLOURS

IALA has made recommendations on colours for lighted Aids to Navigation and for surface colours for visual signals on Aids to Navigation.

Marine Aid to Navigation signal lights uses a five-colour system comprising white, red, green, yellow and blue, as defined in Recommendation R0201 (E200-1) Marine Signal Lights – Colours. The colour regions defined in the IALA recommendation are derived from those given in the International Commission on Illumination (CIE) Standard S 004/E 2001 Colours of Light Signals with small variances in some of the boundaries. More information is available at CIE website address: www.cie.co.at/cie

Recommended surface colours for visual signals on Aids to Navigation are as follows:

- Ordinary colours should be limited to white, black, red, green, yellow or blue.
- Orange and fluorescent red, yellow, green or orange may be used for special purposes requiring high conspicuity.
- Blue surface colours may be used in inland waterways, estuaries and harbours where the colour may be seen at close range.

Refer to IALA publications:

- Recommendation R0106 – Use of retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System
- Recommendation R0108 - Surface Colours Used as Visual Signals on Marine Aids to Navigation
- Guideline G1015 - Painting Aids to Navigation Buoys
- Guideline G1134 - Surface Colours used as visual signals on AtoN
- Guideline G1145 - Application of Retroreflecting material on AtoN
- Guideline G1006 - Plastic Buoys

The CIE standard on the measurement of colours (colorimetry) is based on three reference colours (i.e. a tri-stimulus system) that in varying combination can generate the visual spectrum of colours. A particular colour function is described by the symbols; X, Y and Z that represent the proportions of the reference colours.

Using ratios of the tri-stimulus values, such that: X + Y + Z = 1, colours can be defined in terms of chromaticity using just the x = X / (X+Y+Z) and y = Y / (X+Y+Z) values. The advantage of this arrangement is that colours can be mapped on a two-dimensional chromaticity diagram.

CIE colour standards for marine signalling can be depicted as areas on the chromaticity diagram. These areas are defined by boundaries expressed as functions of x and y (equations).

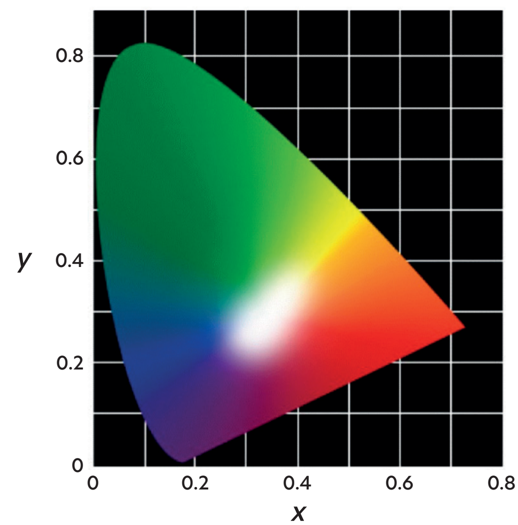


Figure 9. Illustration of the Colour Zones on the 1931 CIE Chromaticity diagram

Note that the colour rendering is only indicative and should not be taken as fully accurate.

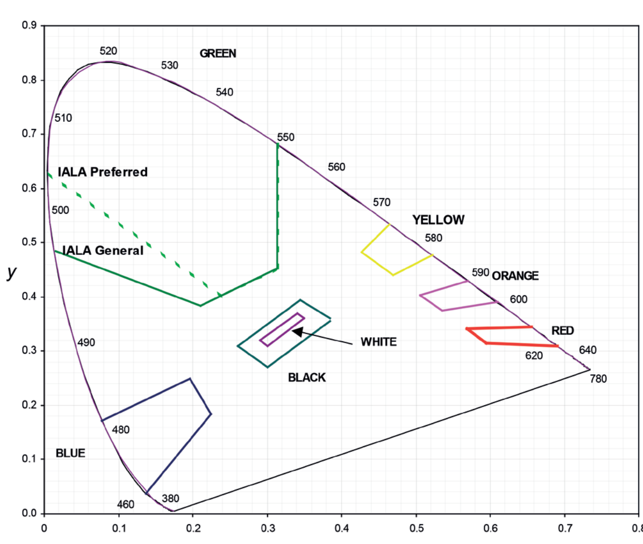


Figure 10. IALA Chromaticity Areas of Ordinary Surface Colours -
As plotted on the 1983 CIE Chromaticity diagram - courtesy of CIE

If the chromaticity co-ordinates of a coloured light, filter material or a paint product are known, its acceptability for marine signalling applications can easily be determined.

Further information on surface colours can be found in IALA Recommendation R0108(E-108) on the surface colours used as visual signals on Aids to Navigation. Information for light signal colours is shown in IALA Recommendation R0201(E-200-1) for the colours for light signals on Aids to Navigation. For further details on this issue, refer to CIE S 004/E-2001 Colours of Light Signals.

3.7.3 METEOROLOGICAL VISIBILITY

Meteorological visibility (V) is defined as the greatest distance at which a black object of suitable dimensions can be seen and recognised by day against the horizon sky, or, in the case of night observations, could be seen if the general illumination were raised to the normal daytime level. It is usually expressed in kilometres or Nautical Miles.

Figure 11. Photo Courtesy of Australian Maritime Safety Authority

3.7.4 ATMOSPHERIC TRANSMISSIVITY

The atmospheric transmissivity (T) is defined as the transmittance, or proportion of light from a source, that remains after passing through a specified distance through the atmosphere at sea level. This is expressed as a ratio. But since the atmosphere is not uniform over the observing distances of most visual aids, a representative value is used:

- typically, the atmospheric transmissivity is taken as T = 0.74 over one Nautical Mile, meaning that 74% of light is still available" (26% of the light is "lost") for every one Nautical Mile due to the atmospheric transmissivity;
- a figure of T = 0.86 is occasionally used in regions where the atmosphere is very clear.

A number of countries collect data on atmospheric transmissivity for different parts of their coastline. This enables the luminous range of lights to be:

- calculated more precisely; and
- better matched to local conditions and user requirements.

3.7.4.1 ATMOSPHERIC REFRACTION

This phenomenon results from the normal decrease in atmospheric density from the Earth's surface to the stratosphere. This causes light rays that are directed obliquely through the atmosphere to be refracted (or bent) towards the Earth in accordance with Snell's Law.

3.7.4.2 CONTRAST

The ability to detect differences in luminance between an object and an otherwise uniform background is a basic visual requirement and is used to define the term contrast. It is represented by the equation:

$$C = \frac{(L_0 - L_B)}{L_B}$$

Where: C = contrast
L_B = luminance of background (cd/m^2)
L_0 = luminance of object (cd/m^2)

The contrast at which an object can be detected against a given background for 50% of the time, is called the threshold contrast. For meteorological observations, a higher threshold must be used to ensure that the object is recognised.

A contrast value of 0.05 has been adopted as the basis for the measurement of meteorological optical range.

3.7.4.3 USE OF BINOCULARS

While it is generally assumed that observations will be made with the naked eye, mariners will quite often use binoculars. This can allow:

- a light being observed, or the characteristics resolved, at a greater luminous range than with the naked eye;
- a limited improvement in the sensitivity of leading lights;
- about a 30% improvement in the detectable difference from a given bearing; and
- the identification of a light operating against background lighting conditions.

Generally, the most suitable binoculars for use at sea are considered to be the type with a magnifying power of 7 and an objective lens of 50 mm at night, and 10 x 50 binoculars by day.

3.7.5 GEOGRAPHICAL RANGE

This is the greatest distance at which an object or a light source could be seen under conditions of perfect visibility, as limited only by the curvature of the earth, by refraction of the atmosphere, and by the elevation of the observer and the object or light.

As the observer moves further away from the object or light source, there will come a point where the object or light source is obscured by the Earth. This is illustrated in Table 7.

table 7. Geographical Range Table in Nautical Miles

Geographical Range (NM)							
Observer eye height (m)	Elevation of light (m)						
	0	1	2	3	4	5	6
1	2.0	4.1	4.9	5.5	6.1	6.6	7.0
2	2.9	4.9	5.7	6.4	6.9	7.4	7.8
5	4.5	6.6	7.4	8.1	8.6	9.1	9.5
10	6.4	8.5	9.3	9.9	10.5	11.0	11.4
20	9.1	11.1	12.0	12.6	13.1	13.6	14.1
30	11.1	13.2	14.0	14.6	15.2	15.7	16.1

The values in Table 7 are derived from the formula:

$$Rg = 2{,}03 \times (\sqrt{h_o} + \sqrt{H_m})$$

Where: Rg = geographical range (nautical miles)
ho = elevation of observer's eye (metres)
Hm = elevation of the mark (metres)

The factor 2.03 accounts for refraction in the atmosphere. Climatic variations around the world may lead to different factors being recommended. The typical range of factors is 2.03 to 2.12.

3.7.6 DAYMARKS

A daymark is a structure with defined shape and colour with the purpose of assisting with marine navigation during daylight.

A number of factors impact the suitability and effectiveness of a structure as a daymark, and these are considered below.

3.7.6.1 VISIBILITY OF A MARK

The visibility of a mark is affected by one or more of the following factors:

- observing distance (range);
- curvature of the Earth;
- atmospheric refraction;
- atmospheric transmissivity (meteorological visibility);
- height of the aid above sea level;
- observer's visual perception;
- observer's height of eye;
- observing conditions (day or night);
- conspicuity of the mark (shape, size, colour, reflectance, and the properties of any retroreflecting material);

- contrast (type of background such as lighting, vegetation, snow, etc.);
- mark is lighted or unlighted; and
- intensity and character.

Refer to IALA publications:

- Recommendation R0106 - Use of retroreflecting material on Aids to Navigation Marks within the IALA Maritime Buoyage System
- Recommendation R0108 - Surface Colours Used as Visual Signals on Marine Aids to Navigation
- Guideline G1094 - Daymarks for Aids to Navigation
- Guideline G1073 - Conspicuity of AtoN lights at night

3.7.6.2 RANGE OF A VISUAL MARK

The range of an Aid to Navigation can broadly be defined as the distance at which the observer's receiver can detect and resolve the signal. In the case of visual marks the observer's receivers are his/her eyes. This broad definition of range leads to a number of more specific definitions that are described later in this chapter.

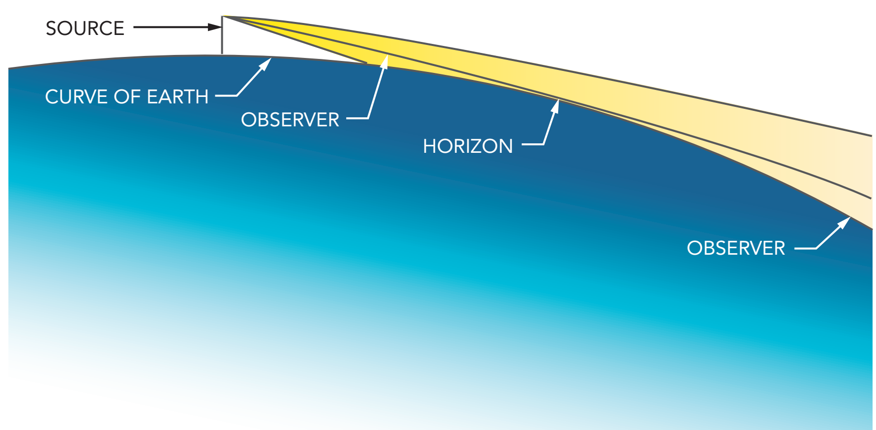


Figure 12. Effect of Exceeding Geographical Range

3.7.6.3 DAYMARK SIZE

The size of a dayboard should be determined for the maximum useful viewing distance and minimum visibility conditions. Daymarks used on leading lines are typically rectangular with the long side vertical. The aspect ratio for the rectangle is commonly 2:1 (height = 2 x width).

The typical operational range of daymarks under different visibility conditions is shown in Table 8.

Table 8. Typical Operational Range of Daymarks

Operational Range of Daymarks (Nautical Miles)					
Minimum visibility (Nautical Miles)	Daymark height (metres) Aspect ratio h=2w				
	1.8	2.4	3.7	4.9	7.3
1	0.5	0.7	0.9	1.0	1.1
2	0.6	0.9	1.2	1.4	1.5
3	0.6	1.1	1.5	1.9	2.1
4	0.7	1.3	1.8	2.3	2.7
5	0.8	1.5	2.1	2.7	3.3
6	0.8	1.6	2.3	2.9	3.6
7	0.9	1.7	2.4	3.3	4.0
8	0.9	1.7	2.6	3.5	4.2
9	0.9	1.9	2.8	3.8	4.5
10	1.0	2.0	3.0	4.0	5.0

3.8 MARINE AIDS TO NAVIGATION SIGNAL LIGHTS

3.8.1 PHOTOMETRY OF MARINE AIDS TO NAVIGATION SIGNAL LIGHTS

"The science of observing visible light is called photometry and provides a basis for creating standards for Marine Aids to Navigation signal lights. Generally, electromagnetic radiation is described by its wavelength in metres and its power in Watts."

However, the study of photometry and the use of lights for signal application has necessitated a parallel set of units to be developed to account for the physiological aspects of how the human eye evaluates a light source, as shown in Table 9.

The spectral sensitivity of the human eye (or the response of the eye to different coloured light) has been evaluated in tests of large numbers of people. The results have been presented as a standard spectral sensitivity distribution or $V(\lambda)$ curve for photopic (daytime) observers and $V'(\lambda)$ for scotopic (night-time) observers.

Photopic vision is the vision of the eye under well-lit conditions, normally usual daylight light intensity. Scotopic vision is the vision of the eye under low light conditions or night. Cone cells in the eye do not function as well as rod cells in the eye in low level lighting so scotopic vision happens through rod cells which are more sensitive to wavelengths of light towards the blue-green bands of colour in the electromagnetic spectrum. Therefore, the sensitivity of the eye shifts towards the blue-green colours at night.

Table 9. Guidance on the impact of background lighting and meteorological conditions on light intensity required to achieve a particular range

Nominal Range	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)
Background lighting or Metrological condition (see 1.3.3)	None	Minor	Substantial	Day VDO	Day DO	Day OO	Day BO	Day BC	Day VBC
Luminance (cd/m^2)				100	200	1000	5000	10000	20000
Illuminance (bc)	2.00E-07	2.00E-06	2.00E-05	1.30E-05	2.39E-05	1.07E-04	5.06E-04	9.99E-04	1.98E-03
Transmissivity (per M)	0.74	0.74	0.74	0.74	0.74	0.74	0.78	0.79	0.81
Visibility (M)	10	10	10	10	10	10	12	13	14
Range (M)									
0.2	0.03	0.3	3	2	3	16	73	144	284
0.5	0.20	2	20	13	24	107	429	961	1,890
0.7	0.41	4	41	27	50	222	1,010	1,970	3,870
1	1	9	93	60	111	495	2,230	4,310	8,410
2	5	50	500	325	597	2,670	11,400	21,700	41,700
3	15	152	1,520	986	1,810	8,110	33,000	61,600	116,000
4	36	364	3,640	2,360	4,350	19,460	75,400	138,000	256,000
5	77	767	7,670	4,990	9,170	41,000	151,000	271,000	495,000
6	149	1,490	14,900	9,690	17,800	79,700	279,000	492,000	883,000
7	274	2,740	27,400	17,800	32,700	146,000	488,000	843,000	1,490,000
8	482	4,820	48,200	31,300	57,600	258,000	818,000	1,390,000	2,410,000
9	824	8,240	82,400	53,500	98,400	441,000	1,330,000	2,210,000	3,770,000
10	1,370	13,700	137,000	89,200	164,000	734,000	2,110,000	3,430,000	5,770,000
11	2,240	22,400	224,000	146,000	268,000	1,200,000	3,270,000	5,230,000	8,650,000
12	3,600	36,000	360,000	234,000	430,000	1,920,000	5,000,000	7,840,000	
13	5,700	57,000	570,000	370,000	681,000	3,050,000	7,530,000		
14	8,910	89,100	891,000	579,000	1,070,000	4,770,000			
15	13,800	138,000	1,380,000	897,000	1,650,000	7,390,000			
16	21,200	212,000	2,120,000	1,380,000	2,530,000				
17	32,300	323,000	3,230,000	2,100,000	3,860,000				
18	48,800	488,000	4,880,000	3,170,000	5,840,000				
19	73,400	734,000	7,340,000	4,770,000	8,770,000				
20	110,000	1,100,000		7,130,000					
21	163,000	1,630,000							
22	242,000	2,420,000							
23	357,000	3,570,000							
24	524,000	5,240,000							
25	767,000	7,670,000							
26	1,120,000								
27	1,630,000								
28	2,360,000								
29	3,420,000								
30	4,940,000								

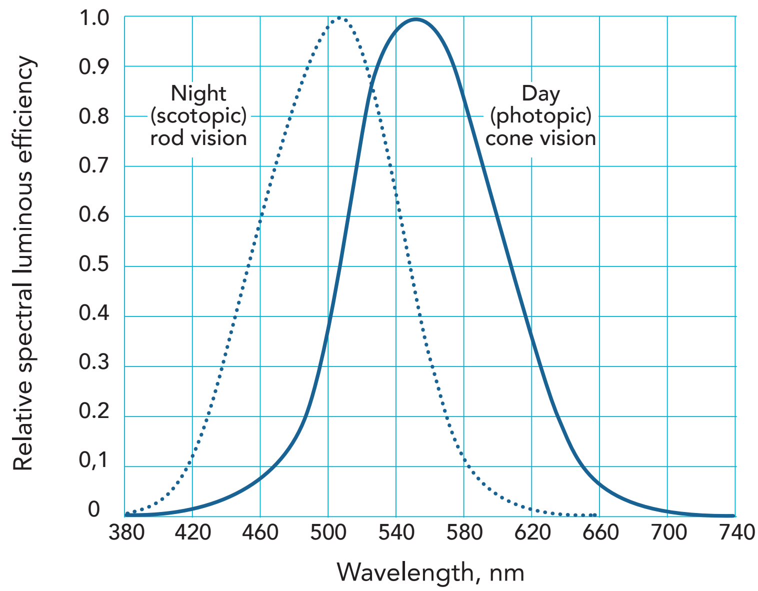


Figure 13. Spectral Sensitivity Distributions or V(λ) and V′(λ) Curves for the Human Observer.

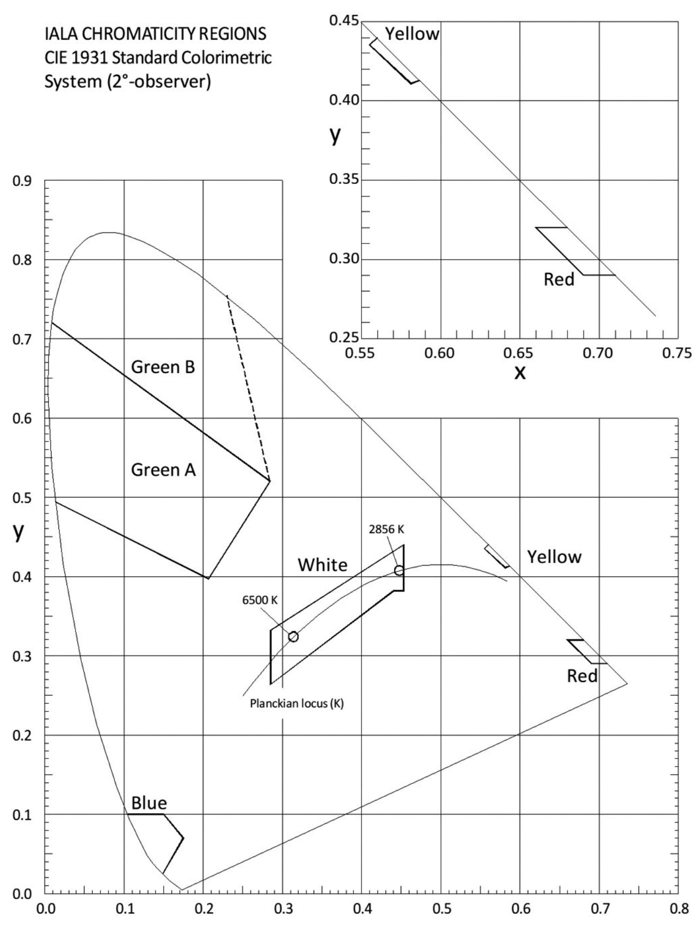


Figure 14. Chromaticity Regions of the Recommended IALA Colours for Lights

3.8.2 COLORIMETRIC MEASUREMENT OF LIGHTS (COLOUR MEASUREMENT)

The measurement of the colour of lights is described in CIE Publication No 15.2 (1986) Colorimetry. There are two main types of instruments for measuring the colour of a light: one is a colorimeter; the other is a **spectroradiometer**.

Colorimeters usually comprise three photoreceptors, each with a coloured filter. Each filter is matched to the response of one of the three eye receptors, red green and blue and such devices are called 'tristimulus' colorimeters. The colorimeter gives three outputs, one for each filtered receptor, and these correspond to the X, Y and Z functions of the human observer.

Spectroradiometers consist of a monochromator and photoreceptor. The monochromator splits the light into individual wavelengths (much like a prism makes a rainbow) and is usually rotated in steps past an exit slit. The photoreceptor, behind the exit slit, measures different sections of the spectrum as the monochromator is rotated. The output is a series of readings enabling a graph of power against wavelength to be displayed. Results may then be weighted with the X, Y and Z functions of the human observer to produce colour information.

Stepping monochromators of the type described previously are fairly slow in operation and are not suitable for measuring flashing lights. **Tristimulus colorimeters**, on the other hand, enable much faster measurements of colour. New types of spectroradiometers, known as **'array-based' spectroradiometers**, are now available. Instead of a single photoreceptor and a rotating monochromator, a fixed monochromator has its output directed at an array of charge-coupled devices (CCDs). Such devices are capable of much faster measurement speeds than stepping monochromators.

Recent developments in colour measurement have resulted from the technology of digital cameras. **'Imaging photometers'**, as they are known, are little more than calibrated digital cameras, some with tristimulus filtering. They are capable of fast measurement of a whole scene, making them useful for work outside the laboratory.

In summary:

- Tristimulus colorimeters are fast, however cheaper models suffer errors when measuring narrowband light sources such as LEDs;
- Stepping monochromators are expensive and slow but very accurate;
- Array-based spectroradiometers are fast, relatively inexpensive, but can suffer with stray light errors; and
- Imaging photometers are expensive and not very accurate, but can record a whole scene and not just one light.

Resultant data from colour measurements are usually displayed on a chromaticity chart, developed by the CIE in 1931. The three X, Y, Z values are reduced to two x, y values as shown in Figure 15.

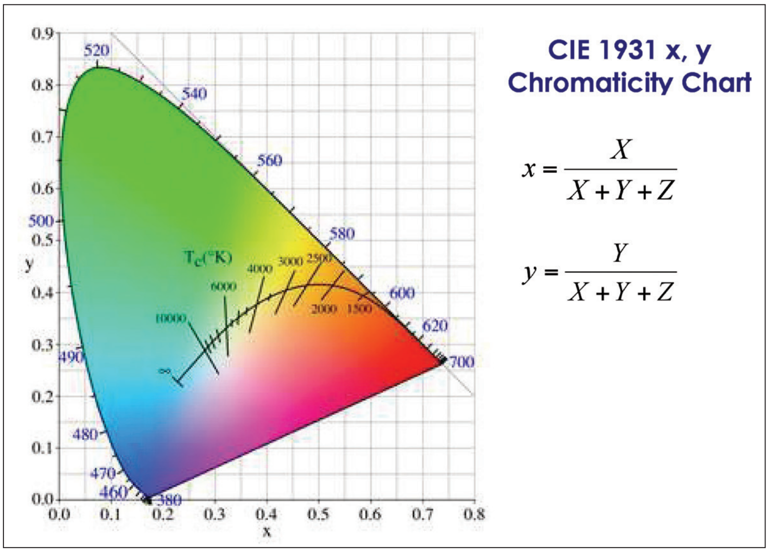


Figure 15. CIE 1931 x, y Chromaticity Chart

3.8.3 PHOTOMETRIC UNITS OF MEASUREMENT

Table 10. Photometric Units of Measurement

Term	Description	Unit	Abbreviation
Luminous flux	This is the total light emitted from the source (i.e. lamp) The peak sensitivity of the human eye occurs at about 555 nanometres, a wavelength that corresponds to green. At this wavelength, the photometric equivalent of one watt is defined as 683 lumens.	lumens	lm
Luminous intensity	This is the part of the luminous flux in a particular direction. Also expressed as the luminous flux per solid angle (or steradian).	candela	cd
Luminance (Brilliance)	This is the portion of the luminous flux emitted in a specific direction by a surface area of a luminous body. Luminance is an important term for rating the brightness impression of light sources and illuminated objects. Luminance is the parameter that causes the response in the eye.	candelas per square meter and also candelas per square centimetre	cd/m^2 cd/cm^2
Illuminance	This is the density of the luminous flux incident on a surface. It is the quotient of the luminous flux by the area of the surface when the surface is uniformly illuminated.	lux (lumens/ square metre)	lx
Luminous efficacy	This is the ratio of luminous output to radiometric output of a light source. It can also be applied to the efficiency with which electrical power is converted to visible radiation.	lumens per watt of electrical power consumed	
Colour Temperature	This related to the temperature of a black body. As a body heats up, it goes through a series of different colours from red through yellow and white, to blue white. The colour appearance of a tungsten filament lamp is similar to a black body at the same temperature.	Kelvin	ºK
Colour Rendering index	Characterises the colour rendering quality of the light from a lamp. It is the same for all incandescent lamps by definition and equal to the maximum value of 100.		CRI

3.8.4 THRESHOLD OF ILLUMINANCE

In physical terms, the threshold of illuminance is the lowest level of illuminance from a point source of light, against a given background level of luminance, that causes a visual response at the eye. For visual signalling applications, the threshold of illuminance (E) is taken to be 0.2 microlux at the eye of the observer. In the case of leading lights of limited range and with a high level of shore illumination, the above figures may be found too low. It is recommended that to observe the relative position of the lights easily and to derive the maximum possible accuracy from leading and sector lights, it is generally necessary to have a minimum illuminance of 1 microlux at the eye of the observer.

This condition is to be met at the outer limits of the useful segment for the minimum meteorological visibility under which the leading lights are to be used. IALA Recommendation R0200 series (R0201, R0202, R0203, R0204 and R0205) and associated guidelines provide the method of designing AtoN lights for use in daylight. For lights on floating aids, care must be taken to provide adequate vertical divergence so that the minimum illuminance at the observer is maintained as the floating aid rolls and pitches.

3.8.4.1 LUMINOUS INTENSITY

The luminous intensity of a navigation light is directly proportional to the luminance of the light source. The luminance of a light source depends on its size and the luminous flux in the direction of observation. The vertical and horizontal divergence is also directly proportional to the size of the light source.

Candela (cd) is the measurement unit used to quantify the luminous intensity of a light.

3.8.4.2 INVERSE SQUARE LAW

Light emitted from a source radiates out in all directions. For a point source, the wave front of the light can be imagined generating a series of spherical surfaces. As shown in Figure 16, the further the light travels from the source, the greater is the surface area of the sphere and consequently, the lower the illuminance. Since illuminance is measured in lumens per square metre, and the surface area of a sphere increases in proportion to the square of the radius, the illuminance decreases in proportion to the square of the distance from the source. The decline in illuminance with distance is described as an inverse-square law.

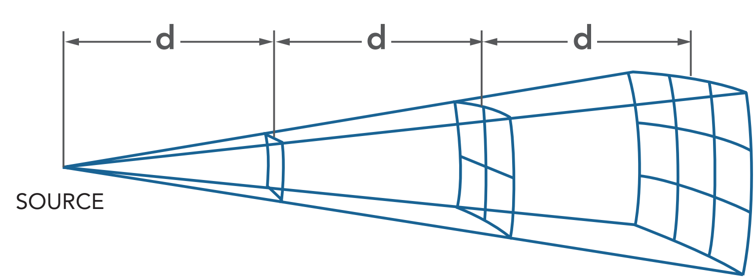


Figure 16. Illustration of the Inverse Square Law Concept.

3.8.4.3 ALLARD'S *LAW*

The illuminance of a light source reaching an observer's eye determines whether the light can be seen. The relationship between the illuminance produced at the observer's eye, the luminous intensity of the light source, the distance to the observer and the atmospheric transmissivity is given by the relationships shown in Allard's Law:

Allard's law applies only when the luminance of the background is small compared to the average illuminance of the light.

$$E(d) = \frac{I}{(3.43 \times 10^6)} \frac{T_M^{\,d}}{d^2}$$

Where:

E(d) is the illuminance at the eye of the observer in lm/m^2 [lx]

I is the luminous intensity of the light [cd]

T_M is the transmissivity for one Nautical Mile of the atmosphere

d is the numerical value of the distance in Nautical Miles

Refer to IALA publications:

- Recommendation R0201 – Marine signal lights - colours
- Recommendation R0202 - Marine Signal Lights - Calculation, Definition and Notation of Luminous Range
- Recommendation R0203 – Marine signal lights – measurement
- Recommendation R0204 – Marine signal lights – determination and calculation of effective intensity
- Recommendation R0205 – Marine signal lights – estimation of the performance of optical apparatus
- Guideline G1148 – Determination of required luminous intensity for marine signal lights
- Guideline G1065 - AtoN signal light vertical divergence
- Guideline G1135 – Determination and calculation of effective intensity

3.8.5 RHYTHMS AND CHARACTERS

IALA has produced a recommendation on the characters for light on Aids to Navigation. The full table of classifications and specifications of Aid to Navigation characters are provided in Table 12 while the maximum periods for Light Characters are shown in Table 11.

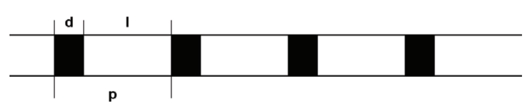
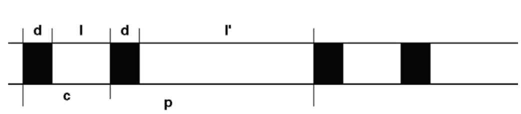
Refer to IALA publications:

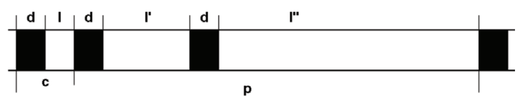
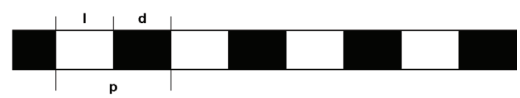
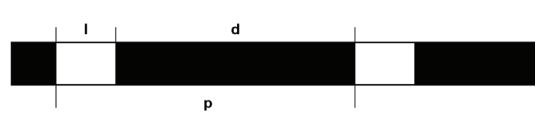
- Recommendation R0110 - Rhythmic characters of lights on AtoN
- Guideline G1116 - Selection of Rhythmic characters & synchronisation of Lights for AtoN

Table 11. Rhythmic Characters of the Lights in the IALA Maritime Buoyage System: Maximum Periods for Light Characters

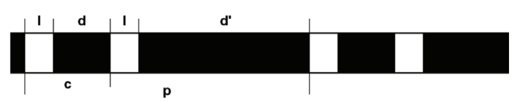
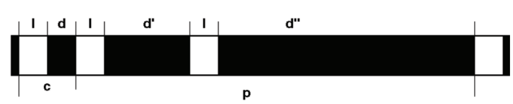
Character Class	Maximum period
Isophase light	12 s
Single-occulting light Single-flashing light Group very quick light	15 s
Group-occulting light of two eclipses Long-flashing light Group-flashing light of two flashes Group quick light	20 s
Group-occulting light of three or more eclipses Group-flashing light of three or more flashes Composite group-flashing light Morse Code light	30 s

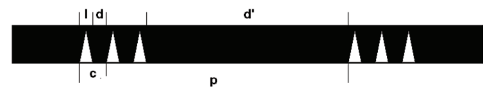
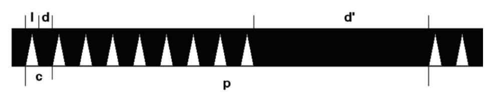
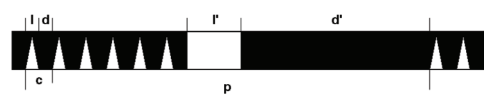
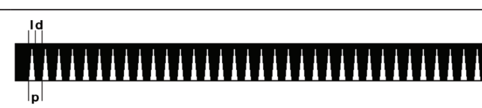
Table 12. Rhythmic character of lights

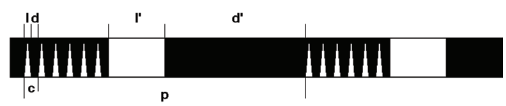
	Class	Abbrev-iation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
1	Fixed light	F	A light showing continuously and steadily.	A single fixed light should be used with care because it may not be recognized as an Aid to Navigation light.	A single fixed light shall not be used.
2	Occulting light		A light in which the total duration of light in a period is longer than the total duration of darkness and the intervals of darkness (eclipses) are usually of equal duration.	A light in which the total duration of light in a period is clearly longer than the total duration of darkness and all the eclipses are of equal duration.	
2.1	Single-occulting light	Oc	An occulting light in which an eclipse is regularly repeated	The duration of an appearance of light should not be less than three times the duration of an eclipse. The period should not be less than 2 s  l ≥ 3 d p ≥ 2 s Example: d = 1 s; l = 3 s; p = 4 s	A single occulting White light indicates a safewater mark.
2.2	Group occulting light	Oc(#) e.g. Oc(2)	An occulting light in which a group of eclipses, specified in number, is regularly repeated.	The appearances of light between the eclipses in a group are of equal duration, and this duration is clearly shorter than the duration of the appearance of light between successive groups. The number of eclipses in a group should not be greater than four in general, and should be five only as an exception. The duration of an appearance of light within a group should not be less than the duration of an eclipse. The duration of an appearance of light between groups should not be less than three times the duration of an appearance of light within a group. In a group of two eclipses, the duration of an eclipse together with the duration of the appearance of light within a, group should not be less than 1 s. In a group of three or more eclipses, the duration of an eclipse together with the duration of an appearance of light within the group should not be less than 2 s. Oc(2)  l ≥ d l' ≥ 3 l c ≥ 1 s Example: d = 1 s; l = 2 s; c = 3 s; l' = 6 s; p = 10 s	A group occulting Yellow light indicates a special mark.

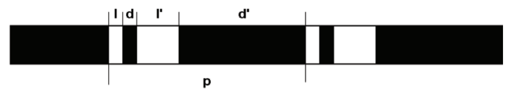
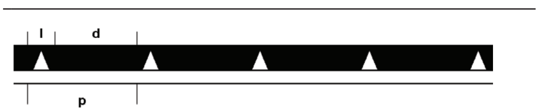
	Class	Abbrev-iation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
2.3	Composite group occulting light	Oc(#+#) e.g. Oc(2 + 1)	A light similar to a groupocculting light except that successive groups in a period have different numbers of eclipses.	This class of light character is not recommended because it is difficult to recognize. Oc(2+1)  l ≥ d l' ≥ 3 l l'' ≥ l' c ≥ 1 s Example: d = 1 s; l = 1 s; c = 2 s; l' = 3 s; l'' = 9 s; p = 16 s	
3	Isophase light	Iso	A light in which all the durations of light and darkness are clearly equal.	The period should never be less than 2 s, but preferably it should not be less than 4 s in order to reduce the risk of confusion with occulting or flashing lights of similar periods.  l = d p ≥ 2 s Example: l = d = 2 s; p = 4 s	An isophase White light indicates a safewater mark.
4	Flashing light		A light in which the total duration of light in a period is shorter than the total duration of darkness and the appearances of light (flashes) are usually of equal duration.	A light in which the total duration of light in a period is clearly shorter than the total duration of darkness and all the flashes are of equal duration.	
4.1	Single flashing light	Fl	A flashing light in which a flash is regularly repeated (at a rate of less than 50 flashes per minute).	The duration of the interval of darkness (eclipse) between two successive flashes should not be less than three times the duration of a flash. The period should not be less than 2 s (or not less than 2.5 s in those countries where a quick rate of 50 flashes per minute is used).  d ≥ 3 l p ≥ 2 s Example: l = 1 s; d = 3 s; p = 4 s	A singleflashing Yellow light indicates a special mark.
4.2	Long flashing light	LFl	A singleflashing light in which an appearance of light of not less than 2 s duration (long flash)[1] is regularly repeated.	 l ≥ 2 s d ≥ 3 l Example: l = 2 s; d = 8 s; p = 10 s	A long flashing White light with a period of 10 s indicates a safewater mark.

1 The term “long flash”, which is used in the descriptions of the long-flashing light and of the light characters reserved for south cardinal marks, means an appearance of light of not less than 2 seconds duration. The term “short flash” is not commonly used and does not appear in the Classification. If an Authority requires discrimination between two flashing lights that only differ in having flashes of different durations, then the longer flash should be described as “long flash” and be of not less than 2 seconds duration, and the shorter flash may be described as “short flash” and should be of not more rhythmic character of such a light is than one third of the duration of the longer flash.

	Class	Abbrev-iation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
4.3	Group flashing light	Fl(#) e.g. Fl(2)	A flashing light in which a group of flashes, specified in number, is regularly repeated.	The eclipses between the flashes in a group are of equal duration, and this duration is clearly shorter than the duration of the eclipse between successive groups. The number of flashes in a group should not be greater than five in general, and should be six only as an exception. The duration of an eclipse within a group should not be less than the duration of a flash. The duration of an eclipse between groups should not be less than three times the duration of an eclipse within a group. In a group of two flashes, the duration of a flash together with the duration of the eclipse within the group should not be less than 1 s. In a group of three or more flashes, the duration of a flash together with the duration of an eclipse within a group should not be less than 2 s (or not less than 2.5 s in those countries where a quick rate of 50 flashes per minute is used). Fl(2)  d ≥ l d' ≥ 3 d c ≥ 1 s Example: l = 1 s; d = 2 s; c = 3 s; d' = 6 s; p = 10 s	A group flashing White light with a group of two flashes, in a period of 5 s or 10 s, indicates an isolated danger mark. A group flashing Yellow light with a group of four, five or (exceptionally) six flashes indicates a special mark
4.4	Composite group flashing light	Fl(# + #) e.g. Fl(2 + 1)	A light similar to a groupflashing light except that successive groups in a period have different numbers of flashes.	Light characters should be restricted to (2 + 1) flashes in general, and should be (3 + 1) flashes only as an exception. Fl(2+1)  d ≥ l d' ≥ 3 d d'' ≥ d' c ≥ 1 s Example: l = 1 s; d = 1 s; c = 2 s; d' = 3 s; d'' = 9 s; p = 16 s	A composite group flashing Red or Green light with a group of (2 + 1) flashes indicates a modified lateral (preferred channel) mark. A composite group flashing Yellow light indicates a special mark.
5	QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 50 flashes per minute but less than 80 flashes per minute.	A light in which identical flashes are repeated at the rate of 60 flashes per minute.	
5.1	Continuous quick light	Q	A quick light in which a flash is regularly repeated.	 d ≥ l l s ≤ p ≤ 1.2 s Example: l = d = 0.5 s; p = 1 s	A continuous quick White light indicates a north cardinal mark.

	Class	Abbrev-iation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
5.2	Group quick light	Q(#) e.g. Q(3) e.g. Q(9) e.g. Q(6) + LFl	A quick light in which a specified group of flashes is regularly repeated.	The number of flashes in a group should be three or nine. An exceptional light character is reserved for use in the IALA Maritime Buoyage System to indicate a south cardinal mark. Q(3)  Example: l = d = 0.5 s; c = 1 s ; d' = 7.5 s; p = 10 s d ≥ l d'>d 1 s ≤ c ≤ 1.2 s	A group quick White light with a group of three flashes, in a period of 10 s, indicates an east cardinal mark.
				Q(9)  Example: l = d = 0.5 s; c = 1 s; d' = 6.5 s; p = 15 s d ≥ l d'>d 1 s ≤ c ≤ 1.2 s	A group quick White light with a group of nine flashes, in a period of 15 s, indicates a west cardinal mark.
				Q(6)+LFl  Example: l = d = 0.5 s; c = 1 s; l' = 2 s; d' = 7 s; p = 15 s l' ≥ 2 s d ≥ l d' ≥ 3 l' 1 s ≤ c ≤ 1.2 s	A group quick White light with a group of six flashes followed by a long flash of not less than 2 s duration, in a period of 15 s, indicates a south cardinal mark.
6	Very quick light		A light in which flashes are repeated at a rate of not less than 80 flashes per minute but less than 160 flashes per minute.	A light in which identical flashes are repeated at the rate of 120 flashes per minute.	
6.1	Continuous very quick light	VQ	A very quick light in which a flash is regularly repeated.	 Example: l = d = 0.25 s; p = 0.5 s d ≥ l 0.5 s ≤ p ≤ 1.6 s	A continuous very quick White light indicates a north cardinal mark.

	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
6.2	Group very quick light	VQ(#) e.g. VQ(3) e.g. VQ(9) e.g. VQ(6) +LFl	A very quick light in which a specified group of flashes is regularly repeated.	The number of flashes in a group should be three or nine. An exceptional light character is reserved for use in the IALA Maritime Buoyage System to indicate a south cardinal mark. VQ(3)  d ≥ l d' ≥ 1.5 s 0.5 s ≤ c ≤ 0.6 s Example: l = d = 0.25 s; c = 0.5 s; d' = 3.75 s; p = 5 s VQ(9)  d ≥ l d' ≥ 1.5 s 0.5 s ≤ c ≤ 0.6 s Example: l = d = 0.25 s; c = 0.5 s; d' = 5.75 s; p = 10 s VQ(6)+LFl  l' ≥ 2 s d ≥ l d' ≥ 1.5 l' 0.5 s ≤ c ≤ 0.6 s Example: l = d = 0.25 s; c = 0.5 s; l' = 2 s; d' = 5s; p = 10 s	A group very quick White light with a group of three flashes, in a period of 5 s, indicates an east cardinal mark. A group very quick White light with a group of nine flashes, in a period of 10 s, indicates a west cardinal mark. A group very quick White light with a group of six flashes followed by a long flash of not less than 2 s duration, in a period of 10 s, indicates a south cardinal mark.
7	Ultra quick light		A light in which flashes are repeated at a rate of not less than 160 flashes per minute and not more than 300 flashes per minute.	A light in which identical flashes are repeated at the rate of 240 flashes per minute.	
7.1	Continuous ultra quick light	UQ	An ultra quick light in which a flash is regularly repeated.		

	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
8	Morse code light	Mo(#) e.g. Mo(A)	A light in which appearances of light of two clearly different durations are grouped to represent a character or characters in the Morse Code.	Light characters should be restricted to a single letter in the Morse Code in general, and should be two letters only as an exception. The duration of a “dot” should be about 0.5 s, and the duration of a “dash” should not be less than three times the duration of a “dot”. Mo(A)  l = 0.5 s l’ ≥ 3 l d ≥ l Example: l = 0.5 s; d = 0.5 s; l’ = 1.5 s; d’ = 4.5 s; p = 7 s	A Morse Code White light with the single character “A” indicates a safe-water mark. A Morse Code Yellow light, but not with either of the single characters “A” or “U”*, indicates a special mark.
9	Fixed and flashing light	F+ relevant character abbreviation, e.g. FFl, FIso	A light in which a low intensity fixed light phase is combined with a flashing phase of higher luminous intensity compliant with preceding classes of rhythmic characters in this table.	Implementation of an FFl rhythmic character is shown below. Other combinations may be implemented as necessary.  l ≤ 1 s d ≥ 3 l Example: l = 1 s; d = 3 s; p = 4 s	

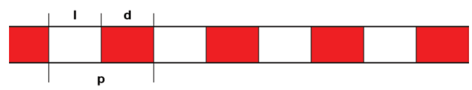
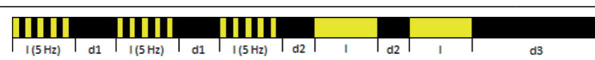
	Class	Abbrev-iation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
10	Alternating light	Al## e.g. AlWR	A light showing different colours alternately.	This class of light character should be used with care, and efforts should be made to ensure that the different colours appear equally visible to an observer. AlWR  l @ d Example: l = d = 2 s; p = 4 s	
11	Occulting alternating light	OcAl	A light showing different colours alternately and a light in which the total duration of light in an period is longer than the total duration of darkness and the intervals of darkness (eclipses) are of equal duration.	This class of light is particular to the use of Emergency Wreck Marking, and efforts should be made to ensure that the different colours appear equally visible to an observer. OcAlBY  Example: l = 1 s; d = 0.5 s; p = 3 s	An Occulting-Alternating Blue and Yellow light indicates an Emergency Wreck Marking Buoy mark.
12	Flickering light	Flkr	A character containing flashes with a perceivable flicker. The flickering flash must have a frequency of 5 Hz and a duty cycle of 50 %.	This class of light is particular to the use of Mobile AtoN, and is a distinctive character incorporating flicker and non-flicker flashes. The first three flashes comprises of a flicker flash with a flicker frequency of 5 Hz. This is followed by two non-flicker flashes. Flkr(3)+Fl(2)Y  Example: l = 1 s; d1 = 0.7 s; d2 = 0.5 s; d3 = 3 s; p = 10.4 s	This character is used solely for the Mobile AtoN application. The light colour is always yellow.

Table 13. Rhythmic Characters of the Lights in the IALA Maritime Buoyage System

Mark	Rhythmic character of the light	Remarks and further recommendations
LATERAL	All recommended classes of rhythmic character, but a composite group flashing light with a group of (2+1) flashes is solely assigned to modified lateral marks that indicate preferred channels.	Only the colours Red and Green are used.
Modified lateral (preferred channel)	Composite group flashing light with a group of (2+1) flashes, in a period of not more than 16s.	The duration of the eclipse after the single flash should not be less than three times the duration of the eclipse after the group of two flashes.
CARDINAL		Only the colour White is used.
North cardinal	(a) Continuous very quick light. (b) Continuous quick light.	

East cardinal	(a) Group very quick light with a group of three flashes in a period of 5s. (b) Group quick light with a group of three flashes in a period of 10s.	
South cardinal	(a) Group very quick light with a group of six flashes followed by a long flash of not less than 2s duration, in a period of 10s. (b) Group quick light with a group of six flashes followed by a long flash of not less than 2s duration, in a period of 15s.	The duration of the eclipse immediately preceding a long flash should be equal to the duration of the eclipses between the flashes at the very quick rate. The duration of a long flash should not be greater than the duration of the eclipse immediately following the long flash. The duration of the eclipse immediately preceding a long flash should be equal to the duration of the eclipses between the flashes at the quick rate. The duration of a long flash should not be greater than the duration of the eclipse immediately following the long flash.
West cardinal	(a) Group very quick light with a group of nine flashes, in a period of 10s. (b) Group quick light with a group of nine flashes, in a period of 15s.	
ISOLATED DANGER	(a) Group flashing light with a group of two flashes, in a period of 5s. (b) Group flashing light with a group of two flashes, in a period of 10s.	Only the colour White is used. The duration of a flash together with the duration of the eclipse within the group should be not less than 1s and not more than 1.5s. The duration of a flash together with the duration of the eclipse within the group should be not less than 2s and not more than 3s
SAFE WATER	8 Long flashing light with a period of 10s. 9 Isophase light. (c) Single occulting light. (d) Morse Code light with the single character "A".	Only the colour White is used.
SPECIAL	(a) Group occulting light. (b) Single flashing light, but not a long flashing light with a period of 10s. (c) Group flashing light with a group of four, five (exceptionally) six flashes. (d) Composite group flashing light. (e) Morse Code light, but not with either of the single characters "A" or "U".	Only the colour Yellow is used. A group flashing light with a group of five flashes at a rate of 30 flashes per minute, in a period of 20s, is assigned to Ocean Data Acquisition Systems (ODAS) buoys.

A single fixed light shall not be used on a mark within the scope of the IALA Maritime Buoyage System because it may not be recognized as an Aid to Navigation light.

A Morse Code white light with the single character "U" is assigned to offshore structures.

3.8.5.1 TIMING OF ASTRONOMICAL EVENTS

The night-time operation of lighted Aids to Navigation is emphasised, but daytime role is often as important. The astronomical events that define the transitions from day to night are shown below.

Table 14. Timing of Astronomical Events

Event	Condition	Illumination Lux	Comment
Sunset/Sunrise	Upper edge of the sun's disc is coincident with the horizon.	600	
Civil Twilight (start / end)	Centre of sun is at a depression angle of six (6) degrees below the horizon.	6	Large objects are seen, but details are not discernible. Brightest stars and planets are visible and the sea horizon is clearly defined.
Nautical Twilight (start / end)	Centre of sun is at a depression angle of twelve (12) degrees below the horizon.	0.06	It is dark for normal practical purposes and the sea horizon is not normally visible.
Astronomical Twilight(start / end)	Centre of sun is at a depression angle of eighteen (18) degrees below the horizon.	0.0006	Illumination is less than that from starlight and other natural light sources in the sky.

3.8.5.2 SWITCH-ON / SWITCH-OFF LIGHT LEVELS

For lighted Aids to Navigation that only operate at night, the ambient light level at which an AtoN light switches on (or off) should be chosen so that the AtoN light switches on (or off) while the ambient light level is still sufficiently high to allow safe navigation while not switching on during overcast conditions when the AtoN is not necessary for safe navigation.

Refer to IALA publication:

- Guideline G1038 – Methods and Ambient Light Levels for the activation of AtoN Lights

3.8.6 NOMINAL RANGE AND LUMINOUS INTENSITY

Table 15 is an extract of the IALA recommendation for the notation of luminous intensity and range of lights and provides a conversion between nominal range and luminous intensity.

Table 15. IALA Conversion Table for Luminous Intensity and Nominal Range for Night Observations

Nominal Range (Nautical Miles)	Luminous Intensity (candela)	Nominal Range (Nautical Miles)	Luminous Intensity (candela)
1	1-2	14	7,140-11,100
2	3-9	15	11,200-17,100
3	10-23	16	17,200-26,100
4	24-53	17	26,200-39,700
5	54-107	18	39,800-59,900
6	108-203	19	60,000-89,800
7	204-364	20	89,900-133,000
8	365-632	21	134,000-198,000
9	633-1060	22	199,000-293,000
10	1,070-1,750	23	294,000-432,000
11	1,760-2,840	24	433,000-634,000
12	2,850-4,500	25	635,000-962,000
13	4,540-7,130	26	927,000-1,135,000

This table assumes an atmospheric transmissivity of T=0.74 and a threshold of illumination of 0.2 microlux.

3.8.6.1 BACKGROUND LIGHTING

Nominal range at night is calculated with no allowance for glare from background lighting. Excessive background lighting, from streetlights, neon signs etc., frequently makes an Aid to Navigation light less effective and, in some cases, it becomes completely lost in the general background clutter. Such a light can be made more conspicuous by increasing its intensity, changing its colour or by varying its rhythm.

3.8.6.2 GLARE

Glare can be caused by bright lights emitted from the shore, such as car headlights or security lighting, or from another vessel indiscreetly using a search light. An Aid to Navigation light can also cause glare if it is too bright for the shortest viewing distance, especially when the focal plane of the light and the observer’s eye are at the same height. This situation can arise with two station leading lines. For Aids to Navigation lights, it is generally accepted that the illuminance at the eye of the navigator from the light:

- should not exceed 0.1 lux; and
- should be reduced to 0.01 lux if the background is very dark.

Refer to IALA publications:

- Recommendation R0112 - Leading Lights (includes Excel program)
- Guideline G1023 - Design of Leading Lines
- Guideline G1073 - Conspicuity of AtoN lights at night

In situations where glare is a problem, one or more of the following alterations may lead to a satisfactory result:

- raising the focal plane of the light so that the mariner uses the loom of the light or a less intense part of the vertical distribution of the light;
- reducing the intensity of the light source;
- reducing the size of the optic;
- masking the optic with, for example, perforated metal sheet;
- screening unnecessary arcs of the light; and
- using two or more lower intensity lights instead of one higher intensity light.

Whatever methods are used, it will be necessary to measure or calculate the intensity and distribution of the modified light or lighting system.

Guidance on the impact of background lighting and meteorological conditions on the light intensity required to achieve a particular range is provided in Table 16. This shows the required illuminance of the AtoN light under different daytime conditions. If typical meteorological conditions can be cited for the location of the AtoN, then this table can be used to ensure that the light intensity is sufficient to be seen in the useable range or area during those conditions.

Table 16. Required illuminance in varying Meteorological Conditions

Abbreviation	Metrological Condition	Luminance (cd/m^2)	Required Illuminance (μlx)
Day VDO	Very Dark Overcast Sky	100	13
Day DO	Dark Overcast Sky	200	24
Day OO	Ordinary Overcast Sky	1,000	107
Day BO	Bright Overcast Sky Away From Sun	5,000	506
Day BC	Bright Sky or Cloud Near Sun	10,000	1000
Day VBC	Very Bright Cloud	20,000	1980
Day GC	Glaring Cloud	50,000	4910

This table is intended as guidance only. It is not to be used for Nominal Range Publication.

3.8.6.3 GLAZING LOSS FACTOR

Some lighting equipment has to be installed inside a protective lantern housing. Unless it is practicable to measure the luminous intensity of the complete installation, it is normal practice to apply a de-rating factor to the intensity of the lighting equipment to allow for the reflection and transmission losses at the lantern glazing, generally referred to as the glazing loss factor.

Glazing bars or astragals may reduce the intensity of the light at certain bearings. The installation of non-vertical astragals will overcome this reduction to a certain extent. The focal plane of the light should be positioned away from any horizontal glazing bars or intersections.

IALA recommends that, in the absence of more definitive information, the glazing loss factor be taken as 0.85 for a system in clean condition.

Refer to IALA publications:

- Recommendation R0203 – Marine signal lights - measurement
- Recommendation R0204 - Marine Signal Lights - Determination and Calculation of Effective Intensity
- Recommendation R0205 - Marine Signal Lights – Estimation of the Performance of Optical Apparatus
- Guideline G1135 - Determination and Calculation of Effective Intensity
- Guideline G1148 - Determination of Required luminous intensity for Marine Signal Lights
- Guideline G1065 - AtoN signal light beam vertical divergence

3.8.6.4 SERVICE CONDITIONS FACTOR

Under normal operating conditions, the luminous intensity of a light is likely to degrade between service (maintenance) intervals. There are several components to this degradation:

- meteorological conditions (which may only be temporary);
- dirt and salt deposition (which can be minimised by an efficient regular programme of cleaning of the optical system and housing/lantern room glazing); and
- progressive deterioration of the light source over the service interval.

It is clearly impossible to represent such a complex array of factors in any simple way, and a proper assessment of the various effects could only be made by measurements on-site at regular intervals. However, in order to give a more realistic figure for the performance of the light under normal operating conditions than when the luminous intensity is measured in a laboratory or on a photometric range, it may be appropriate to apply a service conditions factor to the measured intensity.

Refer to IALA publications:

- Recommendation R0202 - Marine Signal Lights – Calculation, Definition and Notation of Luminous Range
- Guideline G1148 - Determination of required Luminous Intensity for Marine Signal Lights

3.8.6.5 DAY OPERATIONS

A number of authorities have established daytime lighted leading lines in major ports and waterways to achieve a more consistent performance than is possible with dayboards.

Nominal Daytime Range and Luminous Intensity

Refer to IALA publications:

- Recommendation R0202 - Marine Signal Lights – Calculation, Definition and Notation of Luminous Range
- Recommendation R0111 - Port Traffic Signals

Figure 17 and Table 17 are extracts of Recommendation R0202 On Marine Signal Lights Calculation, Definition and Notation of Luminous Range and provides a conversion between nominal daytime range and luminous intensity.

The Luminous Range Diagram enables the mariner to determine the approximate range at which a light may be sighted, by day in the meteorological conditions prevailing at the time, and for various levels of sky luminance.

Threshold value for illuminance: $E_t = 1x10^{-3}lx$

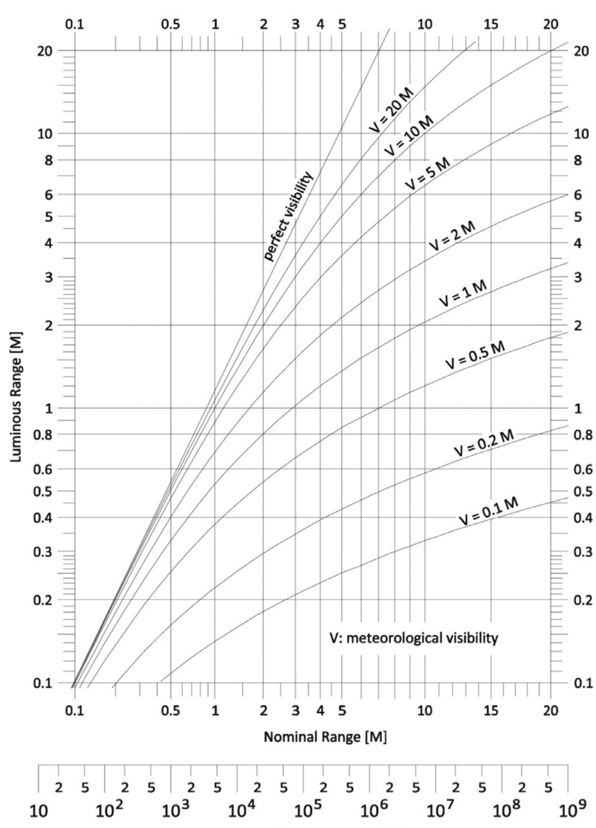


Figure 17. Daytime Luminous Range Diagram

The graph has been drawn for a sky luminance of 10 000 cd/m^2. For other values of sky luminance mark off along the scale of abscissae the distance between the luminance of 10 000 cd/m^2 and that under consideration as it appears on the auxiliary scale.

Example:

Suppose that it is required to calculate the luminous range of a light of 2 000 000 cd for a meteorological visibility of 2 Nautical Miles under an ordinary overcast sky (luminance 1 000 cd/m^2).

Measure the distance 'A' separating graduations 10 000 cd and 1 000 cd on the auxiliary scale of sky luminance. Transfer this distance to the scale of abscissae (Luminous Intensity) from the graduation corresponding to 2 000 000 cd (2x10^6 cd) in the same sense/direction. A point slightly to the right of graduation corresponding to 12 Nautical Miles is obtained. Erect from this point a parallel to the axis of ordinates (Luminous Range) to meet the curve for 2 Nautical Miles visibility (V = 2M). Read off the luminous range on the vertical scale against the point so obtained. It should read approx. 4 Nautical Miles.

Table 17. IALA Conversion Table for Luminous Intensity and Nominal Daytime Range

Luminous intensity	Nominal range (rounded)	Luminous intensity	Nominal range (rounded)
kilocandelas (10^3 cd)	**Nautical Miles (NM)**	**Megacandelas (10^6 cd)**	**Nautical Miles (NM)**
1 – 12.0	1	1.02 – 1.82	7
12.1 – 45.3	2	1.83 – 3.16	8
45.4 – 119	3	3.17 – 5.32	9
120 – 267	4	5.33 – 8.78	10
268 – 538	5	8.79 – 14.2	11
539 – 1010	6	14.3 – 22.6	12
		22.7 – 35.6	13
		35.7 – 55.5	14
		55.6 – 85.6	15
		85.7 – 130	16
		131 – 198	17

3.8.6.6 METEOROLOGICAL OPTICAL RANGE

This is the distance through the atmosphere that is required for 95% attenuation in the luminous flux of a collimated beam of light using a source colour temperature of 2700ºK.

The meteorological optical range is related to the atmospheric transmissivity by the formula:

$$V = d\,\frac{\log 0.05}{\log T} \text{ or } T = 0.05^{\frac{d}{V}}$$

Where:

V = meteorological optical range (Nautical Miles)
d = distance (Nautical Miles)
T = atmospheric transmissivity

It is often convenient to simplify the above expression by giving the distance term a value of one, such that:

$T = 0.05^{\frac{1}{V}}$ or $T^V = 0.05$

3.8.6.7 VISUAL RANGE

This is the maximum distance at which the contrast of the object against its background is reduced by the atmosphere to the contrast threshold of the observer. The visual range can be enhanced if the observer uses binoculars, although the effectiveness depends on the stability of the observer's platform. Visual Range can be interpreted as the distance that a given light is seen by an observer.

3.8.6.8 LUMINOUS RANGE

This is the maximum distance at which a given light signal can be seen by the eye of the observer at a given time, as determined by the meteorological visibility prevailing at that time. It does not take into account the height of the light, observer's height of eye, or curvature of the Earth.

3.8.6.9 NOMINAL RANGE

Nominal range is the luminous range when the meteorological visibility is 10 Nautical Miles, which is equivalent to a transmission factor of T = 0.74. Nominal Range is generally the figure used in official documentation such as nautical charts, Lists of Lights, etc. Nominal range assumes that the light is observed against a dark background, free of background lighting.

3.8.7 INCREASING CONSPICUITY

This section includes information on options for increasing the conspicuity of Aids to Navigation structures.

3.8.7.1 ILLUMINATION OF STRUCTURES

Illumination of structures can provide an important AtoN function. Illumination of fixed structures is frequently called floodlighting or facade-lighting.

The purpose of structure illumination is to assist the mariner to positively identify the object and to allow estimation of distance and relative position to the object. Illumination can be direct or indirect and can be used on structures, signs and daymarks and is considered complimentary to the main Aid to Navigation light.

> Refer to IALA publication:
> - Guideline G1061 - Light Applications - Illumination of Structures

3.8.7.2 RETROREFLECTING MATERIALS

The use of retroreflecting material for Aids to Navigation has a widespread use in Scandinavian and other high latitude countries. With narrow and complicated waters and fairways, including ice condition and long and dark nights during wintertime, retroreflecting material is a cheap and effective way to obtain a high level of night-time conspicuity.

The use of retroreflecting material for Aids to Navigation, particularly in the case of unlighted aids, whereby the projection of a light (which may range from a hand-held spotlight to a powerful searchlight), allows an Aid to Navigation to be more easily located and sometimes identified.

> Refer to IALA publications:
> - Recommendation R0106 – Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System
> - Guideline 1145 - Application of Retroreflecting material on AtoN

3.9 LIGHT SOURCES

There are a variety of light sources currently used in Aid to Navigation applications, however due to developments in Light Emitting Diode (LED) technology LEDs are now widely used. Table 18 compares the performance and other characteristics of various light sources.

Table 18. Light source performance and other characteristics

Light source	Max lifetime hours	Max Lumen/Watt	Flashable?
Filament lamp	2000	16	Yes
Tungsten Halogen	4000	25	Yes
Metal Halide	20,000	120	No
LED	100,000	140	Yes
Low Pressure Sodium	10,000	150	No
Xenon	3,000	40	No

3.9.1 LIGHT EMITTING DIODE (LED)

3.9.1.1 COLOURED LED

Light Emitting Diodes are electronic semiconductor devices that produce near monochromatic light. The semiconductor junction is encapsulated in a clear plastic housing that usually incorporates a lens. Several LEDs may be grouped together in a cluster, or an array, to provide a light source of the required size and intensity with in-built redundancy. LEDs operate from a low voltage DC supply. Correct operation depends on accurate control of the supply current. LED marine lanterns are sometimes reported as having intense colours and ranges longer than the current IALA calculation method would suggest. IALA is currently investigating this.

3.9.1.2 WHITE LED

A semiconductor junction emitting blue/violet light is encapsulated with an integral phosphor such that both blue and broad band yellow light are emitted together to form a near white light.

Typical Use:

- Lighted beacons on buoys and other short and medium range AtoN, but longer range LED lanterns are increasingly available in the market;
- Range lights consisting of flat arrays of LEDs or single high power LEDs; and
- Signs and signals formed by arrays of LEDs in the shape of letters, numerals, signs etc.

Technical data:

- Power: Single LED: 1 milliwatt to over 32 Watts, Cluster LED: 1 to 60 Watts or higher
- Efficiency: Luminous Efficacy of LEDs is improving steadily.
- Lifetime: 100,000 hours

Advantages:

- Very long life (if input power and temperature are carefully controlled) and hence low whole life costs;
- Life is so long that lampchangers are not considered necessary;
- High luminous efficiency in red and green;
- Light produced in saturated signal colours therefore coloured filters not needed;
- Mechanically robust when compared with conventional lamps;
- Light switching times are very fast;
- Relatively cool operation; and
- Easy to cluster LEDs, providing built-in redundancy.

Disadvantages:

- Complex electronic control needed to achieve long life and high performance;
- Generally difficult to match to existing optics;
- Luminous efficiency decreases slowly with life;
- White LEDs will be very inefficient with red and green filters; and
- LED life can be severely reduced if input power and temperature are not carefully controlled.

Safety:

- No special hazard.

Disposal:

- Consult local and national disposal regulations.

Operating lifetime will depend on the LED junction operating temperature and operating environment.

Detailed information on light sources and their associated operational considerations, lifetime, reliability, operating costs and power consumption are covered in the following IALA Guidelines.

Refer to IALA publications:

- Guideline G1043 - Light Sources Used in Visual AtoN
- Guideline G1048 – LED technologies and their use in Signal Lights

3.10 INTEGRATED POWER SYSTEM LANTERNS

An Integrated Power System Lantern (IPSL) is a single unit that includes a photovoltaic power source plus a lens focussed LED light source together with other functionality. An IPSL has application advantages for certain situations. By incorporating modern technologies, they can be small, durable, reliable, cost effective and fully self-contained. Technological advances in light emitting diodes (LEDs), photovoltaics (Solar Panels) and batteries complement each other and facilitate a compact lantern. In order to operate efficiently, these lanterns must be designed for a wide range of solar conditions (i.e. sunlight available to charge the lantern) while maintaining a specified optical output over the expected operating lifetime.

The application criteria for IPSL include nominal light ranges up to 5NM; areas with good solar insolation; areas that suffer from vandalism or theft and small buoys with limited weight carrying ability. They are not suitable where high duty cycle rhythmic characters are required or in areas suffering from icing. An IPSL device houses power source, power storage, LED light source, rhythmic character coding and switching together in a single unit. IPSL can accept external programming commands and include options for GPS, synchronization, and communication modules.

Refer to IALA publication:

- Guideline G1064 - Integrated Power Systems Lantern (Solar LED lanterns)

Figure 18. IPSL: Integrated Power Systems Lantern (Solar LED lanterns)

3.11 AUDIBLE SIGNALS

The following provides a brief overview of audible AtoN signals, more detailed information is provided by referring to the following IALA publications.

Refer to IALA publications:

- Recommendation R0109 - Calculation of the Range of a Sound Signal
- Guideline G1090 – The Use of Audible Signals
- IALA Model Course C2004-1 - Aids to Navigation Technician Level 2 – Sound Signals

Nominal Range Audible AtoN signal range is calculated as nominal and is expressed in Nautical Miles. The nominal range is defined by a probability of 90% of hearing the signal when subjected to a noise as defined in IALA Guideline G1090. Specific ranges cited in the above paragraphs refer to the nominal range calculation.

Hazard Warning It has been IALA policy since 1985 that audible signals, also referred to as sound signals, should only be used as a hazard warning. These hazards refer to certain man-made structures such as offshore structures, renewable energy infrastructure, bridges, breakwaters, and isolated AtoN. The Competent Authority shall determine whether a hazard requires an audible signal and the level of reduced visibility per year that justifies its installation (e.g. 10 days of visibility under 1 Nautical Mile per year).

Where provided, audible signals for navigational hazards should have a nominal range of at least 1 Nautical Mile. In addition, Competent Authorities may require a backup audible signal of a reduced range (these do not necessarily need to be separate units); 0.5 Nautical Mile nominal range is considered adequate for these backup audible signals.

Augmentation of Floating Aids to Navigation Audible signals may also be used to augment buoys, both lighted and unlighted, to enhance their effectiveness to the mariner in reduced visibility. Audible signals on buoys are most often powered by the motion of the sea and include bells, gongs, and whistles. Buoys may also be fitted with electronic horns. Audible signals on buoys should be used to warn mariners of a particular hazard, such as proximity to shoals, rocks or other hazards; or to alert the mariner to a change in navigational requirements, such as the entrance to a restricted channel. Where electronic audible signals are used to augment buoys, they should have a nominal range of 0.25 to 0.5 Nautical Miles.

3.12 OTHER AIDS TO NAVIGATION

3.12.1 OTHER MARKS

Other Marks are visual marks, intended to aid navigation as information to mariners, not necessarily regarding channel limits or obstructions.

3.12.2 LEADING LINES/RANGES TRANSITS / LEADING (RANGE) LINES

Figure 19. Margaree Harbour Range Lights – Nova Scotia – Canada

A transit is defined as the alignment of two or more marks. A Leading (or Range) light is a specialised application of a transit.

A simple transit can be used to:

- Provide a turning reference;
- Define a clearing line for the limits of safe navigation; and
- Provide a distance mark along a waterway.

3.12.3 LEADING LINES

A leading line is an Aid to Navigation system that comprises two separated structures with marks or lights that, when viewed from the centreline or deepest route along a straight section of channel, are aligned.

In a two-station leading line, the structures lie along an extension of the centreline of the nominated channel. The rear structure must have a greater elevation than the front structure to enable both marks or lights to be viewed simultaneously.

A leading line provides a vessel with a heading reference and a visual indication of the size and direction of any cross-track error.

3.12.3.1 PURPOSES OF LEADING LINES

A leading line may be used to:

- indicate the centreline of a straight section of a navigable channel;
- indicate to deep draught vessels the deepest part of the waterway;

- indicate the navigable channel where fixed and floating Aids to Navigation are not available or do not satisfy the accuracy requirements for safe navigation;
- define a safe approach bearing to a harbour or river entrance, particularly where there are cross currents; and/or
- separate two-way traffic (i.e. when passing a bridge).

3.12.3.2 DESIGN CONSIDERATIONS FOR LEADING LINES

A well-designed leading line will enable the type and size of vessels that typically use the channel to:

- Identify the marks or lights when the ship is at the inner and outer sections of the channel and readily detect cross track position errors from the centreline of the channel;
- Detect cross track position errors with sufficient sensitivity that the channel can be utilised without abrupt changes to the vessel's heading and speed;
- Observe both lights together, by selection of leading light character rhythms that appropriately overlap in their free running condition. In some situations it may be preferable to provide additional equipment to synchronise the light characters; and
- Observe the lights in all ambient conditions for which they are designed to be used without glare. If lights are to be used for both day and night operations light intensities will need to be varied.

The characters of rhythmic leading lights should be selected so that the front and rear lights, in their free running states, can generally be observed together.

In some situations it may be preferable to provide additional equipment to synchronise the light characters. If lights are to be used both day and night, the light intensities should be adapted for each situation to avoid glare at night. Radar transponders (RACONs) may be used as leading line markers.

Refer to IALA publications:

- Recommendation R0112 - Leading Lights (includes excel program)
- Guideline G1023 - Design of Leading Lines

3.12.4 SECTOR LIGHTS

A sector light is an Aid to Navigation that displays different colours and/or rhythms over designated arcs. A common means of creating a sector is to fit a coloured filter in front of the main light. However, sector lights with LED light sources are being introduced to the market thereby reducing the need for filters as they produce the coloured light. A sector can also be produced by filtering or by using a secondary light (or several lights) on the same structure. The secondary light can take any of the following forms:

- Range (directional) light;
- Beacon with a coloured lens, masked to achieve the sector angle;

- Beacon fitted with internal or external filter panels;
- Beacon or beacons with different coloured light sources, masked to achieve the sector angle; and/or
- Precision Direction Light.

The limits or boundaries of a sector are not always precisely cut off due to the characteristics of the light source, fading of colours or changing rhythms between adjacent sectors.

For a beacon fitted with coloured filter panels, the reason for the lack of a precise transition at the sector boundary is readily apparent from Figure 21 which shows the light source, lens and filter geometry. The transition zone is defined by an "angle of uncertainty". A similar geometry exists with multiple coloured beacons and masking

Bearings, directions of leading (range) lines and limits of sectors should always be stated in terms of the bearings that would be seen by the mariner. Bearings may carry a suffix 'TBS" or True Bearing from Seaward as confirmation.

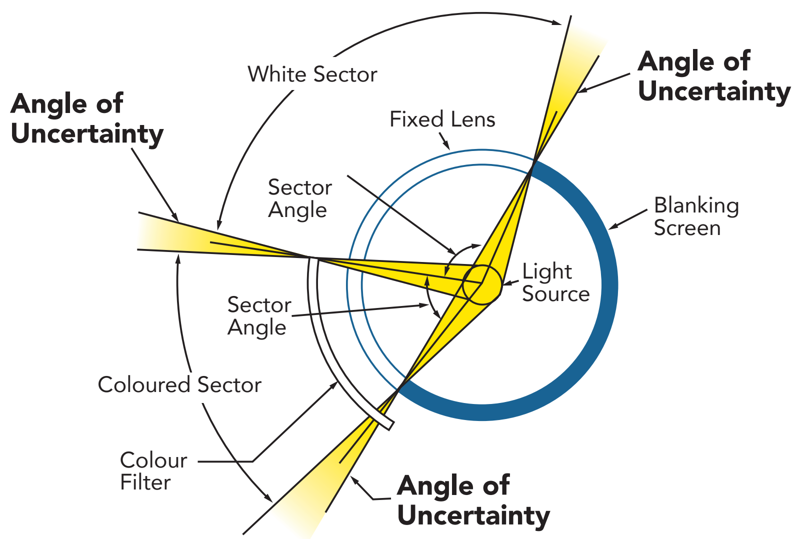


Figure 20. Angle of Uncertainty

It can also be noted that:

- the observed angle of uncertainty is generally less than the geometric angle due to the relative intensities of sector colours (i.e. colour mixing) as the observer passes through the transition zone;
- if space on the Aid to Navigation structure is not a limiting factor, it is usually possible to achieve an angle of uncertainty of around 0.25° with this type of sector arrangement;
- the angle of uncertainty can be reduced by decreasing the physical width of the light source or by increasing the radial distance to the coloured filter; and
- in situations where the main light has a large projected area, such as a rotating lens or reflector array, it is generally preferable to use a separate sector light rather than installing a coloured filter in front of the main light.

From time to time specialised sector lights have been developed to exhibit different rhythms over different sector bearings. This capability is found in some Precision Direction Lights (PDL).

A PDL is a specialised form of sector light that can generate sharply defined sector boundaries. This feature is particularly useful for applications that require one or several narrow sectors or high precision boundaries. The PDL may use a white light source with coloured filter, but newer designs are utilising LED and possibly laser as a light source. A PDL may also be known by the trade name of PEL light.

PDL sector lights are very precise, allowing a complete colour change at a sector boundary to occur over an angle of less than 1 minute of arc in most models.

3.12.4.1 APPLICATIONS

Figure 21. LED Sector Projector Light – Photo courtesy of Cybernetica AS/ Sabik

The design of sector lights can be a complex task. The process should be carried out with reference to an accurate chart of the area. In some cases good local knowledge is also required.

A sector light may indicate one or more of the following:

- boundaries of a navigable waterway;
- change of course position;
- shoals, banks, etc.;
- an area or position (eg.an anchorage);
- the deepest part of a waterway; and/or
- position checks for floating aids.

A PDL allows for further applications that include the ability to:

- produce narrow sectors with an angle of uncertainty down to approximately one minute of arc;
- define the central zone of a channel;
- accurately mark one side of a straight channel (a pair of PDLs can cover the permutations of converging, diverging and parallel channels); and/or
- define different rhythms over adjacent sectors.

3.12.4.2 EXAMPLES

Some examples of sector lights applications are illustrated in Figure 23 and Figure 24.

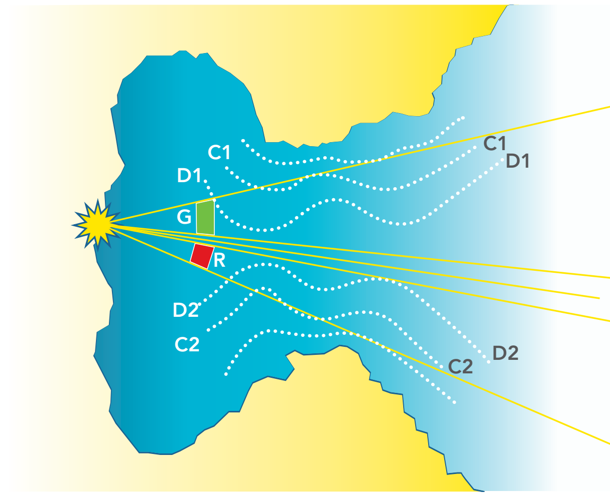


Figure 22. Sector Light Application

Figure 23 follows the IALA Maritime Buoyage System colour convention for Region A ('red to port when approaching the aid from seaward'). The white sector should, if possible, be wide enough to provide a margin of safety for a vessel that inadvertently leaves the white sector. Curves C and D indicate depth contours or limiting dangers that dictate the boundaries of sectors.

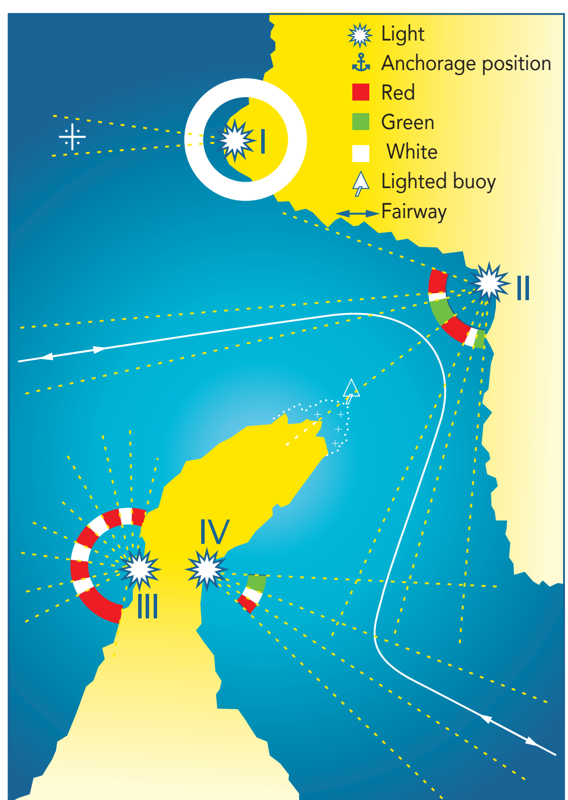


Figure 23. Various Applications for Sector Lights

Sector Lights can be used in various applications. The function of each light in Figure 24 is described below:

- Light I is a coastal white light with a red sector indicating a danger.
- Light II is a sector light obscured over the shore, with two white sectors indicating a safe channel. When sailing towards the sector light it shows red to port and green to starboard following the IALA Maritime Buoyage System colour convention for Region A and vice versa for Region B. The boundary between the red and the green sector also indicates the position of a buoy.
- Light III is a sector light with a red light and 4 white sectors indicating four anchorage positions. It is obscured over the shore.
- Light IV is a sector light with a white sector indicating a safe channel.

3.12.4.3 DESIGN CONSIDERATIONS FOR SECTOR LIGHTS

Where a single sector light defines a navigable channel the following points should be considered:

Lateral Position: There is no reference of the vessel's lateral position within the channel until a sector boundary is reached. This may cause a problem in channels subject to a strong cross current. For vessels with local knowledge, the zones defined by the angle of uncertainty can sometimes provide a useful guide to the vessel's proximity to a sector boundary;

Safety Margin: Where practicable, there should be a margin of safety between the sector boundary and adjacent hazards. If an appropriate safety margin cannot be achieved within the sector boundary, the hazards could be marked separately.

Angle of Uncertainty: Zones defined by the angle of uncertainty should be considered an additional margin of safety over the actual sector boundary.

Vessel Size: The design process for a sector light needs to consider the draught and manoeuvrability of the largest vessels likely to utilise the sector, how quickly they can respond once they cross a sector boundary and the situations that may develop when other vessels are in the vicinity.

Lights and Filters: When using an incandescent light source the sector design should take account of the spectral distribution of the light source and the proportion of this light transmitted through the filter material as this will affect the resultant colour and intensity of the light exhibited. The process should also check for potential glare problems.

Flash Characteristic: The period of the light flash should be selected to provide ample time for a mariner to recognise the transitional phases that occur at the sector boundary.

Sector Colours: A white light is normally the first preference for a lighthouse or beacon. If a single coloured sector is added, red is often used. If a white sector light is used to mark a navigation channel, coloured sectors may be used either side of the white to indicate the lateral limits. In such cases it is common practice to use red and green sectors that follow the convention of the IALA Maritime Buoyage System.

Lamp Position and Type: The position of the light source within the optical system is critical for the correct alignment of the sectors. When replacing lamps or using lampchangers, it is important to ensure that the light source (e.g. filament) position is identical. If a lampchanger is incorporated, the sector system should be designed for the widest light source used in the lampchanger.

Note that the importance of correct lamp position and type relates to all light sources within a lens.

Refer to IALA publication:

- Guideline G1041 - Sector Lights

3.13 FIXED AIDS TO NAVIGATION - LIGHTHOUSES AND BEACONS

The IALA International Dictionary of Aids to Marine Navigation defines a beacon as "a fixed artificial navigation mark" that can be recognised by its shape, colour, pattern, topmark or light character, or a combination of these. While this functional definition includes lighthouses and other fixed Aids to Navigation, the terms lighthouse and beacon are used more specifically to indicate importance and size.

Lighthouse: A lighthouse is generally considered to be a large conspicuous structure (visual mark) on land, close to the shoreline or in the water that:

- acts as a daymark; and
- provides a platform generally for higher range marine AtoN signal lights.

Other Aids to Navigation such as audible signals and radio Aids to Navigation may be located on or near the lighthouse. A lighthouse may be a staffed or an automated facility, although the staffing of lighthouses is becoming less common. An automated lighthouse may be remotely monitored and in some cases remotely controlled.

Beacon: Visual characteristics of a beacon are often defined by daymarks, topmarks, and by numbers. A marine signalling light, if fitted, would generally be of a lower range than lighthouses. In navigable channels a pile beacon may be used as an alternative to a buoy.

3.13.1 PURPOSE OF LIGHTHOUSES AND BEACONS

A lighthouse or beacon may perform one or more of the following navigational functions:

- mark a landfall position;
- mark an obstruction or a danger;
- indicate the lateral limits of a channel or navigable waterway;
- indicate a turning point or a junction in a waterway;
- mark the entrance of a Traffic Separation Scheme (TSS);
- form part of a leading (range) line;
- mark an area; and
- provide a reference for mariners to take a bearing or line of position (LOP).

Other purposes for which a lighthouse can be used include:

- base for AIS equipment; racon; radar; radionavigation systems; reference station for GNSS;
- coast-watch or coastguard functions;
- VTS functions;
- base for audible (fog) signals;
- collection of meteorological and oceanographic data;
- radio and telecommunication facilities; and
- tourist facilities.

3.14 FLOATING AIDS TO NAVIGATION - MINOR AND MAJOR

A floating Aid to Navigation serves a similar purpose to a beacon or a lighthouse. However the floating Aid to Navigation is normally associated with locations where:

- it would be impractical due to water depth, seabed conditions or cost to establish a fixed aid;
- the hazard shifts over time (e.g. sand banks, an unstable wreck, etc.);
- the aid is at high risk of damage or loss from ice flows or ship impacts and as a consequence is treated as expendable;
- a temporary mark is required; and/or
- a seasonal mark is required.

3.14.1 BUOYS

Buoys are defined as minor floating aids and whilst it is normal that they are lighted, there are instances where no light is installed. These types of Aids to Navigation are specifically covered by the IALA Maritime Buoyage System and tend to have circular hull forms up to 3 m diameter. Buoys may be fitted with sound signals. Most buoys are equipped with a radar reflector.

In addition, due to limitations of the structure, the following may apply:

- where lights are exhibited, they are usually solar or primary battery powered. There are gas powered buoys still in operation, although gas powered buoys are not normally used for new installations;
- where lights are exhibited, due to power limitations and/or operational requirements, light ranges are typically restricted to 1 to 5 Nautical Miles; although longer ranges may be required in some applications;
- additional services are restricted due to limited power on a buoy, but RACONs, AIS AtoN, and remote monitoring units are sometimes installed in addition to a light; and
- audible signals are used on buoys in some countries.

3.14.2 LIGHT VESSELS, LIGHTSHIPS AND LARGE NAVIGATIONAL BUOYS

Light Vessels, Lightships, and Large Navigational Buoys (LNB), sometimes referred to as LANBYs, are defined as major floating aids and may carry one or more of: RACONs, AIS AtoN or audible signals in addition to the Aid to Navigation light. A light vessel may also display a white riding light to signify a vessel at anchor. All major floating aids should be equipped with a radar reflector and a monitoring unit.

Major Aids to Navigation:

- generally have high operating costs;
- are only deployed at critical locations;
- are often assigned an aid availability target that is higher than for a buoy; and
- are not specifically covered by the IALA Maritime Buoyage System.

Refer to IALA publications:

- Recommendation R0104 - 'Off Station' Signals for Major Floating Aids to Navigation
- Guideline G1006 - Plastic Buoys
- Guideline G1099 - Hydrostatic Design of Buoys
- Guideline G1015 - Painting AtoN Buoys
- Guideline G1098 – On the Application of AIS - AIS on Buoys

Figure 24. Examples of Floating Aids

3.14.3 PERFORMANCE CRITERIA FOR FLOATING AIDS

Availability is defined as the probability that an Aid to Navigation or a system of Aids to Navigation, as defined by the Competent Authority, is performing its specified function at any randomly chosen time. This is expressed as a percentage of total time that an Aid to

Navigation or a system of Aids to Navigation should be performing their specified function.

The availability objective assigned to floating Aids to Navigation conforming to the IALA Maritime Buoyage System should also apply to the topmark.

Fuller details on availability are discussed in a later section on Availability Objectives.

3.14.4 TECHNICAL CONSIDERATIONS FOR FLOATING AIDS TO NAVIGATION

There are various technical considerations that should be taken into account, including: cost, design factors, positioning, water conditions and markings.

3.14.5 COST

The cost of establishing a floating aid at a given location will generally be less than for a fixed structure. The cost difference increases with increasing water depth and exposure to wind and waves.

In contrast, the maintenance cost of floating Aids to Navigation tends to be high relative to the capital value. This has caused many authorities to critically examine the potential for savings through design changes, use of alternative materials, alternate service deliveries (contracting out) and amending maintenance practices, generally with the aim of extending maintenance intervals.

Where a Competent Authority operates a large number of floating aids, it may become practicable to operate a dedicated buoy tender vessel with specialised equipment to minimise buoy change-out times and to improve occupational safety.

> Refer to IALA publication:
>
> - Guideline 1047 – Cost Comparison Methodology of Buoy Technologies

3.14.6 FLOATING AID DESIGN

The process of designing a buoy to meet specific requirements is a specialised task. It involves, but is not limited to:

- defining the operational performance characteristics;
- defining the equipment, power requirements and power source(s);
- defining the type and capabilities of the vessels that will be used to service the buoy;
- selecting the initial type proportions and mooring for the buoy;
- integrating of equipment and power supply;
- considering of the maintenance requirements;
- identifying deployment and recovery techniques;
- protecting equipment from damage;
- providing the ability to rectify faults without having to lift the buoy;

- determining the buoy response to the wave, wind and current conditions at the site(s); and
- optimising the design.

Refer to IALA publications:

- Recommendation R1001 – IALA Maritime Buoyage System (and supporting guidelines)
- Recommendation R0106 - Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System
- Guideline G1006 - Plastic Buoys
- Guideline G1039 – Designing Solar Power Systems for AtoN
- Guideline GG1039-1 – Solar Power System Calculation Tool (Excel file)
- Guideline G1039-2 – Handbook for Meteorological Data for IALA Solar Power System Calculation Tool
- Guideline G1036 - Environmental Considerations in Aids to Navigation Engineering
- Guideline G1043 - Light Sources Used in Visual Aids to Navigation
- Guideline G1094 - Daymarks for Aids to Navigation
- Guideline G1099 - The Hydrostatic Design of Buoys
- IALA Model Course C2001-2 - Aids to Navigation Technician Level 2 - Introduction to Aids to Navigation Buoyage

3.14.7 MOORING DESIGN

The mooring system for a floating Aid to Navigation is the sum of the components that keep the aid within a nominated area. These components have to withstand the forces of wind, wave, current and ice on the floating aid and drag on the mooring line.

The basic assumptions made are that the:

- mooring system tethered to the buoys sinker is usually tangential to the sea bed;
- buoy axis is vertical under the most common conditions of current and wind;
- ratio of the breaking stress of the mooring system to the calculated stress is not less than 5 under the most unfavourable conditions of current and wind; and
- reserve buoyancy of the fully equipped floating aid is greater than the combined loads of current and wind under the most unfavourable conditions.

An approximate value for the minimum length of a chain mooring is given by the following formula:

L_{min} = 3H for depths less than 50 metres;
L_{min} = 2H for depths greater than 50 metres.

Where: L = Length of mooring line (m)
H = Depth of water (m)

All moorings should be designed as per Guideline G1066 – Design of Floating Aids to Navigation moorings.

> Refer to IALA publications:
> - Recommendation R0107 - Moorings for Floating Aids to Navigation
> - Guideline G1066 - Design of Floating Aids to Navigation Moorings
> - IALA Model Course C2001-4 - Aids to Navigation Technician Level 2 - Buoy Moorings

3.14.8 POSITIONING OF FLOATING AIDS

The charted position of a floating aid defines the nominal (or true) position for the anchor. With most floating aids there is potential for the mooring anchor/sinker to be moved off-station during storms or due to ice flows. Additionally, positional errors can occur while laying the anchors/sinkers.

The positioning process for anchors/sinkers should utilise radionavigation or radio-positioning aids. The use of GNSS position fixing is increasingly seen as the preferred method. The benefits of GNSS position fixing are: convenience, accuracy and repeatability. A buoy tender using GNSS can generally be brought to within 10 metres of the nominal buoy position at the time of releasing the anchor/sinker.

If the anchor/sinker is allowed to free-fall, its final resting position will depend on the prevailing current, water depth, shape of the anchor/sinker and the nature of the seabed. Controlling the decent of the anchor/sinker may serve to improve the positional accuracy of the buoy.

3.14.9 MARKINGS AND TOPMARKS

Markings

Floating Aids to Navigation are often identified by names, abbreviations of names, letters and/or numbers. Authorities should ensure that the actual marking is identical to the List of Lights reference and the charted marking.

Topmarks

The type, colour and arrangement of topmarks on a buoy are shown in the IALA Maritime Buoyage System. Topmarks should conform to Guideline 1094 on Daymarks for Aids to Navigation.

> Refer to IALA publications:
> - Guideline G1094 - Daymarks for Aids to Navigation

CHAPTER 4

TECHNICAL ASPECTS OF ATON

4.1 POWER SUPPLIES

4.1.1 TYPES OF POWER SUPPLIES AND ENERGY SOURCES

A wide range of power systems and energy sources have been used or contemplated for operating lighthouses and floating aids. Everything from clockwork to radio-active isotopes have been used. Some of the more common types are listed in Table 19.

Table 19. Power Sources for Operating Lighted Aids to Navigation

Electric Energy Sources & Storage	Non-Electric Energy Sources
Utilit1 generated electricity	Acetylene
Photovoltaic solar modules	Propane
Diesel and petrol engine driven generators	Butane
Primary & secondary battery cells	Kerosene
Wind generators	
Wave activated generators	
Fuel cells using alcohol or hydrogen	
Thermo-nuclear devices	

The most popular method of powering AtoN is by utility generated electricity if it is available. If it is not available then by solar powered photovoltaic cells charging secondary battery cells.

IALA has created a series of documents to assist in the selection of electrical power systems for Aids to Navigation.

Refer to IALA publications:

- Guideline G1067-0 - Selection of Power Systems for Aids to Navigation and Associated Equipment
- Guideline G1067-1 - Total Electrical Loads of AtoN
- Guideline G1067-2 - Power Sources
- Guideline G1067-3 - Electrical Energy Storage for AtoN
- Guideline G1039 - Designing solar power systems for AtoN (also Solar Sizing Program & handbook)

Refer also to:

- Applicable national standards for the safe handling of gases.

4.2 ELECTRIC - RENEWABLE ENERGY SOURCES

4.2.1 SOLAR POWER (PHOTOVOLTAIC CELL)

Solar power is an ideal power source for many Aids to Navigation applications. It offers:

- a power source with no moving parts;
- no maintenance requirements other than being cleaned;
- slight deterioration in power output over its life;
- low life-cycle costs; and
- enhanced electrical safety on extra low voltage systems.

When used to power a light, the battery recharging process is separated from the operation of the light source so that the recharge voltage can be optimized without detriment to the light's operation.

Potential difficulties associated with solar power are:

- AtoN exposed to icing conditions are perhaps the only applications unsuited to the use of solar modules.

4.2.1.1 PHOTOVOLTAIC TECHNOLOGIES

The three common technologies employed in the manufacture of silicon based solar modules are listed in Table 20.

Table 20. Silicon Solar Cell Technology

Technology	Comments
Monocrystalline Cells	Made from a thin slice cut from a single large crystal of silicon, usually produced as a circular section rod. Generally have the highest efficiency of the three technologies. If circular wafers of silicon are used, the module fill factor is significantly less than with polycrystalline cells. It is now usual for the cells to be trimmed to approximate a square.
Polycrystalline Cells	Made from a thin slice cut from a large cast billet of silicon comprising many crystals. Are slightly less efficient than the mono crystalline cell but they can be shaped to completely fill the module.
Thin Film Technology	Made by depositing thin films or layers of silicon directly onto a glass or stainless steel substrate. The cell has a lower efficiency than either of other technologies but can be multi-layered for enhanced performance. Problems have been found with the lifetime of these cells.

In addition to the silicon cell technologies, there are two optional module configurations based on the numbers of series connected cells. The standard module normally has 36 cells in series to give an open circuit voltage of around 20 volts. This is ideal to charge a 12V battery or two modules connected in series to charge a 24V battery. Modules or pairs of modules are usually connected in parallel to provide the required charging current (power requirement). For all battery charging applications, a voltage (charge) regulator is considered essential.

Modern developments in electronics have allowed voltage (charge) regulators to be developed that use maximum power point tracking (MPPT). This ensures that they charge the solar module at an operating level to obtain the maximum power, for any given level of irradiance. This operating level is independent of the battery charge voltage level. This technology can gain up to 30% more output than would be achieved with conventional voltage regulators and can ensure effective solar charging in locations where high ambient temperature exists. It should be noted that better output is achieved when the panel voltage is at least twice that of the nominal battery voltage.

4.2.1.2 MODULE OR ARRAY ORIENTATION

In the northern hemisphere, solar modules are normally installed facing south and inclined at an angle to the horizontal that is related to the latitude of the site such that they can maximise output during the period of the year when irradiance is least. Installation is vice versa for the southern hemisphere. The inclination angle for solar modules is often optimised for the particular site as part of the sizing calculations.

One of the main problems experienced with solar powered Aids to Navigation has been bird fouling. Numerous, innovative solutions have been trialled, generally with mixed results. Generally solar modules mounted at an angle or vertically benefit from self-washing from rain.

The cost of additional solar modules needed for a vertical installation may be largely off-set by the savings that result from simplifying the mounting arrangements or framework.

Refer to IALA publications:

- Guideline G1170 – Solar Modules for a Marine Environment
- Guideline G1039 - Designing solar power systems for AtoN (also Solar Sizing Program & handbook)
- IALA Model Course C2002-3 - Aids to Navigation Technician Level 2 – Photovoltaic (Solar Panel) Systems and Maintenance

4.2.2 WIND ENERGY

4.2.2.1 AIDS TO NAVIGATION APPLICATIONS

Wind generators (or wind turbines) have been used by a number of IALA Members to charge batteries for powering their Aids to Navigation.

The most popular type are horizontal axis machines with a two or more bladed (propeller type) turbine.

The maintenance requirements arising from the number of moving parts of a wind generator and the susceptibility to storm damage, has limited the wide use of wind generators and they are not considered as reliable as photovoltaic cells but can provide a good back up power supply where solar irradiance is poor due to latitude, fog or high-power requirements.

4.2.2.2 INSTALLATIONS

Wind generator installations at Aids to Navigation sites pose a number of problems:

- wind generators tend to require considerable and on-going maintenance if operated in turbulent air flows;
- if the wind generator is installed on a separate mast some distance from the Aid to Navigation, consideration has to be given to the inherent cable voltage drop;
- operation of wind generators to power Aids to Navigation needs to take into account the impact it may have on any environmental factors associated with the location, such as flora and fauna, especially bird mortality.

Refer to IALA publication:

- IALA Model Course C2002-4 - Aids to Navigation Technician Level 2 - Wind Generators

4.2.3 WAVE ENERGY

The wave activated generator (WAG) was developed in Japan and has been successfully used to power lighted buoys. The interaction between the buoy and wave motions acts as a simple air pump that is used to drive an air turbine and electricity generator. The WAG is mounted on an extension of a hollow tail tube that passes through the buoy hull. With wave heights of 0.5 metres, the power output can be as much as 100 watts. WAGs have limited life and current systems suffer from excessive wear.

Site conditions will determine the rate at which the tail tube of the buoy accumulates weed and other forms of fouling. These aspects need to be taken into consideration when developing the maintenance regime for the WAG. WAGs can also be very susceptible to storm damage.

4.3 BATTERIES

4.3.1 PRIMARY BATTERY CELLS

Primary battery (non-rechargeable) cells provide electrical energy by a non-reversible chemical process. They were used in large numbers up until the 1980's to operate buoys and automatic beacon lights. The usage of primary cells has declined sharply since commercial solar power (photovoltaic) modules have become available. A related issue that hastened the decline of primary cells was the tightening environmental standards in a number of countries that required cells to be recovered from site for disposal in an approved manner. Disposal compliance costs together with occupational health and safety aspects for the frequent replacement of primary cells have worked in favour of converting to renewable energy sources. They remain a useful power source where solar irradiance is low or where theft is prevalent as they are less attractive to steal.

4.3.1.1 ZINC-AIR CELL

The zinc-air primary cell was a common energy source for operating buoy and beacon applications. The cell uses a porous carbon block to supply oxygen from the air through an alkaline electrolyte to oxidize a zinc anode. Individual primary cells have an open circuit voltage of about 1.2 volts and can supply 1000 to 2000 Ahr at a maximum rate of about 1 ampere.

4.3.1.2 SEALED ALKALINE BATTERY

This type is commonly used in some countries, and has the benefits of good low temperature performance.

4.3.2 SECONDARY (RECHARGEABLE) BATTERY CELLS

There are various types of rechargeable battery technologies applied to Aids to Navigation – lead acid, Lithium-ion and nickel alkaline (usually cadmium) being the most common.

Recently, new secondary battery technologies have appeared, including nickel-metal-hydride (Ni-MH) batteries, lithium-iron phosphate (LiFePO4) batteries and lead crystal batteries. These batteries offer good weight and a greater cycle life for a given capacity but come at a premium cost.

Battery technology is a rapidly developing field with power density to size and weight improving all the time. This technology is being driven by the automotive sector and will undoubtedly migrate into AtoN applications.

4.3.2.1 LEAD ACID

The lead acid type is the generally preferred secondary battery cell because of its lower cost, good energy exchange efficiency (95% vs. 80%) and general reliability and availability. The basic form of this battery uses a lead dioxide positive plate and a pure lead negative plate immersed in an electrolyte of dilute sulphuric acid.

Lead acid batteries are available in two main designs, flooded lead acid and valve regulated (VRLA). The VRLA comes in two types, absorbed glass-mat (that use a micro glass separator system to absorb the electrolyte), and gel batteries, that use a jellified electrolyte and polymeric separators to prevent short circuits between the positive and negative plates.

4.3.2.2 NICKEL ALKALINE BATTERY

These batteries use compounds of nickel and, generally, cadmium with a solution of potassium hydroxide as the electrolyte.

Nickel-cadmium cells use perforated steel plates that hold the active material, mainly a nickel hydroxide in the positive plate and a cadmium compound in the negative plate. The construction is generally referred to as a "pocket plate" cell.

A range of valve regulated nickel-cadmium batteries that use a recombination process now complements the traditional flooded cell design. Under normal float charging conditions any gas produced is recombined within the battery and water loss is negligible. However if the battery is overcharged it will vent but water can be added if necessary.

The nickel cadmium battery can operate in low temperatures and for a greater number of deep discharge cycles.

4.3.2.3 LITHIUM ION BATTERY

The Lithium ion battery is a fast developing technology with many established variants on the market offering proven performance, their general advantages are a high energy density with potential for yet higher capacities, they do not need conditioning when new to acquire maximum capacity, they have a relatively low self-discharge and do not require a periodic discharge to maintain performance. They are also suitable for low and high power applications.

The disadvantages of the Lithium ion battery are that they require a protection circuit to maintain voltage and current within safe limits and are subject to transportation restrictions due to safety concerns. They are expensive to manufacture and there is emerging debate about the social impact of the raw materials required to make them.

Lithium-ion is becoming much more popular with its higher power density though is more expensive to purchase.

4.3.3 BATTERY DISPOSAL

A number of countries now have standards and regulations relating to the safe and environmentally acceptable methods of disposing or recycling of batteries as well as the environmental and social impacts of acquiring battery raw materials. This should be a key factor when selecting a suitable battery for an AtoN application.

Refer to IALA publications:

- IALA Model Course C2002-1 - Aids to Navigation Technician Level 2 – DC Power Systems
- IALA Model Course C2002-2 - Aids to Navigation Technician Level 2 - Primary and Secondary Battery Maintenance

4.4 INTERNAL COMBUSTION ENGINE/GENERATORS

4.4.1 DIESEL GENERATORS

Diesel engine driven generators are often used as the primary source of electrical power where the location of an Aid to Navigation is too remote to be supplied from utility generated electricity and the power demand is high. Diesel generators are also used to provide emergency or backup power.

The generator capacity to support the operational and domestic loads of a standard lighthouse is in the region of 10kW. Smaller generators in the range of 2 to 5kW, combined with batteries and inverter-charger systems are now available to meet this variable load. This arrangement can be more suitable and flexible if the load is likely to be light for extended periods, with short periods of heavy loads.

The requirement for diesel generators in lighthouses is decreasing as a result of:

- reduction in electrical load for the Aids to Navigation;
- improved efficiency of renewable energy sources; and
- reduction or elimination of domestic loads.

4.4.2 PETROL ENGINE GENERATORS

Petrol engine generators are a useful source of power for maintenance work, but are less common in permanent installations due to:

- fuel storage and transportation safety issues;
- maintenance requirements on the spark-ignition system; and
- petrol engine generally being regarded as less durable than a diesel.

Refer to IALA publication:

- IALA Model Course C2002-5 - Aids to Navigation Technician Level 2 – Mains AC Utility Power Systems; Diesel and Petrol Generators

4.5 FUEL CELL

This is a solid-state device that uses a catalytic process to oxidise fuel to generate an electrical current. A common fuel is hydrogen, or hydrogen rich fuels such as Methanol. It can be thought of as a continuously fed battery, ideally preferring a constant load.

The fuel cell is now commercially available, although the technology is still being further developed. Fuel cells offer a reliable and environmentally friendly energy source for supplementing AtoN power supplies.

Fuel cells do present an environmentally suitable solution, as methanol can be manufactured from sustainable sources and the by-products of the generation of electrical energy is heat and water. There is some interest in the use of fuel cells in hybrid power systems with wind energy or solar energy.

4.6 ELECTRICAL LOADS AND LIGHTNING PROTECTION

4.6.1 ELECTRICAL LOADS

IALA has prepared a standard methodology for calculating and defining the load profile of electric Aids to Navigation.

Some of the loads that this methodology covers are:

- light source and optic equipment;
- RACONs;
- AIS AtoN;
- audible warning signals;
- visibility detectors;
- monitoring and telemetry systems; and
- charge controllers.

Refer to IALA publication:

- Guideline 1067-1 - Total Electrical Loads of AtoN

4.6.2 LIGHTNING PROTECTION

To ensure reliable operation of Aids to Navigation during electrical storm events, both physical lightning protection and zoned surge protection should be considered. IALA has produced guidelines to describe practical methods for the design, installation, inspection and testing of lightning protection systems. The information covers lightning protection for Aids to Navigation structures, equipment and systems.

Refer to IALA publications:

- Guideline G1012 - Protection of Lighthouses and other AtoN against damage from Lightning
- IALA Model Course C2002-6 - Aids to Navigation Technician Level 2 – Lightning Protection

4.7 NON-ELECTRIC ENERGY SOURCES

Historically, non-electric energy sources were frequently used in Aids to Navigation, however, the use of electric energy sources is currently the norm and is the recommended practice for new installations. There are various non-electric power supplies, the main types used in Aids to Navigation are acetylene and propane.

4.7.1 ACETYLENE

Acetylene (C2H2) has been used to operate lights on buoys and unattended Aids to Navigation for many years. Acetylene can explode if compressed directly but can be safely contained under low pressure in special cylinders when dissolved in acetone. The manufacture of acetylene, standards for the cylinders and the filling process are usually controlled by government regulations.

Acetylene has been a convenient and reliable energy source for Aids to Navigation. However appropriate attention should be given to:

- safe handling of cylinders;
- the broad range of explosive mixtures with air (between 3 and 82% acetylene);
- the purity of the gas; and
- minimizing leaks in pipe work and fittings.

4.7.2 PROPANE

Propane gas (C3H8) has been used as an alternative fuel to acetylene, particularly in buoys. Although propane has to be consumed in an incandescent mantle burner to provide a white light, it has several advantages over acetylene:

- it is a by-product in oil refining processes;
- its abundance and low cost;
- propane liquefies at a pressure of 6 atmospheres at 17ºC, and can be transported in low weight and low cost gas bottles;
- propane will maintain a positive pressure down to -40ºC and will not freeze in conditions likely to be encountered at sea;
- placing the bottles in pockets in the buoy or by filling it directly into the body of an buoy, or pressure vessel;
- the comparable containers are the 20 kg propane bottle with gross weight of 48 kg and the 7,000 litre acetylene cylinder, weighing 105 kg;
- furthermore the cost of the propane bottle is only about one third of that of a acetylene cylinder;
- propane is a particularly safe gas, as only some 6% of all its possible mixtures with air are explosive against a figure of 80% for acetylene; and
- burns cleanly without the risk of sooting that can occur with a poorly adjusted acetylene burner.

Refer to:

- Applicable national standards for the safe handling of gases.

4.8 STRUCTURES AND MATERIALS

4.8.1 STRUCTURAL DESIGN OF FIXED ATON

The complexity of fixed AtoN design depends on various factors including focal height, foundation conditions and environmental loadings. It is important that the design complies with the regulations, codes, standards and guidelines, applicable for the geographical region and that these are incorporated into AtoN design and construction. It is particularly important in countries with extreme climatic conditions such as cyclones, extreme waves, or seismic induced activity, that AtoN are designed for relevant environmental conditions.

The height of the AtoN determines the maximum achievable geometrical range and is a key design parameter that influences the design of the AtoN structural elements.

Key design information can include:

- AtoN manager's requirements of functional and operational performance;
- Design codes relevant to the region;
- Basis of Design (BOD) document to confirm the designer's parameters and values; and
- Design output documents including specification, design drawings, risk assessments, etc.

Irrespective of the global location, the regional design codes often cover common themes to assist designers, and compliance with such standards is generally considered to be best practice.

Regional standards often include the following areas:

- Principles for design;
- Loadings;
- Structural steelwork;
- Reinforced concrete;
- Geotechnics;
- Piling; and
- Timber.

Structural engineering design should be carried out by suitably qualified and competent engineers who are duly registered with an appropriate professional engineering body.

AtoN structures can be made of many different construction materials or a composite of materials. All structures and buildings deteriorate with age so methods to slow down or stop the deterioration are an important part of any AtoN maintenance regime.

Refer to IALA publications:

- Guideline G1006 - Plastic buoys
- Guideline G1015 - Painting Aids to Navigation buoys
- Guideline G1036 - Environmental Management in Aids to Navigation
- Guideline G1077 - Maintenance of Aids to Navigation
- Guideline G1091 - Bird Deterrents and Bird Fouling Solutions
- Guideline G1109 - Theft and Vandalism Deterrents
- Guideline G1165 – Sustainable Structural Design of Marine Aids to Navigation
- Guideline G1175 – AtoN Equipment and Structures Exposed to Extreme Environmental Conditions
- IALA Model Course C2011-1 – Aids to Navigation Technician Level 2 - Marine Aids to Navigation Structures: Materials, Corrosion and Protection
- IALA Model Course C2011-2 - Aids to Navigation Technician Level 2 – Preservation of Structures

4.8.2 TYPES OF MATERIALS

There are seven main types of material used in the construction of AtoN structures or parts of that structure. These types fall under the categories of material with their use identified in Table 21.

Table 21. Materials used in the construction of AtoN structures

Material	Construction use
Timber (wood)	Lighthouses, beacons, towers and piles
Masonry (bricks/stone) and concrete	Lighthouses, beacons and towers
Ferrous metals (iron-based e.g. steel)	Lighthouses, beacons, towers and buoys
Non-ferrous metals (e.g. aluminium)	Beacons, towers and buoys
Steel wire and rope	Guys/fasteners on beacons and piles
Glass Reinforced Plastic (GRP)	Beacons and buoys
Plastic and rubber	Buoys and fendering

4.8.3 MATERIALS AND BUILDING CONDITIONING

Building conditioning is a general term used to cover heating, ventilation, dehumidification and air conditioning of a building or structure to prevent its deterioration.

Environmental conditions at coastal sites generally feature high humidity and salt laden moisture in the air, strong winds and varied temperature extremes dependant on location. Factors influencing Building Conditioning such as the design and history of the building(s) plus materials used in construction are examined followed by methods of providing Building Conditioning.

Refer to IALA publication:

- Guideline G1077 - Maintenance of AtoN Structures

Table 22. Materials and Threats including Corrosion

	Material	Threats
1	Timber and metal fasteners	Fungal rot, marine borers and insects, impact
2	Quarry stone and masonry (brickwork)	Gravity-related debris release; salt; sand; crustaceans; vegetation
3	Reinforced concrete	Problems with internal reinforcement
4	Metal – ferrous (iron based)	Electro-chemical corrosion, abrasion and wear
5	Metal - non- ferrous (aluminium etc.) structures and components	Galvanic corrosion; dissimilar metals; microbiological (bird droppings – guano)
6	Glass Reinforced Plastic	Impact, sun, ice
7	Plastics and rubber	

4.8.3.1 FERROUS METAL –THREATS AND PROTECTION

Of all the materials used at AtoN sites, the most obvious one that will suffer rapid deterioration if not protected is ferrous metal. The main threat is rusting of the metal, especially when exposed to salt air, while the main protection comprises painting on a regular basis.

While stainless steel can be used where metalwork is required, it is considerably more expensive than mild steel and requires special fabrication techniques. However, the difference in price is negligible for nuts, bolts and washers and these should always be used, especially on buoys. Using cheaper mild steel bolts (which may fail through rusting) may result in the loss of equipment from a buoy and therefore failure of the AtoN. The different protection methods for various materials is shown in Table 23.

Table 23. Protection of Structures

Material	Protection Methods
Timber	Wood preservative, pitch (tar)
Quarry stone and Masonry	Removal of vegetation; humidity control; replacement of mortar between bricks and stone ("pointing")
Concrete	Removal of vegetation; humidity control; replacement of mortar between bricks and stone ("pointing")
Ferrous metals	Cathodic protection; impressed current; bird deterrents; paint
Non-ferrous metals	Dissimilar metal isolators; bird deterrents; paint
Steel wire and rope (ferrous)	Greases
Glass Reinforced Plastic	None
Plastic and rubber	None (but rubber fenders around plastic buoys can be effective)

As already noted, of all the above protection methods, the most important one which needs to be repeated periodically is the painting of metal structures and components. This is especially the case for any metalwork (handrails, access ladders etc.) which are exposed to the harsh saline conditions experienced by many AtoN deployed in or near the sea.

4.9 EXTREME ENVIRONMENTAL CONDITIONS

AtoN operation is affected by external forces, including environmental conditions. If these conditions become extreme, they can adversely affect expected AtoN operation, reducing the operating performance and its (useful) lifespan. There may also be a requirement to increase and/or modify maintenance.

Refer to IALA publication:

- Guideline G1175 - AtoN Equipment and Structures Exposed to Extreme Environmental Conditions

4.9.1 WIND AND WAVES

Wind has particular impact on AtoN performance since, depending on its speed and direction, it generates a "swell effect" which modifies the behaviour of hydrostatic buoys. Wind has direct impact on the loads imposed on the mooring system, the buoy position, vertical divergence of the lantern, and the mooring chain deterioration rate

For fixed AtoN wind loads are also a significant consideration in the design process and material selection.

4.9.2 GEOMORPHOLOGY

Sandbank accretion or the collapse of the coast associated with significant sedimentation and erosion processes, typical of river behaviour, can affect the stability of the fixed AtoN installed on the coastline. Positioning of AtoN in these areas should be carefully considered and a maintenance plan for proactive relocation of floating and fixed AtoN, where necessary and due to morphological changes is required.

Specifically, in buoy mooring systems, abrasion from sediment movement generally leads to a higher rate of wear in the mooring system.

4.9.3 TEMPERATURE

Extremely low or high temperatures can affect the performance of the external equipment; it can shorten the expected useful life of the equipment and make certain materials fragile, compromising the ingress protection index (IP##) provided by the manufacturer or even the structural integrity.

Other examples include high and low temperatures affecting the useful life of batteries and freezing temperatures affecting moving parts, for example, the wind generators.

Refer to IALA publication:

- Guideline G1108 – Challenges of providing AtoN services in polar regions
- Guideline G1136 – Providing AtoN services in extremely hot and humid conditions

4.9.4 ULTRAVIOLET (UV) LIGHT

High ultraviolet (UV) light levels in prolonged periods of strong sunlight can cause degradation of material properties including colour retention, plastic lenses, steel and plastic buoys, structures, coating systems and electrical/electronic equipment and fixtures. UV exposure can also be a significant risk to workers and requires careful management and specific mitigation control.

Maintenance of lanterns should include inspection to re-verify the light range as this can be affected by high UV.

4.9.5 WATER CONDITIONS

Salinity, sulphate content, temperature, dissolved oxygen, and pH can all separately, and in combination, influence the corrosion of steel AtoN. Generally, higher temperatures as experienced in tropical waters, and higher levels of dissolved oxygen will combine to increase corrosive mechanisms.

The corrosion of steel in seawater is an electrochemical process, which is exacerbated by increased salinity. pH of the water also has a variable efect on corrosion. pH of waters can be locally affected by artificial influences such as discharges from oil refineries and chemical plants.

Accelerated low water corrosion (ALWC) of steel structures is found in certain regions. ALWC is an aggressive form of microbially influenced corrosion that may occur on steel in estuarine and marine structures. The effects are most prevalent in tidal waters and ALWC is often observed around the low water level.

Cathodic protection is a means of reducing corrosion in metallic structures and major components exposed to seawater. The system provides sacrificial anodes that corrode in place of the metal. This can reduce the rate of corrosion. AtoN structures can be painted, wrapped with a bituminous tape or sheathed in a protective jacket to minimise the contact of seawater with the structure.

Mobile sediments made up of abrasive sand such as basalt, can have an abrasive effect on all submerged materials including fixed, marine based AtoN foundations and floating AtoN mooring chains. Maintenance operations should gather information over time regarding the rate of corrosion of steel chains and other mooring components. This allows the material thickness to be sized accordingly, allowing for sacrificial loss of material.

4.10 VEGETATION

Vegetation is one threat to AtoN structures as well as the AtoN itself that often tends to go unheeded. Trees and bushes tend to grow in height and width plus roots can find their way into the foundations or walls of a structure leading to deterioration of the structure.

Very warm seawater, associated with extremely hot and humid climates, can cause the rapid growth of dense and sometimes destructive marine organisms on both buoy moorings and the foundations of fixed structures. This can increase the frequency and cost of maintenance, can adversely impact buoyancy and accelerate corrosion.

A more urgent threat is that the AtoN can be obscured by vegetation. Remote monitoring will show that the light is working but the mariner cannot see it.

There may also be a Health and Safety aspect if visiting personnel have to cut through vegetation to access the AtoN or have to walk over vegetation which may be slippery.

Vegetation clearing should always be included in planned maintenance.

4.11 BIRDS; GUANO (BIRD DROPPINGS) AND DETERRENTS

Bird fouling (by Guano or bird droppings) of an AtoN site has detrimental effects on its availability and reliability, on workplace health and safety and in general, results in accelerated structural deterioration.

There are a number of detrimental effects on an AtoN due to bird droppings:

- Excessive guano coverage on lanterns or optics can cause partial or full obstruction of the light source;
- Excessive guano coverage of solar panels reduces the active area of the panel;
- Guano coverage on lighthouses or other daymarks can cause a change in the colour; and
- Guano is highly caustic and can increase corrosion on AtoN structures, fittings, components as well as harming electrical equipment including "sun switches".

The most effective way to mitigate against the build-up of Guano is to discourage seabirds landing and roosting, or attempting to land and roost, on an AtoN site. This can be achieved by fitting and maintaining bird spikes; wires or other measures such as anti-graffiti paint. In areas where this does not fully deter the sea-birds, the areas should be washed regularly as part of maintenance procedures.

Refer to IALA publication:

- Guideline G1091 - Bird Deterrents and Bird Fouling Solutions

4.12 THEFT AND VANDALISM

Theft can be defined as the act of stealing or the wrongful taking and carrying away of any element, component or piece of equipment from an AtoN site.

Vandalism can be defined as an action involving deliberate destruction or damage to an AtoN. Unreported damage to floating or fixed AtoN caused by passing vessels may also be considered in this category.

Theft and vandalism may vary greatly but generally result in a decrease in the availability of an AtoN, in some cases to the point where the AtoN is no longer operational or functional, which raises serious implications for shipping safety and protection of the marine environment.

Effectively implemented, theft and vandalism deterrents can be a valuable tool for cost saving and improving AtoN availability. Therefore, site security should always be included in AtoN design.

Refer to IALA publication:

- Guideline G1109 - Theft and Vandalism Deterrents
- IALA Model Course C2011-1 – Aids to Navigation Technician Level 1- Marine Aids to Navigation Structures: Materials, Corrosion and Protection
- IALA Model Course C2022-2 – Aids to Navigation Technician Level 1- Preservation of structures

Detailed guidance is provided to Technicians through the following model courses:

- IALA Model Course C2011-1 – Aids to Navigation Technician Level 1- Marine Aids to Navigation Structures: Materials, Corrosion and Protection
- IALA Model Course C2022-2 – Aids to Navigation Technician Level 1- Preservation of structures

4.13 HAZARDOUS MATERIALS

4.13.1 MERCURY

A number of historic lighthouses still utilise rotating glass lenses and mercury float pedestals. This was a clever method for providing a heavy lens with an almost frictionless bearing so that it could be turned by a clockwork mechanism. However, given the toxic and corrosive properties of mercury, the following information may assist Competent Authorities to implement appropriate safety procedures.

The mercury float pedestal for a first-order rotating lens contains about 13 litres of mercury. Quantities of mercury may also be found in the electrical slip-ring units in rotating lamp array lighting equipment, some tilt-action switches, high current contact breakers, manometers and thermometers. It is being phased out by some Authorities now due to the tighter legislative restrictions about its use and transport.

4.13.1.1 PHYSICAL PROPERTIES

Mercury is a heavy metal that has the unusual property of remaining liquid at normal temperatures (above – 38°C).

4.13.1.2 SPILL RISK

The mercury in a lighthouse optic system does not present a significant hazard, unless personnel come into contact with "uncontained" mercury as a result of accidental spills. Such events are usually the result of a mishap during maintenance work, or as a result of a natural disaster such as an earth tremor that displaces mercury from its containment bath. If spilt, the mercury can enter cracks in floors, and is readily absorbed into porous surfaces such as concrete, masonry and timber. When broken into small globules or droplets, the surface area and vaporisation rate rises rapidly. Minute droplets will adhere readily to dust and can form particles that can be inhaled.

Mercury is a corrosive substance if it comes into contact with metals such as zinc and aluminium.

4.13.1.3 OCCUPATIONAL HAZARD

The occupational hazard associated with mercury relates to:

Vapour Inhalation: Some vaporization from a free mercury surface will occur at normal room temperature and this is the most likely first contact that lighthouse personnel will have with mercury. Unless the mercury vapour levels have been measured, personnel are unlikely to be aware of the hazard. If the workspace around lighthouse equipment containing mercury is not well ventilated, the concentration levels can rise above recommended limits and there is potential for mercury poisoning. Mercury vapour is heavier than air and in still air will tend to concentrate in low parts of the workspace. Well-designed ventilation will allow such concentrations to disperse.

Ingestion: This can lead to acute mercurial poisoning.

Skin Absorption: Mercury is not easily absorbed through the skin.

Precautions: It is essential for the Authority to have detailed and strictly managed working procedures for all personnel working with, or in close proximity to mercury.

Staff must be trained in these work procedures and regularly medically monitored to ensure that they do not become contaminated with mercury.

The working procedures must follow national health and safety regulations and should be written by an expert in this field.

For work on optics the procedure will cover emptying, cleaning and re-filling the optic bath. Clean-up procedures will detail methods to recover all visible particles of mercury and the use of chemicals to neutralise smaller spills.

Personal Protective Equipment (PPE) must be supplied that is specifically designed for use with mercury. This will include overalls, gloves, overshoes, respirator and eye protection. Procedures for the safe storage and disposal of this equipment must be in place.

A mercury vapour meter must be available to monitor the working environment and procedures in place for regular testing and calibration.

4.13.1.4 TRANSPORTATION

Mercury is a hazardous substance and the relevant national and international regulations must be followed with regard to the type of container to be used, the packaging of this container for transport and the marking of this packaging.

Both IMO and the International Air Transport Association (IATA) have regulations covering the transportation of mercury.

4.13.2 PAINTS

Aids to Navigation authorities use a significant quantity and variety of paints and related surfacing materials. There is potential for hazardous situations to arise and for environmental pollution. For example:

- storage of inflammable paints and solvents;
- during surface preparation and removal of paint prior to repainting;
- contact with vapours and solvents during application; and/or
- clean-up and waste disposal.

4.13.2.1 LEAD AND ISOCYANATE

Lead and Isocyanate based paints have been widely used in the past, but are now restricted or prohibited in some countries. Authorities maintaining older lighthouses are likely to be faced, at some stage, with having to remove lead based paint and disposing of the waste.

Members are encouraged to assess the risks and to adopt appropriate measures to safeguard maintenance personnel and the environment.

4.13.2.2 ANTIFOULING COATINGS

Antifouling paints contain biocides and are applied to vessels and floating Aids to Navigation to reduce the accumulation of marine organisms. For service vessels the antifouling paint assists to minimise fuel consumption.

On buoys and lightvessels the build-up of marine growth is not particularly detrimental. In view of the concentration of these types of Aids to Navigation in port approaches and internal waterways, less toxic paint systems may be preferred to minimise environmental pollution.

A particular group of antifouling paints using Tributyltin (TBT) has been banned from use. For further information, consult the International Convention on the Control of Harmful Antifouling Systems on Ships, published by the International Maritime Organization (IMO).

4.13.3 ASBESTOS

Asbestos is a carcinogenic substance that was (and in some areas, still is) used in the construction of buildings. Asbestos has excellent properties and with its resistance to fire, mould, rot and electrical insulation made it a material of choice through the early 20th century and many Authorities now have a regulatory duty to manage the safe retention or disposal of all asbestos in their estate. Asbestos is highly dangerous to anyone breathing in the microscopic fibres and it can take many years for the symptoms to become evident to the exposed person in the form of Mesothelioma which is generally fatal. Asbestos must be treated with care and relevant regulatory guidance on handling and disposing of it must be followed.

4.14 STEEL, PLASTIC AND COMPOSITE BUOYS

Many older buoys are made of steel and can weigh a few tons. There may still be some in use by AtoN authorities which are over 100 years old, testament to them being very robust. However, they do need periodic maintenance especially repainting. A dedicated Lighthouse Tender is usually required to deploy these steel buoys due to their weight.

Refer to IALA publications:

- IALA Model Course C2001-3 –Aids to Navigation Technician Level 2 – Buoy Handling and Safe Working Practices
- IALA Model Course C2001-4 –Aids to Navigation Technician Level 2 – Buoy Moorings
- IALA Model Course C2001-5 –Aids to Navigation Technician Level 2 – Buoy Cleaning
- IALA Model Course C2001-7 –Aids to Navigation Technician Level 2 – Maintenance of Plastic Buoys
- IALA Model Course C2001-8 –Aids to Navigation Technician Level 2 – Maintenance of Steel Buoys

More modern buoys are often plastic and much lighter so deployment is often easier. However, they may not be as robust as steel buoys and may suffer from colour fading. They usually have some composite steelwork for ballast, mooring eyes etc.

4.15 ENVIRONMENTAL IMPACT

IALA encourages all members to deliver AtoN services in environmentally responsible manner in line with its motto *"Successful Voyages, Sustainable Planet"*.

Aids to Navigation play a critical role in protecting the environment by preventing maritime disasters that could have potentially catastrophic ecological consequences at sea and on shore. However, the Aids to Navigation equipment and activities themselves can create significant environmental damage through pollution, waste generation, and the disruption of ecosystems. It is essential to minimise these negative impacts so that the benefits of Aids to Navigation are not outweighed by unintended harm to the environment, and to eliminate the potential for pollution and waste of the Earth's limited resources.

International standard ISO 14001 provides a framework for environmentally responsible service delivery.

IALA is committed to align its activities and that of its members with the 17 United Nations Sustainability Goals.

Refer to IALA publications:

- Recommendation R1004 - Sustainability in the provision of Marine Aids to Navigation
- Guideline G1036 – Environmental Management in Aids to Navigation
- Guideline G1137 – AtoN management in protected areas

4.16 PRESERVATION OF HISTORIC AIDS TO NAVIGATION

The IALA Advisory Panel on the Preservation of Lighthouses, Aids to Navigation, and Related Equipment of Historic Interest (PHL) was established by the IALA Council in 1996 in response to membership interest in the heritage value of lighthouses. In 2002, this Panel became part of the IALA Committee on Engineering, Environment, and Preservation (EEP) now AtoN Engineering and Sustainability (ENG) Committee. This work was supported further by the Incheon Declaration signed at the IALA General Assembly in Incheon, Republic of Korea in 2018.

Objectives of the Incheon Declaration are to:

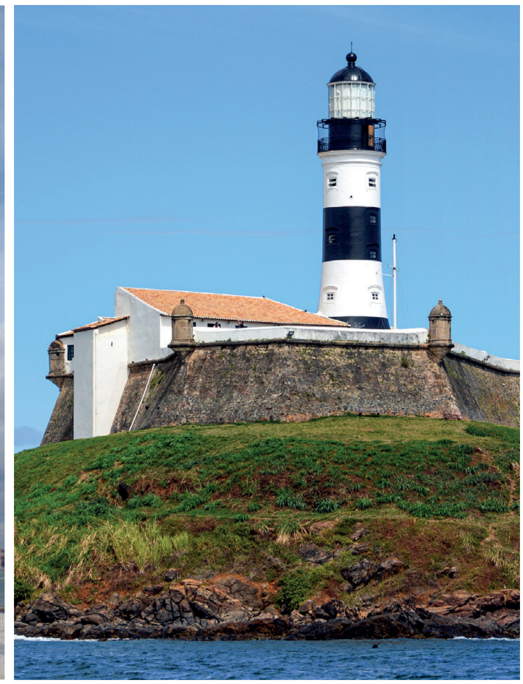
- Raise awareness of the need for the conservation and sustainable management of historical lighthouses as cultural heritage;
- Recognize that the significance of historical lighthouses extends beyond the navigational and architectural value to include maritime culture and history, social history, environmental aspects and that there is great value in documenting, researching and interpreting these for the benefit and inspiration of future generations;
- Conserve and develop historical lighthouse sites and associated maritime cultural spaces in order that people of all ages and backgrounds can appreciate and enjoy their respective nations' maritime contribution and culture;
- Support IALA's efforts to further sustainable lighthouse management through knowledge sharing, training and international cooperation projects; which will strengthen the capacity of coastal nations to manage their lighthouses in a coordinated manner and will encourage good conservation practices and foster interest in lighthouse heritage globally; and
- Note the launch of the Incheon Project designed for IALA and its members to provide assistance for developing nations through education, training, technology transfer and capacity building as well as contributing to the advancement of global Aids to Navigation by means of various programmes and management in efficient and coordinated manner as an important legacy of the 19th IALA Conference in Incheon, Korea in 2018.

Examples of work accomplished to date:

- the creation of the format for an IALA database for recording details of historic lighthouses;
- the development of The Lighthouse of the Year award, based on international nominations and awarded on World AtoN day each year;

- planning of a Heritage Workshop to share ideas and experiences on Lighthouse heritage;
- the approval of Recommendation R1005 on Conserving the build heritage of Lighthouses and other AtoN; and
- publication of the Complimentary Lighthouse Use Manual.

Restoring a Heritage Lighthouse - Photo courtesy of Instituto Hidrografico (Portugal)



Santo Antônio da Barra Lighthouse - IALA Heritage Lighthouse of The Year - Photo by Tunisio Alves Filho

Refer to IALA publications:

- Lighthouse Conservation Manual
- Recommendation R1005 - Conserving the Build Heritage of Lighthouses and other Aids to Navigation
- Guideline G1093 - Management of Surplus Lighthouse Property
- Guideline G1063 – Agreement for complimentary use of lighthouse property
- Guideline G1049 - Use of Modern Light Sources in Traditional Lighthouse Optics
- Guideline G1074 – Branding and marketing of historical lighthouses
- Guideline G1075 - Business Plan for the Complementary Use of a Historic Lighthouse
- Guideline G1080 - Selection and Display of Heritage Artefacts
- IALA Model Course C2003-4 - Aids to Navigation Technician Level 2 – Maintenance of Mercury Rotating Optics

4.16.1 LENS SIZE AND TERMINOLOGY

Information on terminology for historical glass lens systems and the typical amount of mercury held in mercury float pedestals (for rotating lens systems) is provided in Table 24.

Table 24. Terminology for Historical Glass Lens Systems and Associated Quantities of Mercury

Description	Focal distance	Typical Quantity of Mercury For Mercury Float Pedestals	
	mm	kilograms	litres
Hyper-radial	1330		
Meso-radial	1125		
First order	920	175	12.9
Second order	700	126	9.3
Third order	500	105	7.7
Small third order	375	96	7.0
Fourth order	250		
Fifth order	187.5		
Sixth order	150		

Refer to IALA publications:

- Lighthouse Conservation Manual
- Guideline G1049 - Use of Modern Light Sources in Traditional Lighthouse Optics
- IALA Model Course C2003-3 - Aids to Navigation Technician Level 2 – Rotating Beacons and Classic Lenses
- IALA Model Course C2003-4 - Aids to Navigation Technician Level 2 – Maintenance of Mercury Rotating Optics

CHAPTER 5

MANAGEMENT OF ATON

5.1 MAINTENANCE OF AtoN EQUIPMENT AND SYSTEMS

5.1.1 GUIDING PRINCIPLES FOR MAINTENANCE

Maintenance is required to ensure that AtoN equipment and systems continue to perform at the levels required by mariners to safely navigate the World's waterways.

A maintenance system should be adopted to ensure that AtoN assets deliver the desired performance while minimizing Total Cost of Ownership. This performance is normally defined as the level of availability required. Depending on the criticality or category of the AtoN, the same AtoN type might require different maintenance approaches to deliver the required availability outcome in a given location.

The following guiding principles may assist Authorities in developing their overall AtoN maintenance strategy.

5.1.1.1 MINIMISE THE COST OF OWNERSHIP

AtoN service providers are accountable to their stakeholders for the provision of a reliable AtoN network that meets international standards for a reasonable cost. Maintenance strategies adopted by authorities should seek to reduce the total cost of ownership of their AtoN.

5.1.1.2 DESIGN FOR MAINTENANCE

The majority of maintenance costs are determined by the design of the equipment itself. Maintenance costs are usually the most significant component of the total ownership cost of the equipment or system; therefore, it is crucial to account for long-term maintenance and logistics support early on in the design process.

The goal should be to reduce the need for maintenance, extend the time interval between maintenance periods, enable maintenance upon the evidence of need (condition-based maintenance), facilitate the maintenance task by the servicing personnel, and reduce the "logistics footprint" required for maintenance and support.

All of these factors will contribute to reducing the total ownership cost over the entire life cycle of the equipment or system.

5.1.2 IMPROVING EFFICIENCY

Authorities have been able to achieve significant cost savings by a number of means:

5.1.2.1 AUTOMATION

Automation can reduce the work load of light-keepers or allow for de-staffing altogether. This reduces:

- staff costs;
- power consumption;

- the frequency of stores replenishment;
- commitments on infrastructure such as houses or accommodation facilities, water and fuel storage and in some cases jetties and cargo handling equipment;
- the requirements for station vehicles and equipment.

5.1.2.2 EQUIPMENT

It may be possible to use more reliable equipment, better system designs, with “fail safe” or “fail by stages” features coupled with:

- longer intervals between maintenance visits;
- a review of maintenance management procedures.

In addition, it may be possible to use standardised equipment to simplify spare part management.

This could also:

- benefit the purchasing power of the organisation;
- reduce the range of skills required by maintenance staff (and thus the training burden);
- give more flexibility in the choice of basic qualification when recruiting maintenance staff; and
- provide more opportunity to understand the inherent deficiencies in particular pieces of equipment and for remedial actions to be implemented.

5.1.2.3 MATERIALS

By introducing low maintenance materials such as high density polyethylene, Glass Reinforced Plastic (GRP), stainless steel, etc., it may be possible to reduce maintenance requirements and time on site. This may also decrease the number of ship-day requirements and reduce the need for construction (or structural maintenance) skills.

5.1.2.4 REMOTE CONTROL AND MONITORING

Remote control and monitoring (RCMS) of distant or isolated Aids to Navigation can save on the cost of responding to what is later found to be a false outage report. It can also allow for analysis of Aids to Navigation systems using risk analysis / risk management techniques that may produce cost savings from a rearrangement and or reduction of the Aids to Navigation within a nominated area. Correctly applied, the monitoring will enable staff to travel to site with the required spares to repair an issue without a return visit. The provision of a control function enables a remote reset which may avoid the need for a site visit.

Refer to IALA publication:

- Guideline 1008 - Remote control and monitoring of AtoN

5.1.3 MAINTENANCE TRENDS

IALA Conference papers, IALA Bulletin articles and feedback from IALA Members demonstrate an increasing trend in the extension of maintenance intervals for Aids to Navigation sites. The ongoing striving for greater efficiency in the delivery of Aids to Navigation reflected in measures such as the automation of lighthouses has seen alteration of the maintenance intervals from a daily activity to significantly less frequent regimes.

The optimal maintenance interval for Aids to Navigation is determined from a consideration of national priorities and the Authority's administrative, technical and environmental constraints.

Where cost efficiency and effectiveness is the driving issue, Authorities are:

- using automation, alternative structural materials, more durable coatings and renewable power supplies to contain or reduce costs;
- addressing the potential for new technology to reduce acquisition and operating costs;
- extend maintenance intervals;
- remote maintenance by design and remote control to avoid additional visits; and
- reviewing transport service options.

Extension of maintenance intervals at sites exposed to more extreme weather conditions may result in more extensive maintenance works at each visit which may offset some of the cost savings achieved through extension of service intervals.

5.1.4 MAINTENANCE INTERVALS

The maintenance intervals for Aids to Navigation vary from daily in the case of a manned lighthouse to perhaps five years for a lighted buoy.

It is difficult to establish a clear view of the appropriate maintenance interval as this will vary from authority to authority. This will vary on the quality of the installation, the prevailing environmental conditions and the performance of the AtoN.

Advances in self-contained beacons, lamps, solar power supplies and remote monitoring make it relatively easy for a well-designed system on a fixed structure to achieve annual or biannual servicing intervals. Systems that can be maintained in multiples of a year can be set up to take advantage of the times of the year that minimise the weather risk on work schedules and disturbance to flora and fauna.

However, a balance has to be found since longer maintenance intervals affect the authority's knowledge of storm damage, general deterioration to Aids to Navigation, and control over vegetation growth and dirty glazing that could increase the risk of obscuration and fire damage etc. There may also be a detrimental effect on the detailed level of knowledge held by maintenance personnel.

Refer to IALA publications:

- Recommendation R1018 - Responsible design, operation and maintenance in the provision of Marine Aids to Navigation
- Guideline 1077 - Maintenance of Aids to Navigation
- Guideline G1151 – The maintenance of AtoN structure
- IALA Model Courses – Technician Training Level 2 – Model course overview (Various Maintenance courses)

5.2 AVAILABILITY OBJECTIVES

The measurement of 'Availability' provides a quantitative measure of performance or service to the mariner.

Availability is a useful indicator of the level of service provided by individual or defined groups of Aids to Navigation because it is representative of all the considerations, within the control of the Competent Authority, that have gone into providing and maintaining the facility.

These include:

- quality assurance procedures;
- design and systems engineering;
- procurement;
- installation and commissioning;
- maintenance procedures;
- failure response; and
- logistics.

To obtain a true representation of Availability, it is necessary to measure the long-term performance of an Aid to Navigation. To achieve this, data should be collected on all AtoN outages/failures as well as times to repair. t is recommended that the calculations should use a time interval greater than 2 years.

Refer to IALA publication:

- Guideline G1140 – Commissioning of AtoN equipment and systems

5.2.1 CALCULATION OF AVAILABILITY

The availability of an Aid to Navigation may be calculated using one of the following equations, and is usually expressed as a percentage:

$$\text{Availability} = \frac{(\text{MTBF})}{(\text{MTBF} + \text{MTTR})} \text{ or } \frac{\text{Up time}}{\text{Total time}} \text{ or } \frac{(\text{Total time - Downtime})}{\text{Total time}}$$

MTBF = Mean Time Between Failures

MTTR = Mean Time To Repair

5.2.2 DEFINITION AND COMMENTS ON TERMS

Reliability

Ability of a device or system to satisfy the requirements of its intended use within defined limits, and for a stated period of time.

Availability

The probability that an AtoN or system of AtoN, as defined by the Competent Authority, is performing its specified function at any randomly chosen time. This is expressed as a percentage of the total time that an AtoN or system of AtoN should be performing their specified function.

The percentage of time that an aid, or system of aids, is performing a required function under stated conditions. Non-availability can be caused by scheduled and/or unscheduled interruptions.

- Signal availability. The availability of a radio signal in a specified coverage area.
- System availability. The availability of a system to a user, including signal availability and the performance of the user's receiver.

It is also defined within IMO resolution A.1046(27) for WWRNS as "The system is considered to be available when it provides the required integrity for the given accuracy level". IALA generally uses the term as a historical measure of the percentage of time that an Aid to Navigation was performing its specified function. The non-availability can be caused by scheduled and/or unscheduled interruptions.

Continuity

The probability that, assuming a fault-free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area.

For example, if a GNSS station is functioning correctly when a vessel is about to make its approach into a port, the continuity factor is the probability that the GNSS service will not be interrupted in the time it takes the vessel to reach its berth. As for GNSS systems, IALA has proposed that the time interval for continuity calculations be based on a 15-minute time frame in accordance with IMO A.1046(27) for WWRNS.

Redundancy

The existence of more than one means for accomplishing a given function. The various means of accomplishing the function need not necessarily be identical. The concept is such that a complete failure can occur only when all means have failed.

Integrity

This is the ability to provide users with warnings within a specified time when the system should not be used for navigation.

IMO Resolution A.1046(27) for WWRNS, states that this time to alarm should be within 10 seconds.

Integrity monitoring. The process of determining whether the system performance (or individual observations) allow use for navigation purposes. Overall GNSS system integrity is described by three parameters the threshold value or alert limit, the time to alarm and the

integrity risk. The output of integrity monitoring is that individual (erroneous) observations or the output of the GNSS as a whole cannot be used for navigation.
– Internal integrity monitoring is performed aboard a craft.
– External integrity monitoring is provided by external stations.
- Integrity risk. The probability that a user will experience a position error larger than the threshold value without an alarm being raised within the specified time to alarm at any instant of time at any location in the coverage area.

Failure

This is the (unintentional) termination of the ability of a system or part of a system to perform its required function.

Mean Time Between Failures (MTBF)

This is the average time between successive failures of a system or part of a system. It is a measure of reliability. For components, such as lamps, it is usual to determine the MTBF (or life) statistically by testing a representative sample of components to destruction. As for a system such as a GNSS station, the MTBF is determined from the number of failures that have occurred within a given interval. For example; if four failures occur over a two year interval, the MTBF would be 4380 hours (i.e. =24*365*2/4).

Mean Time to Repair (MTTR)

The total corrective maintenance time divided by the total number of corrective actions during a given period of time.

This is a measure of a Competent Authority's administrative arrangements, resources and technical capability to rectify a failure. For a small port, the MTTR times might only be several hours. Meanwhile, a Competent Authority with a more distributed network of Aids to Navigation may have MTTR times equivalent to several days because of the distances and transport mobilisation limitations.

Failure Response Time

This is a sub-set of the MTTR and relates to the time it takes to be notified of a failure, to confirm the details and mobilise personnel to depart for the Aid to Navigation.

Refer to IALA publications:

- Recommendation R0130 - Categorisation and Availability Objectives for Short Range Aids to Navigation
- Guideline G1035 - Availability and Reliability of Aids to Navigation – theory and examples
- Guideline G1037 – Data collection for AtoN performance calculation

5.3 IALA CATEGORIES FOR TRADITIONAL AIDS TO NAVIGATION

IALA provides a method to categorise and calculate Aids to Navigation availabilities for both individual Aids to Navigation and systems of Aids to Navigation as shown in Table 25. IALA Recommendation O-130 does not consider other Aids to Navigation considered in the mix of Aids to Navigation such as radionavigation systems or Vessel Traffic Services (VTS).

It does provide guidance on suitable and realistic levels of operational performance for Competent Authorities to adopt.

Table 25. Availability Objectives by Category

Category	Availability Objective	Calculation period
1	99.8%	Availability Objectives are calculated over a continuous three-year period, unless otherwise specified
2	99.0%	
3	97.0%	

Category 1

An Aid to Navigation (AtoN) or system of AtoN that is considered by the Competent Authority to be of ***vital*** navigational significance. For example, lighted Aids to Navigation and RACONs that are considered essential for marking landfalls, primary routes, channels, waterways or new dangers or the protection of the marine environment.

Category 2

An AtoN or system of AtoN that is considered by the Competent Authority to be of ***important*** navigational significance. For example, it may include any lighted Aids to Navigation and RACONs that mark secondary routes and those used to supplement the marking of primary routes.

Category 3

An AtoN or system of AtoN that is considered by the Competent Authority to be of ***necessary*** navigational significance.

The Recommendation also states that the absolute minimum level of availability of an individual Aid to Navigation should be set at 95%.

The availability of a Racon is the principal measure of performance determined by IALA. In the absence of any specific considerations, IALA recommends that the availability of a Racon should be at least 99.8%.

5.4 AVAILABILITY AND CONTINUITY OF RADIONAVIGATION SERVICES

The availability objectives for Radionavigation services have been handled somewhat differently from traditional Aids to Navigation. This reflects the broader policy formulation process that includes IMO Resolution A.1046(27) on a World Wide Radionavigation System and IALA Recommendation R0121.

Refer to IALA publication:

- Recommendation R0121 - Performance and Monitoring of DGNSS Services in the Band 283.5 – 325 kHz

Recommendation R0121 retains a previous definition of availability but adds a statement about "non-availability".

Non-availability is equivalent to "down time" but as proposed includes both scheduled and/or unscheduled interruptions (i.e. preventative and corrective maintenance). The revised equation becomes:

$$\text{Availability} = \frac{(\text{MTBO})}{(\text{MTBO} + \text{MTSR})}$$

MTBO = Mean time between outages; based on a 2 year averaging period MTSR = Mean time to service restoration; based on a 2 year averaging period

If the service is available at the beginning of the operation, then the probability "P" that it is still available at a time "t" later is:

$$P = \exp\left(-\frac{t}{\text{MTBF}}\right)$$

This is the standard expression for reliability and excludes scheduled outages. It uses MTBF and assumes that planned outages will be notified.

The Continuity, or probability that the service will be available after a continuity time interval (CTI), is then:

$$C = \exp\left(-\frac{\text{CTI}}{\text{MTBF}}\right)$$

IMO uses a more elaborate definition of Continuity than that given above. It states that: *"Continuity is the probability that, assuming a fault free receiver, a user will be able to determine position with specified accuracy and is able to monitor the integrity of the determined position over the (short) time interval applicable for a particular operation within a limited part of the coverage area. This is the same definition of as 'mission reliability'"*.

If MTBF is much greater than CTI, the equation approximates to:

$$C = 1 - \left(\frac{\text{CTI}}{\text{MTBF}}\right)$$

Where:

MTBF = Mean time between failures based on a 2-year averaging period.

CTI = Continuity Time Interval – in the case of Radionavigation calculations, this is equal to 15 minutes (from A1046(27)).

There is no need to include the availability at the beginning of the time period of the operation because if there is no service, then the operation will not commence.

Example 1: Using the figures in the previous example for a system with a 2-year MTBF, the continuity over a 15 minute period is 1-(15/1,051,200), or 99.9986%.

Example 2: Using the figures in the previous example for a system with a 1000-hour MTBF, the continuity over a 15 minute period is 1-(15/60,000), or 99.9750%.

5.5 OVER AND UNDER ACHIEVEMENT

The actual availability achieved by an individual Aid to Navigation is a reflection of the quality of the logistical processes, the maintenance regime and the skill of personnel involved. There is a cost associated with prescribing a higher level of availability for a system such as an Aid to Navigation. This is irrespective of whether or not the increased availability is required by the mariner. There is also a cost associated with the maintenance of unreliable systems. The interrelationship is complex, but the objective is to find the minimum cost solution as illustrated in Figure 26.

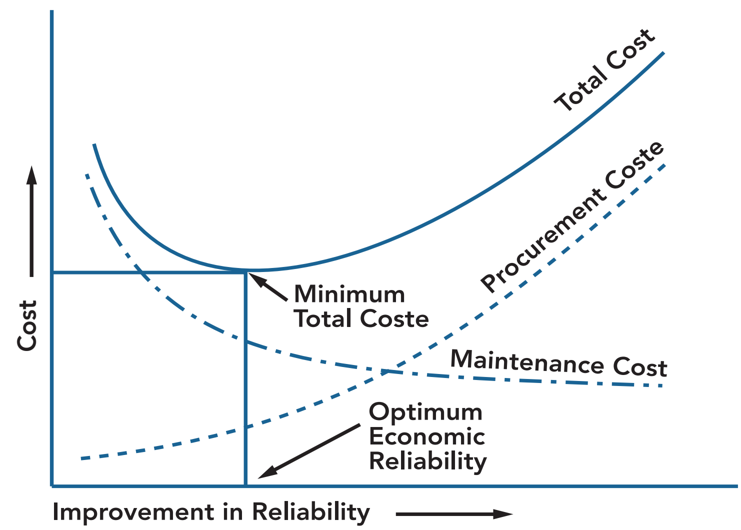


Figure 25. The Cost of Reliability

5.5.1 OVER-ENGINEERING VS. UNRELIABILITY

For a lighthouse in a remote location, the cost of time and transport to rectify equipment failures can be very high.

From this perspective:

- the one-off cost of over-engineering is generally not as expensive in the long term as the ongoing cost of attending to un-reliable equipment and/or poor system designs; and
- a conservative design approach has its merits.

If the Aid to Navigation is not achieving its availability objective, the Authority should ascertain the reasons for this and implement actions that remedy the situation. IALA has recommended that if a facility cannot achieve an availability of 95% (i.e., 50 days out per 1000 days) after reasonable endeavours, consideration should be given to withdrawing the facility (as an Aid to Navigation).

If a single Aid to Navigation within a group is performing above its availability objective, it could be due to either technical or environmental reasons. If the performance difference occurs between sites using similar equipment, and this trend has been established for some time, the Authority should investigate the reasons for the difference.

If a group of Aids to Navigation is found to be over performing for a relatively long period of time, there is an opportunity to review the maintenance practices with a view to determining the reasons, and possibly to consider extending the maintenance intervals or reducing the maintenance effort. This could lead to lower operating costs and issues relating to surplus maintenance capacity.

5.6 RISK MANAGEMENT

Dealing with "risk" is an intrinsic aspect of human existence. The establishment of the early lighthouses represented a tangible way of addressing some of the problems that arose when humans decided to venture out to sea, and then into global trade and the mass transport of people by ships.

The traditional definition of risk (R) is the probability of an unwanted event occurring (P), multiplied by the impact or consequence (C) of that event.

$$R=P*C$$

Unwanted events include deprival, loss or injury to persons, property or the environment.

Risk management is a term applied to a structured (logical and systematic) process illustrated further below.

The correct, efficient and useful result of hazard identification, assessment of risk and establishment of risk control measures, can be affected by Human Factors. The concept of Human Factors and references to relevant models is included in the IALA Guideline 1018 on Risk Management. It is recommended that organisations and persons involved in a risk assessment process have suitable knowledge in the application of Human Factors disciplines.

With the advances of e-Navigation, the mariner will be provided with additional real time information to assist with navigation. The positive impact on ship control and navigation needs to be incorporated into the formal risk assessment process. For risk control options, the continuous development of e-Navigation and man-machine interfaces may provide new possibilities. However, physical AtoN risk control measures will remain important to address the needs of all user groups.

The risk management approach works equally well for identifying the risks at a detailed or broad level. It can also address the risks from different perspectives.

Refer to IALA publications:

- Recommendation R1002 - Risk Management for Marine Aids to Navigation
- Guideline G1018 - Risk Management
- Recommendation R1009 – Disaster recovery
- Guideline G1120 – Disaster recovery

For example, if the issue is the automation and de-staffing of a lighthouse, there are likely to be different sets of risk for:

- service providers (Aids to Navigation Competent Authority, lightkeepers, etc.);

- service users (mariners); and
- external groups (politicians, local community, conservation groups, etc.).

5.6.1 IALA RISK MANAGEMENT TOOLS

IALA continuously develops its Risk Management Toolbox which includes tools that are capable of:

- ➢ assessing the risk in ports or waterways, compared with the risk level considered by Authorities and stakeholders to be acceptable. The elements that can be taken into consideration include those relating to vessel conditions, traffic conditions, navigational conditions, waterway conditions, immediate consequences and subsequent consequences;
- ➢ identifying appropriate risk control options to decrease the risk to the level considered to be acceptable. The risk control options available include improved co-ordination and planning; training; rules and procedures including enforcement; navigational, meteorological and hydrographical information; radio communications; active traffic management and waterway changes; pilotage; and,
- ➢ quantifying the effect on the risk level of an existing port or waterway that may result from a change or reduction of any of the risk control options in use.

Risk management tools can also assist in assessing the risk level of existing ports and waterways as well as determining the probable risk level of proposed new ports and waterways or if substantial changes to existing ports and waterways are being planned. The IALA Risk Management Toolbox includes three different approaches:

1. PAWSA Mk II (Port and Waterway Safety Assessment) which is a Qualitative Risk Assessment approach;
2. IWRAP Mk II (IALA Waterway Risk Assessment Programme) which is a Quantitative Risk Assessment approach;
3. SIRA (Simplified Risk Assessment) which utilizes a basic risk matrix approach.

The three approaches can be used individually, or in combination, sequentially or in parallel. The IALA Risk Management Toolbox is now being used for risk assessments in conjunction with submissions to the IMO. In addition to these three basic IALA tools, various simulation tools are nowadays also widely used for assessing risk in ports and waterways. The IALA World-Wide Academy provides training on the use of the Risk Management Toolbox through regular training courses. Background information on the elements of the toolbox is provided on a wiki accessible through the IALA website. If further guidance or assistance is required, please contact the IALA World-Wide Academy.

Authorities are encouraged to provide copies of risk assessments made with the IALA Risk Management Toolbox to the IALA Secretariat.

Refer to IALA publications:

- Guideline G1123 - The Use of IALA Waterway Risk Assessment Programme (IWRAP Mk II)
- Guideline G1124 -The Use of Ports and Waterways Safety Assessment (PAWSA Mk II) Tool
- Guideline G1138 - The Use of the Simplified IALA Risk Assessment Method (SIRA)
- Guideline G1104 – Application of maritime surface picture for analysis in risk assessment and the provision of AtoN

5.6.2 RISK MANAGEMENT DECISION PROCESS

The Risk Management process described in the IALA Guideline 1018 comprises five steps that follow a standardized management or systems analysis approach:

Identify hazards;

- Assess risks;
- Specify risk control options;
- Make a decision; and
- Take action.

The diagram in Figure 26 provides a guide to the steps involved in the IALA Risk Assessment and Risk Management process.

Hazard – an unwanted event or occurrence, a source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to health, property, the environment, and other things of value; or some combination of these.

Risk – the Risk is a measure of the likelihood that an undesirable event will occur together with a measure of the resulting consequence within a specified time i.e. the combination of the frequency and the severity of the consequence. This can be either a quantitative or qualitative measure.

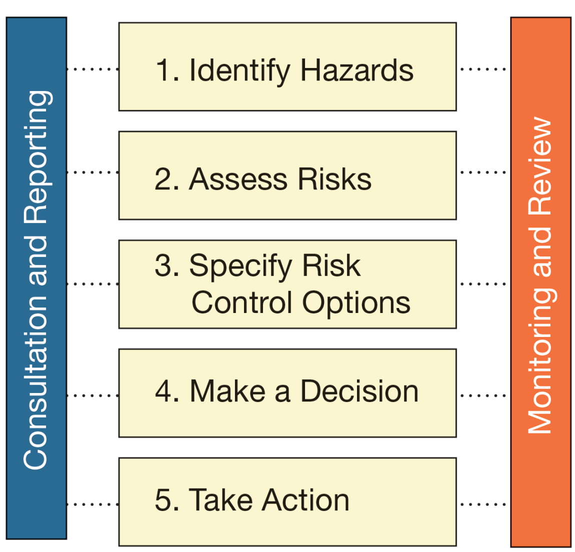


Figure 26. Risk Assessment and Risk Management Process

The central part of the Figure 26 illustrates the five steps in the risk management process. In addition the figure suggests a consultation and reporting element throughout the process.

Stakeholders including practitioners and users shall be consulted and receive feedback continuously to ensure the best possible input to the decision makers, to validate decisions and to ensure ownership of the results and actions taken. The monitoring and review part in the right side of the model is vital to ensure a verification of the decisions, to check if initial conditions have changed and to constantly monitor if control measures are implemented effectively.

5.6.3 RISK LEVEL AND ACCEPTABILITY

Once the possible unwanted risk scenarios have been identified and described, they must be ranked in terms of their probability and associated consequences. This yields a risk value, enabling prioritization by placing each risk scenario in a matrix similar to the one below. This allows resources to be assigned to mitigate the more serious risks first.

		PROBABILITY/(LIKELIHOOD)				
		VERY RARE (1)	RARE (2)	OCCASIONAL (3)	FREQUENT (3)	VERY FREQUENT (3)
CONSEQUENCE (IMPACT)	Catatrophic (5)	5	10	15	20	25
	Major (4)	4	8	12	16	20
	Severe (3)	3	6	9	12	15
	Minor (2)	2	4	6	8	10
	Insignificant (1)	1	2	3	4	5

Figure 27. Risk Value Matrix

The SIRA method provides suitable scoring scales for probability (frequency of occurrence) and consequences/impact. It should be kept in mind that the consequences can include both short- and long-term impacts.

Risks with a low risk value (green) may be fully acceptable and require no action, while risks with a high value (red) need urgent attention. The intermediate risk values (yellow and amber) will need to be addressed at some stage, the essence being that all risk values should be As Low As Reasonably Practicable (ALARP) considering the cost and effectiveness of the identified risk control options.

5.7 SERVICE DELIVERY

Authorities responsible for the provision of Aids to Navigation are generally at a state or national level. They are usually the sole national regulator of marine Aids to Navigation infrastructure and services, but are not necessarily the sole provider of these services.

In some countries there is a division of responsibility between the authority representing the national government and other organisations that include;

- state and territorial authorities;
- local government organisations;
- port, harbour or waterway authorities; and
- local private organisations.

Figure 28. Buoy tender - Photo Courtesy of CEREMA

5.7.1 SERVICE DELIVERY REQUIREMENTS

Where more than one local authority provides Aids to Navigation services, the Contracting Government has the ultimate responsibility to comply with the obligations under the SOLAS Convention.

5.7.2 CONTRACTING OUT

For a number of decades, national authorities have utilized service providers for the delivery and maintenance of Marine Aids to Navigation (AtoN) services.

Every organisation considering contracting AtoN services should have a clear understanding of what is to be achieved by delivering the service through alternative contracted means as opposed to delivering the service directly by the National Authority. The best practices, advantages, disadvantages, and keys to successfully managing a contracted AtoN servicing program are covered in detail in IALA Guideline 1005, Contracting Out Aids to Navigation Services. It is recommended that National Authorities review this Guideline if they are considering the contracting out their AtoN servicing responsibilities and be mindful of retaining in-house expertise to understand the technologies and requirements of AtoN Management and delivery.

Refer to IALA publications:

- Guideline G1005 - Contracting Out Aids to Navigation Services
- Guideline G1168 - Quality Control of third-party AtoN service Providers

5.8 LEVEL OF SERVICE

Level of Service (LOS) is the commitment of service by the Competent Authority to mariners who are navigating or operating in an area, as well as clients and/or governments responsible for funding the provision of the relevant service.

Level of service can be articulated through a Level of Service Statement that should be clear, easy to understand and available to all concerned.

5.8.1 BENEFITS

An established level of service is integral to efficient planning and delivery and provides users with a clear understanding of the expected services. Moreover, it ensures that services are delivered in a nationally consistent, integrated, predictable, measurable and fair manner.

5.8.2 COMPONENTS

A level of service statement should include, at minimum, the following components:

Type

Should describe what the Competent Authority will provide. It is a description of the service provided, such as, visual Aids to Navigation, radionavigation systems, or Vessel Traffic Services.

Extent

Should describe where and why a service will be provided by the Competent Authority. Most Competent Authorities are bound by the International Convention on the Safety of Life at Sea, 1974 as amended (SOLAS) Chapter 5, Regulation 13, which states that Each Contracting Government undertakes to provide, as it deems practical and necessary either individually or in cooperation with other Contracting Governments, such Aids to Navigation as the volume of traffic justifies [*where*] and the degree of risk requires [*why*]. The extent of service provided may also vary by Competent Authorities for specific areas, category of users, or due to national obligations.

Quality

Should address to what level the Competent Authority will provide a service. It is a minimum standard at which clients can expect a service to be performed, also known as a performance standard. A performance standard is a benchmark against which actual performance of a service can be measured. It may be expressed in the form of a target such as percentage of availability of a service or service response times.

5.8.3 LAYERS OF SERVICE

The various type of AtoN have advantages and disadvantages for the user as well as for the provider as indicated in Table 26.

Table 26. Comparison of Different Types of Aids to Navigation

	Users		Providers	
System	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Visual	Can be used to position	Range depends on site, height, colour, background	For hazard warning, traffic regulation, guidance, etc.	Maintenance expensive
	Conveys immediate information	Limited by visibility		Planning for maintenance depends on weather conditions
	Can be used without a chart if user has a good local knowledge	Position of floating aids not always accurate	Placement flexible	Logistic system required
			Maintenance of simple systems requires little training	Maintenance of complex systems requires training
Radar	Identification with Racon possible in reduced visibility conditions	Onboard equipment needed	Can replace visual aids	Radar reflectors needed
		Racons may interfere if not placed in an appropriate configuration,	Warnings of dangers	Some vessels do not have radar
		aids equipped with radar reflector are difficult to identify	(New dangers)	Racon investment is expensive
	Racon identification of low coastline			
	Only one aid is required			
	Rapid deployment			Training for maintenance of Racons
Radio-navigation	Wide scale coverage	On board equipment needed	Reduced maintenance	May not be under Aids to Navigation Authority's control
	All weather use		Automatic monitoring	Monitoring requirement
	Automatic navigation		Reduction of visual aids possible	Training maintenance personnel
	Precision possible			Large investment

Refer to IALA publications:

- Guideline 1004 - Level of Service
- Guideline 1079 - Establishing and Conducting User Consultancy by Aids to Navigation Authorities

5.9 REVIEWS AND PLANNING

5.9.1 REVIEWS

In many countries, the network of Aids to Navigation has been built up over a considerable time, in some cases, centuries.

It should be recognised that the nature of shipping is continually changing and this means that the Aids to Navigation infrastructure should be reviewed periodically.

The rate of change varies from place to place, but it would be reasonable to adopt a review process using one of the change management tools that provides:

- a Strategic Plan with a suggested minimum 10 year outlook;
- an Operational Plan with a suggested rolling 5 year work program.

The increasing availability of AIS-derived ship data (type, position, speed, cargo etc.) is proving to be a very useful tool in reviewing the relevance of existing Aids to Navigation and identifying new requirements.

Effective use of AIS data requires a data management strategy and appropriate technology to efficiently store and manipulate very large amounts of data and be able to be integrated with other electronic data, for example electronic nautical charts to display shipping patterns.

5.9.2 STRATEGIC PLAN

A Strategic Plan is the result of an informed and consultative process that sets the long term goals and objectives for an organisation.

For a Competent Authority it would include:

- the role of the authority, for example: — to promote a high standard of maritime safety; — to provide infrastructure and information services to support the safety of navigation in a particular area;
- how the authority will go about discharging its responsibilities, for example: — outline of the corporate values of the authority; — corporate governance arrangements; — funding arrangements; — reviews of industry trends; and
- an understanding of the users and navigation requirements.

Because of its importance and its effect on the mariners, any strategic plan should be developed as much as possible in full consultation with the mariners and other stakeholders.

5.9.3 OPERATIONAL PLAN

The Operational Plan might cover:

- the implementation of the strategic plan, and may include statements on current policy issues such as:
  - maintenance;
  - current and new technology;
  - the design life of new infrastructure — remote monitoring and control;
  - historic lighthouses;
  - environmental culture and safety;
  - the program for Aids to Navigation reviews;
  - contract services (core and non-core);
  - transport services;
  - sources of revenue;
  - external relationships; and
  - information, communication and consultation management.
- a list of changes to individual Aids to Navigation, including any new facilities. The list would reflect:
  - decisions resulting from user and stakeholder consultations;
  - reviews, including those that use:
    - risk analysis, risk management procedures;
    - a level of service process;
    - the authority's quality management procedures; or
    - the authority's technical and maintenance policies etc.
- project schedules that reflect known priorities, such as: — government policies; — user requirements; — available resources; — budget (revenue) forecasts and constraints.

5.9.4 USE OF GEOGRAPHIC INFORMATION SYSTEMS IN AtoN PLANNING

The use of Geographic Information Systems (GIS) may assist in effective AtoN planning, including evaluation and validation; ensuring that money is invested wisely in new technology.

Coastal waterways are becoming increasingly congested with vessel traffic and developments such as offshore wind farms, tidal turbines and aquaculture sites, which may be required to be marked.

In addition, light pollution through coastal development, the advent of larger and faster ships and the continued growth in small craft usage means that designing suitable AtoN systems becomes ever more complex.

Using GIS, accurate design and provision of AtoN systems as well as suitable simulation can prove very useful and may reduce the chance of costly mistakes being made.

AtoN are distinctly linked to physical locations and their use by mariners invariably involves the use of more than one AtoN at a time, that is, AtoN networks or systems.

These single and interdependent linkages between AtoN and their physical locations mean that GIS technology can provide AtoN authorities with enhancements in many areas of their business, which may ultimately lead to benefits for mariners.

A GIS captures, displays, stores, analyses and manages spatially referenced data. A key feature of GIS is its analytical functionality, which allows a user to interact with spatial data to determine relationships between different types of data and to produce qualitative (diagrammatic/graphical) and quantitative (numeric/tabular) results.

Refer to IALA publications:

- Recommendation R0138 - Use of GIS and Simulation by Aids to Navigation Authorities
- Guideline 1057 - Use of Geographical Information Systems by Aids to Navigation Authorities
- Guideline 1058 - Use of Simulation as a Tool for Waterway Design and Aids to Navigation Planning

5.10 QUALITY MANAGEMENT

Quality Management Systems have been developed and introduced by numerous businesses, but increasingly are being based on the ISO 9000 series of standards. These standards provide a broadly accepted framework for implementing a quality management system. A generic quality management system is process focused and defines procedures for how things are to be done and what resources are necessary.

It addresses:

- who does what?
- what skills and qualifications are necessary?
- what processes have to be followed to get consistent outcomes?
- what resources are necessary to do the work efficiently? The equipment in Aids to Navigation systems can be divided into two aspects: the specific AtoN aspect, and the more generic aspect.

Each aspect must comply with applicable standards and regulations. IALA Recommendations and Guidelines provide a basis for the AtoN specific aspect, while international, national or regional regulations apply to the more generic aspects.

Refer to IALA publications:

- Recommendation R0132 - Quality Management for Aids to Navigation Authorities
- Guideline G1052 - Quality Management in Aids to Navigation Service Delivery
- Guideline G1133 – Requirement traceability
- Guideline G1168 – Quality control of third party AtoN service providers
- Guideline G1005 – Contracting out AtoN service
- Guideline G1054 - Preparing for a Voluntary IMO Audit on Aids to Navigation Service Delivery procedures

5.10.1 PERFORMANCE MEASUREMENT

Performance measurement is the process of collecting, analysing and/or reporting information regarding the performance of an individual, group, organisation, system or component. It is very important to establish a continuous performance measurement as background for the quality management.

- The information obtained can be used to:
- show accountability to government and stake holders;
- demonstrate the efficiency and effectiveness of the service being provided;
- monitor and improve occupational health and safety performance; and
- compare the performance of:
    - similar systems or equipment in different locations;
    - contract and internally provided services;
- amend:
    - system designs;
    - procurement decisions;
    - equipment choices;
    - maintenance procedures and practices;
    - increase or reduce maintenance effort; and
    - adjust maintenance intervals.

Refer to IALA publications:

- Guideline 1037 - Data Collection for Aids to Navigation Performance Calculation
- Guideline 1035 - Availability and Reliability of Aids to Navigation - theory and examples

5.10.2 INTERNATIONAL STANDARDS

ISO 9000 Series

The ISO 9000 series, a set of quality management standards, was updated in 2015 with the amalgamation of the 1994 versions of ISO 9001, 9002, and 9003 into the revised ISO 9001-2015. The new ISO 9000 series includes:

- ISO 9000 Quality management systems - Fundamentals and vocabulary.
- ISO 9001 Quality management systems - Requirements.
- ISO 9004 Quality management systems - Guidance for Performance Improvement.

ISO 9001-2015 focuses on specifying requirements for a quality management system that can be used internally by organizations or for certification and contractual purposes. The standard emphasizes the effectiveness of the quality management system in meeting customer requirements.

ISO 9004-2009 provides guidance on a broader range of objectives for a quality management system compared to ISO 9001, particularly for continual improvement of an organization's overall performance, efficiency, and effectiveness. It is recommended for organizations whose top management seeks to go beyond ISO 9001's requirements in pursuit of continual performance improvement. However, it is not intended for certification or contractual purposes.

The ISO 14000 series is a collection of voluntary consensus standards developed to help organizations achieve environmental and economic benefits through the implementation of effective environmental management systems. The series includes three standards focused on Environmental Management Systems (EMS): ISO 14001, 14002, and 14004. Among these, only ISO 14001 is intended for third-party accreditation, while the others serve as guidance.

ISO 14001 specifies the requirements for an environmental management system, enabling an organization to:

- formulate a policy and objectives taking into account legislative requirements and information about significant environmental impacts;
- apply the requirements to those environmental aspects that the organisation can control and over which it can be expected to have an influence;
- demonstrate to itself, and to other interested parties, conformance with its stated environmental policy;
- seek certification/registration of its environmental management system by an external organisation; and
- manage and measure a program of continual improvement.

It is important to note that ISO 14001 does not state specific environmental performance criteria.

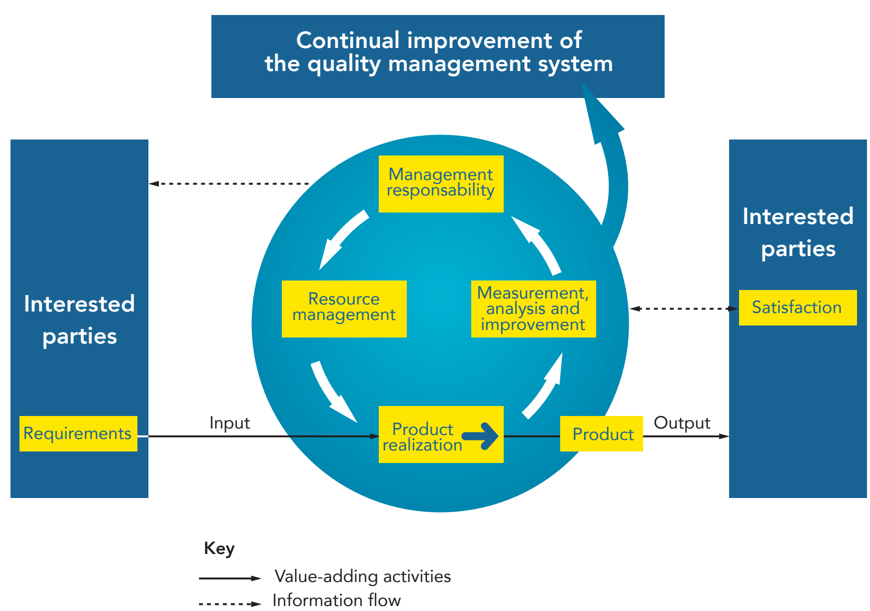


Figure 29. ISO 9001 Diagram on the Emphasis on Satisfying Customer Requirements

Refer to IALA publications:

- Recommendation R1004 - Sustainability in the provision of Marine Aids to Navigation
- Guideline G1036 - Environmental Management in Aids to Navigation
- Guideline G1137 - AtoN Management in protected areas

5.11 THIRD PARTY ACCESS TO AIDS TO NAVIGATION SITES

IALA acknowledges that Authorities face an increased demand to share Aids to Navigation sites with "third parties". While it is important to ensure that the integrity and security of Aids to Navigation are maintained, the presence of a third party may be beneficial:

- in reducing the risk of vandalism;
- as a source of revenue or sharing of operational costs (e.g. power, road maintenance, etc.); and
- as a means of monitoring the operation of the aid.

If an Authority receives a request for a third-party installation, it should first establish whether such involvement is permitted in the Authority's legislation. If there are no impediments, the Authority may consider negotiating an agreement with the potential third party to clearly establish the responsibilities and liabilities of each party. The agreement may also address:

1. conditions to apply to the third-party installation and operation to ensure that the equipment does not compromise the integrity and security of the Aids to Navigation and other property owned by the Authority;
2. access to electrical power. At sites with main power, it may be advisable for the Authority to require separate metering of the third-party supply so that electricity costs can be recovered;
3. if no mains power is available, it is reasonable to require that the third party provide its own power supply; and
4. where practical, the installation of the third-party equipment should take into consideration and preserve the heritage value of the Aid to Navigation.

Third party access may also involve cooperation with a local tourism or heritage group. This may include the use of former Lighthouse Keeper houses being used as holiday cottages or turning redundant buildings into Visitors Centres. As well as the benefits noted above, these heritage/tourism initiatives may also serve to inform the public on important aspects of AtoN and maritime safety as well as raising the profile of the Authority.

Authorities should reserve the right to cancel any third-party agreement if continued use jeopardizes the performance or functionality of the Aid to Navigation.

Refer to IALA publications:

- Guideline G1063 - Agreement for Complementary Use of Lighthouse property
- Guideline G1075 - Business Plan for the Complementary Use of a Historic Lighthouse

CHAPTER 6

RADIONAVIGATION SERVICES (PNT)

IALA Standard S1030 applies to Radionavigation Services. This Standard references normative and informative provisions, detailed in the listed IALA Recommendations, covering the following scope.

- Satellite positioning and timing
- Terrestrial positioning and timing
- Racon and radar positioning
- Augmentation services

6.1 POSITIONING, NAVIGATION AND TIMING

Positioning, Navigation and Timing (PNT) information is widely used across the maritime sector. It supports vessel navigation, e-Navigation services and provides timing and positioning information for Marine Aids to Navigation.

Over the past decade it's become clear that reliance on PNT has grown dramatically while at the same time the threat of signal disruption or corruption has grown. There is a clear need for resilience in the provision of PNT information as it underpins so many aspects of maritime navigation and communications as well as marine AtoN operations.

Resilience may look like and mean different things depending on the operation at hand, the threat faced and available local options. It is widely recognised that one solution cannot mitigate all threats in all locations, and what is needed are scalable, configurable solutions through what is often referred to as a system-of-systems approach.

Global Navigation Satellite Systems (GNSS) are widely used as the primary means of navigation today and that is expected to remain so into the future. Resilience is achieved when GNSS PNT information is supported by data from other, independent, PNT sources and combined in such a way that the integrity of the data is maintained and the mariner or AtoN service provider can retain their PNT solution, should any of the PNT sources fail.

There are many different systems which can provide PNT information, and this chapter introduces the most prominent.

Refer to IALA publications:

- Recommendation R1017 - Resilient Positioning, Navigation and Timing (PNT)
- Recommendation R0129 – GNSS Vulnerability and Mitigation Measures

6.2 SATELLITE POSITIONING AND TIMING

Global Navigation Satellite System (GNSS) is the generic term for satellite navigation systems that provide timing signals that enable the users' receiver to calculate its position, velocity and time.

GNSS consists of three segments – a satellite constellation (space segment), a ground segment (or Control segment) and the user's receiver (User segment). The satellites continuously transmit coded signals in one or more frequency bands. A user's receiver, positioned anywhere on the earth's surface, can use these signals to determine position and velocity in real time, based on ranging measurements.

If a GNSS is recognised by the IMO as a component of its Worldwide Radio Navigation System (WWRNS), as set out in IMO Resolution A.1046 (27), the receivers of that GNSS are deemed to satisfy the IMO carriage requirements for position fixing equipment referred to in Chapter V of the SOLAS Convention.

GNSS receivers, in combination with other equipment, can be used to obtain:

- absolute positioning;
- relative positioning (this can be further processed to derive speed over ground (SOG), course over ground (COG), etc.); and
- timing.

This information may refer to a stationary observer (static positioning) or to a moving observer (kinematic positioning).

There are several GNSS available today, with GPS, GLONASS, BeiDou and Galileo recognised as components of the IMO's WWRNS. It is planned that regional GNSS components like QZSS and NAVIC will become operational in the next few years. GPS, GLONASS, Galileo, BeiDou, QZSS and NAVIC operate interoperable services under the framework of the International Telecommunication Union (ITU).

6.2.1 GLOBAL POSITIONING SYSTEM (GPS)

The Global Positioning System (GPS) became fully operational in 1995. The system is operated by the United States Department of Defense (DOD) on behalf of the United States Government.

GPS provides two levels of service. The Standard Positioning Service (SPS) provides accurate positioning to all users since it is available for peaceful civil, commercial, and scientific use. Otherwise, the Precise Positioning Service (PPS) provides full system accuracy to those designated and authorised users among U.S. and allied national security systems.

The GPS Space Segment consists of a minimum constellation of 24 operational satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900NM) high orbits at an inclination angle of 55 degrees and with a 12-hour period.

The GPS SPS is available on a non-discriminatory basis, free of direct user fees, to all users with an appropriate receiver. The service satisfies the requirements for general navigation and harbour approach with a horizontal position accuracy of 9 metres (95% probability).

A modernisation program aims to improve the accuracy and availability for all users and involves new ground stations, new satellites and four additional navigation signals: three new civilian signals known as L2C, L5 and L1C and a new military code termed M-Code.

Further information on GPS can be found at the USCG NAVCEN website (www.navcen.uscg.gov). The website also has a link to the latest United States Federal Radionavigation Plan that provides a comprehensive account of current and future developments for GPS.

6.2.2 GLOBAL NAVIGATION SATELLITE SYSTEM (GLONASS)

GLONASS is a three-dimensional positioning, velocity and time system managed by the Russian Space Agency on behalf of the Russian Federation.

It is available on a non-discriminatory basis and free of direct user fees to all users with an appropriate receiver. With a full complement of 25 satellites, the service satisfies the requirements for general navigation and gives an average User Range Error of 1-6m (95%).

Recent satellites have introduced a second civil signal, with future satellites expected to provide a third civilian signal on the L3 frequency.

GLONASS satellites use Frequency Division Multiple Access (FDMA). However new satellites will provide additional signals using code division multiple access (CDMA) to become interoperable with other GNSS.

Equivalent to the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS) of GPS, GLONASS provides a standard precision (SP) navigation signal and a high precision (HP) navigation signal, namely the Channel of Standard Accuracy (CSA) and Channel of High Accuracy (CHA), respectively. The Open Service (OS) provides positioning and timing service with the open access provided by way of the aggregate ranging FDMA signals generated by the GLONASS OC, broadcast at L1 and L2, and whose performance is associated with that of CSA (Chanel of Standard Accuracy) in the GLONASS service volume. The OS with the associated CSA performance is available to any user globally and continuously.

GLONASS High Precision signal is broadcast in phase quadrature with the SP signal providing full system accuracy to those authorised users by the Russian Armed Forces.

Further information on GLONASS and future developments, is available on the Information and Analysis Centre's website (https://www.glonass-iac.ru/en/).

6.2.3 BEIDOU

BeiDou Navigation Satellite System (BDS) is China's independently constructed and operated GNSS system. It can be compatible with other GNSS in the world. BDS can provide all-time, all-weather PNT services with high accuracy and high reliability for all kinds of users.

BDS consists of three major components: the space constellation, the ground control segment and the user segment. The global constellation consists of 3 GEO satellites, 3 IGSO satellites and 24 MEO satellites. BDS now can provide the following services:

The Open Service (OS)

With positioning accurate to 10 meters globally and to 5 meters in Asia-Pacific region free of user charge. The OS can be used on one (B1C or B1I) frequency and the better performed B1C is priority recommended. It is also recommended to use two (B1C and B2a) frequencies.

The Message Service.

As for message services in China and surrounding areas, the service capacity will be increased to 10 million times per hour and the receiver transmission power will be reduced to 1-3W, capable of transmitting 1,000 Chinese characters per message (14,000 bits). As for global message services, the service capability is 40 Chinese characters per message (560 bits).

The Search and Rescue (SAR) service is a contribution of BDS to the Cospas-Sarsat MEOSAR program through the provision of a Forward Link Alert Service (FLS). In addition, Return Link Service (RLS)/BDS is provided through B2b signal.

BDS Precise Point Positioning (PPP) Service Signal PPP-B2b is transmitted by BDS GEO satellites. The PPP-B2b signal serves as the data broadcasting channel for correction parameters, such as satellite precise orbit and clock offset parameters of BDS and other GNSS, and provides PPP services for users in China and surrounding areas, with the dynamic precise position service accuracy at decimetre level and static precise potion service at centimetre level.

Further information on BDS can be found via website (www.beidou.gov.cn).

6.2.4 GALILEO

Galileo is the European GNSS designed to be interoperable with other GNSS, managed and operated under civil control. Galileo uses a constellation of 24 satellites to achieve its positioning performance targets but aims to have a constellation of 30 satellites when fully operational (including in-orbit spares).

Galileo Initial services were declared in 2016 together with the recognition of IMO as part of the World Wide Radionavigation System. Galileo is offering today the following services:

- **An Open Service (OS):** With horizontal position accuracy of 2 metres (95%), free of user charges and providing positioning, time and synchronisation information;
- **Search and Rescue Services (SAR):** EU contribution to the MEOSAR system of COSPAS-SARSAT. Galileo search-and-rescue service forwards since 2017 distress signals to Cospas-Sarsat Mission Control Centres by detecting emergency signals from beacons and relaying messages to them in near real time that are then sent to the Rescue Coordination Centres (Forward Link Service). Galileo also delivers since 2020 an acknowledgment message to beacons with the return link capability to inform the user that the alarm has been received (Return Link Service);
- **High Accuracy Service (HAS):** A free access service complementing the OS by delivering high accuracy data and providing better ranging accuracy, enabling users to achieve sub-meter level positioning accuracy. With HAS, Galileo will be the first constellation able to provide a high-accuracy PPP service globally directly through the Signal in Space. High-accuracy data will be transmitted using an open format in the Galileo E6-B signal and via the internet for Galileo and GPS (single and multi-frequency) to achieve real-time improved user positioning performances (positioning error of less than two decimetres in nominal conditions); and
- **Public Regulated Service (PRS):** Encrypted navigation service restricted to government-authorised users, for sensitive applications that require a high level of service continuity. PRS is primarily intended for use by EU Member State government authorised military or civil users, e.g. emergency services and police.

6.2.5 REGIONAL SYSTEMS

6.2.5.1 QUASI-ZENITH SATELLITE SYSTEM

Japan is developing a Quasi-Zenith Satellite System (QZSS). QZSS is based on three satellites in high elliptical, inclined orbits and one geo-stationary satellite. The final constellation is expected to consist of 7 satellites, with each transmitting 6 signals in the Lband: 3 in L1, 1 in E6, 1 in L2 and 1 in L5. The signal in E6 (L6) aims to support a commercial service with high data rate (2 kbps). Full implementation will also provide augmentation services to GPS and QZSS.

Further information is available at http://QZSS.go.jp/en/.

6.2.5.2 INDIAN REGIONAL NAVIGATIONAL SATELLITE SYSTEM

The Indian Regional Navigational Satellite System (IRNSS) with an operational name of NAVIC (Navigation with Indian Constellation) will be an independent navigation system covering the Indian region through a space segment of 3 GEO satellites and 4 IGSO satellites. The inclination of the orbital plane of the IGSO satellites is low, so that all the satellites can be seen simultaneously over India.

The three NAVIC services are:

- Open Service using signals in the L5 and S bands;
- Precise Positioning Service using signals in the L5 and S bands; and
- Restricted Access Service using signals in the L5 band only.

The Open and Precise services target dual frequency users, but it is also intended to compute and broadcast ionosphere-corrections to support single frequency users. Owing to the limited coverage of the NAVIC network of reference stations, the satellites will, apart from the navigation payload, also include a dedicated C-band uplink/down-link ranging payload to support precise satellite orbit determination.

6.3 TERRESTRIAL POSITIONING AND TIMING

Within this section, different terrestrial navigation and timing systems are considered.

6.3.1 LORAN-C

Loran-C is a hyperbolic radionavigation system that was developed during the 1960's to meet U.S. Department of Defense requirements. The Russian Federation operates a similar radionavigation system called CHAYKA.

Loran-C chains comprise between three to five stations that have a spacing of 600 to 1000 Nautical Miles. The signal format is a structured sequence of specially designed radio pulses on a carrier wave frequency centred on 100 kHz. One of the stations is designated as the 'master' and transmits groups of 9 pulses. The other stations are called 'secondaries' and these transmit groups of 8 pulses. The spacing between groups of 'master' pulses from a single chain is a characteristic unique to that chain and is referred to as the Group Repetition Interval (GRI).

The 100 kHz carrier wave frequency favours the propagation of a stable ground wave over long distances. Careful signal design allows Loran receivers to determine positions using the ground wave and reject the delayed sky wave that would potentially distort the received signal.

The transmissions from each chain are monitored and controlled continuously. System abnormality indicators are built into the signal format and can be identified by the receiver providing inherent integrity warnings.

6.3.2 eLORAN

Enhanced Loran (eLoran) is a terrestrial navigation system developed from Loran-C. It is a Positioning, Velocity, and Timing (PVT) service for use by land, sea and air navigation, as well as other applications reliant on timing data.

eLoran is independent of, and has dissimilar failure modes to GNSS, and therefore complements GNSS in support of resilient PNT. eLoran provides positional accuracy in the region of 8 - 20 metres and time and frequency performance (to stratum-1 level) similar to current GNSS.

eLoran differs from Loran-C as it uses an all-in-view method of operation, calculating the distance to all eLoran stations in view. eLoran stations are synchronised with, but independent of GNSS time. Synchronising to a common time source allows receivers to employ a mixture of eLoran and other systems, such as GNSS.

eLoran receivers calculate the distance from each station by firstly assuming that the entire earth's surface is covered in sea-water. By knowing the speed of the signal over sea-water, along with the times of transmission and reception, a pseudorange can be calculated. This pseudorange is then adjusted to take into account the propagation delays due to the signal passing over land. These delays are called Additional Secondary Factor delays (ASFs). ASFs are measured by the service provider and supplied to users as a database built into their receivers. ASFs may change slightly due to weather or seasonal effects, reducing the efficiency of the correction and affecting accuracy. However, this is resolved by installing a differential Loran reference station nearby, which is able to measure the difference and calculate a correction. The correction information is then passed to the eLoran station for dissemination to the user over the eLoran data channel.

The inclusion of a data channel as part of the main transmission is one of the inherent features of eLoran. It can be used to provide other data services in addition to differential corrections.

The eLoran signal is standardised by SAE within its Transmitted Enhanced Loran (eLoran) Signal standard (SAE9990).

Refer to IALA publications:

- Recommendation R1011- The performance and monitoring of eLoran services in the frequency band 90-110 kHz
- Guideline G1125 – The Technical Approach to Establishing a Maritime eLoran Service

6.3.3 RANGING MODE (R-MODE)

Ranging mode (R-Mode) is a terrestrial positioning system under development. It uses the frequency bands of existing maritime radio infrastructure for the provision of timing signals that enables GNSS independent position and time estimation. At present, the MF band of the IALA radio beacon system and the VHF bands AIS, ASM and VDE-TER of the VDES are being used in R-Mode testbeds in Europe, Asia and North America.

By providing timing information over MF or VHF transmissions, a shipboard receiver may then calculate a distance (range) to each transmitter. By calculating the range to several stations, the user is able to calculate the ship's position. Coverage, geometry and interference issues still need to be fully investigated.

Three transmitters must be received to perform R-Mode based positioning at sea. Due to the different range of the transmitter of about 250 km for MF and several tens of km for VHF, which strongly depends on the antenna tower height, the coverage of MF and VHF R-Mode service can differ noticeably. Both signals are subject to different effects of signal attenuation, interference and distortion which decreases the performance. The combination of MF and VHF R-Mode signals can noticeably increase the R-Mode positioning performance.

All R-Mode transmitters are synchronized to an R-Mode system time. Depending on the synchronization source and technology to perform synchronization, the system time refers to a time scale which is traceable to UTC. Usually GNSS is used for synchronisation today within the testbeds. However, to reduce the dependence or to be completely independent from GNSS, R-Mode stations would require the availability of an accurate non-GNSS timing source at the transmitter. High stability clocks, such as atomic clocks, could be an expensive option and it is more likely that time would be sourced from a low frequency radio time clock or eLoran.

The use of ranging signals (R-Mode) transmitted by shore-based communication systems as an alternative to GNSS signals is covered in Chapter 9.5.

Refer to IALA publication:

- Guideline G1158 – VDES R-Mode

6.4 AUGMENTATION SERVICES

The aim of GNSS augmentation services such as Differential Global Navigational Satellite Systems (DGNSS) is the improvement of GNSS-based positioning in a given area. In this context, various methods can be applied to increase the accuracy of GNSS-based positioning, and to verify the integrity of applied components (systems, services) and provided data. An essential basis for the provision of DGNSS service is own GNSS measurements gathered in real time at single reference stations or a network of stations.

There are two main approaches:

- ground based differential services such as the IALA radio beacon DGNSS system; and
- space-based services, such as Satellite Based Augmentation Systems (SBAS). The following sections introduce each system in more detail, however they work in similar manners – they both compare the performance of high-grade GNSS receivers to the known location of the antenna in order to observe position errors introduced by the earth's atmosphere and other such sources.

In safety-critical applications, DGNSS services should also include integrity monitoring functions to ensure signals are valid and fit for use. Such monitoring can be realised by plausibility and consistency tests, as well as methods estimating error behaviour and budgets, to provide integrity warnings in real time to the end user, informing them if a particular satellite or satellites should not be used or if the system should not be used.

The DGNSS service provision is realised by radio signals carrying augmentation, correction and integrity data. Users operating in service areas and equipped with appropriate receivers can use this augmentation data to:

- enhance accuracy of GNSS based positioning;
- notify of faulty satellites or GNSS failure;
- detect satellite signals with increased propagation errors;
- exclude disturbed signals from positioning; and
- be informed about the usability of services or other information.

Currently, DGNSS services are provided for operational satellite navigation systems such as GPS and GLONASS. In principle, similar DGNSS services can be provided for developing GNSS such as GALILEO, BeiDou and QZSS.

Each DGNSS service can be separated into two parts - generating and distributing the augmentation data. The generation of DGNSS augmentation data requires own GNSS measurements gathered at a single reference station or a network of stations. Different DGNSS messages and services may use different generation methods and means of dissemination. At present, certain communication channels used for the provision of DGNSS augmentation data are assigned to specific DGNSS services. For example, the provision of DGNSS augmentation data is realised by SBAS.

Refer to IALA publications:

- Recommendation R1022 - Provision of GNSS Augmentation Service for maritime navigation applications
- Recommendation R0135 – Future of DGNSS

6.4.1 TERRESTRIAL AUGMENTATION SYSTEMS

6.4.1.1 IALA BEACON DGNSS

IALA beacon DGNSS provides differential corrections, as well as integrity information, to nearby maritime users to improve accuracy and integrity of GNSS based determination of position, velocity and time data (PVT).

The method of differential positioning was developed in the 1990's, is internationally accepted and supported in most coastal waters, especially in areas of high traffic density. By placing high grade GNSS receivers at know surveyed locations, it's possible to calculate the difference between the estimated GNSS position and the true surveyed location. The difference for each satellite's pseudorange are observed from which corrections are determined and shared with nearby users, enabling their receiver to improve their estimated position.

Additionally, integrity monitoring functionalities assess the usability of GNSS signals, ensuring mariners employing such marine radio beacon DGNSS service use valid and healthy satellite signals.

The radio link used for the provision of DGNSS correction and integrity data is defined by ITU (Recommendation ITU-R M.823-3). For such services, the DGNSS signal transmission is realized in the maritime radionavigation band (283.5 to 325 kHz). At user sites, type-approved DGNSS radio beacon receivers (meeting IEC 61108-4 test and performance standards) are necessary to enable the ship-side use of DGNSS services for an improved PVT data determination.

The full list of radio beacon based DGNSS stations (as notified to IALA by Aids to Navigation authorities) is at the IALA website (www.iala-aism.org/technical/positioning-navigation-and-timing/). Note that this list is updated periodically.

Refer to IALA publications:

- Recommendation R0115 - Provision of maritime radionavigation services in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Regions 2 and 3
- Recommendation R0121 - Performance and Monitoring of a DGNSS Service in the frequency band 283.5-325kHz
- Guideline G1112 - Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325kHz)

6.4.1.2 AIS FOR DGNSS TRANSMISSIONS

Automatic Identification System (AIS) is a ship to ship and ship to shore data exchange and broadcast system, operating in the VHF maritime band. It is described in more detail in Chapter 5.

AIS has the capability of providing DGNSS corrections to onboard equipment using standardised transmissions (Message No 17) as described in IALA Recommendation A-124.

6.4.1.3 THE BEIDOU GROUND AUGMENTATION SYSTEM.

BDS utilizes mobile communication networks or the Internet to provide users within the coverage area of reference station network, with high-precision positioning services at meter, decimetre, centimetre and millimetre levels.

6.4.2 MARITIME PHASE-BASED GBAS (MGBAS)

6.4.2.1 REAL TIME KINEMATIC (RTK)-BASED POSITIONING

In the past few decades, the development of phase-based measurement techniques was driven by surveying needs, to achieve position accuracies with GNSS in the centimetre level. In IALA Recommendation on the Future of DGNSS (R-135), the RTK technique is mentioned as an approach to meet maritime requirements on high-precision positioning in port areas and for docking. Several manufacturers of maritime GNSS/DGNSS equipment provide solutions supporting RTK-based positioning.

6.4.2.2 RTK OVER AIS

In survey applications, the RTK correction information is usually distributed to users via VHF/UHF radio modems or via commercial broadband internet. However, when used in hydrographic measurements further away from the shoreline, these communication options might not be always available. The communication options in these areas would then be via satellite or via AIS (the latter is also available only within coastal VHF coverage, usually up to 50 - 70km from the coastline).

RTK over AIS is in operational use for selected user groups in some countries and it has been reported to function without major problems and deliver the required positioning accuracy.

When using RTK over AIS, it should be noted that it puts a high demand on the VHF Data Link. Other limitations of this technique are that only one mobile user can be served by one AIS base station at a time, there is reduced understanding of accuracy due to rapid atmospheric fluctuations and that it may not be applicable in areas of high channel loading. The channel loading problem may be addressed in the future by using the additional channels allocated for VDES.

It is noted that RTK is a short-range system, and that there is a need to introduce monitoring and assessment of the integrity of RTK services and RTK based positioning in the context of safety-critical applications.

6.4.3 SATELLITE BASED AUGMENTATION SYSTEMS (SBAS)

SBAS support wide-area or regional augmentation through the collection of data from reference stations located across a region, with differential data provided to the user via satellite-broadcast messages. The basic arrangement is to use a set of monitoring stations (at precisely known positions) to receive GNSS signals. Data from these stations are processed in order to obtain estimations of the errors that are also applicable to the users (i.e. ionospheric errors, satellite position/clock errors, etc.). Once these estimations have been computed, they are transmitted to the users by means of a GEO satellite.

There are many SBAS current in operation or planned, as shown in Figure 30.

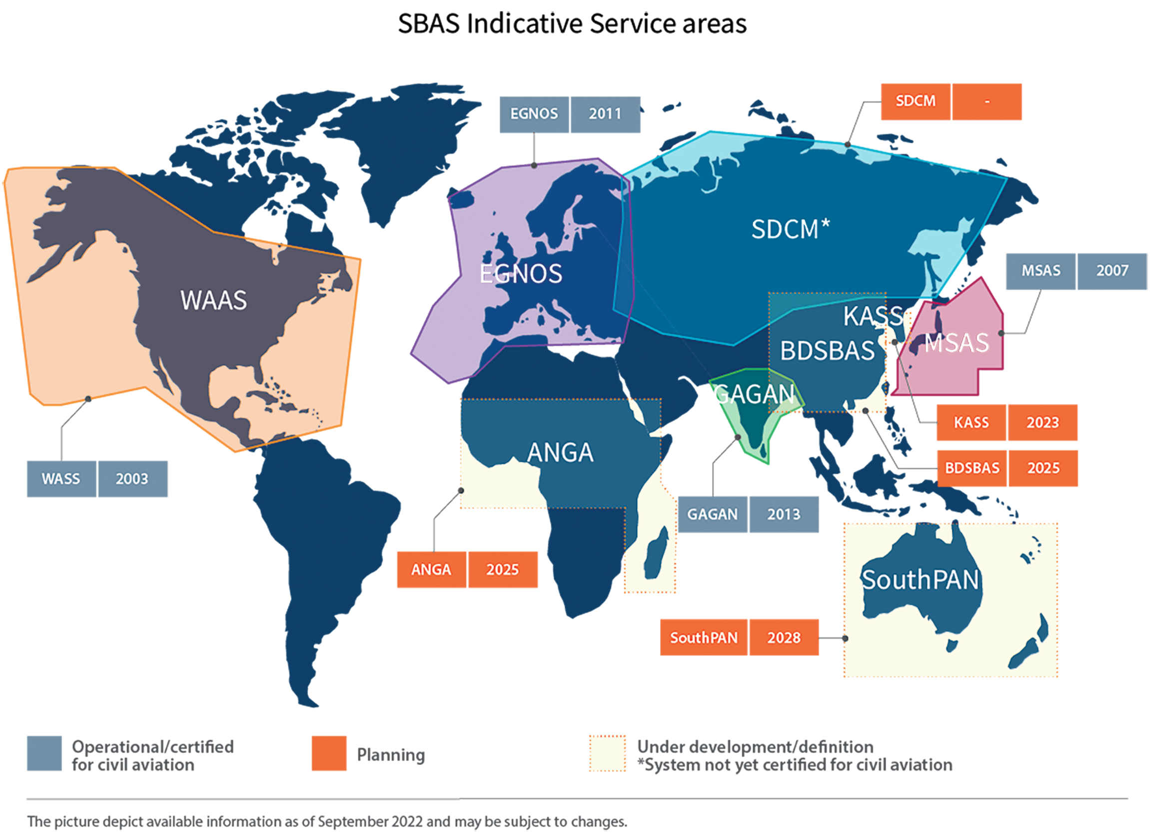


Figure 30. Existing and under definition SBAS systems
(Source: 09b sbas image november 2022)

Refer to IALA publications:

- Guideline G1129 – The retransmission of SBAS Corrections using MF radio beacon and AIS
- Guideline G1152 – SBAS Maritime Service

6.4.3.1 WIDE AREA AUGMENTATION SYSTEM (WAAS)

WAAS has been implemented by the US Federal Aviation Authority (FAA) to support the use of GPS for general and commercial aviation over continental United States. It has also been extended to cover parts of Mexico and Canada. At present, the WAAS architecture includes 38 reference stations, 3 master stations, 3 geostationary satellites, 6 GEO up-link stations and 2 operational control centres. Further information on WAAS can be found on the Federal Aviation Administration website (www.faa.gov).

6.4.3.2 EUROPEAN GEO-STATIONARY NAVIGATION OVERLAY SERVICE (EGNOS)

EGNOS is the European satellite-based augmentation system that provides safety critical navigation services to aviation, maritime and land-based users over most of Europe. EGNOS augments the GPS L1 Coarse/Acquisition (C/A) civilian signal by providing corrections and integrity information.

EGNOS provides three services:

- **Open Service (OS)**, freely available to any user. The main objective of the EGNOS OS is achievable positioning accuracy by correcting several error sources affecting GPS signals (EGNOS-SDD)
- **Safety of Life (SoL) Service**, provides the most stringent level of signal-in-space performance developed primarily to support aviation (EGNOS-SDD); A service in the maritime sector is under development with a specific service provision layer including performance monitoring and the promulgation of Maritime Safety Information (MSI). The publication of the IEC Standard for SBAS receiver tests is needed (PNW 80-996 ED1).
- **EGNOS Data Access Service (EDAS)** is the EGNOS terrestrial data service which offers ground-based access to EGNOS data in real time and also in a historical FTP archive to authorised users (e.g. added-value application providers) (EGNOS-SDD). The EGNOS Space Segment comprises 3 geostationary (GEO) satellites. The EGNOS Ground Segment comprises a network of Ranging Integrity Monitoring Stations (RIMS), two Mission Control Centres (MCC), six Navigation Land Earth Stations (NLES), and the EGNOS Wide Area Network (EWAN) which provides the communication network for all the components of the ground segment.

Further information on EGNOS can be found at www.egnos-portal.eu.

6.4.3.3 BEIDOU SATELLITE BASED AUGMENTATION SYSTEM (BDSBAS)

BDSBAS is an important part of BDS. The constellation of BDSBAS includes 3 GEO satellites operating at an altitude of 35,786 km and are located at 80°E, 110.5°E, and 140°E. These satellites use Pseudo Random Noise (PRN) code 144, 143 and 130, respectively. The coordinate system of BDSBAS is WGS-84.

The deviation of BDSBAS service network time to GPS Time is within 50 nanoseconds. BDSBAS provide the Single Frequency (SF) service through BDSBAS-B1C signal and the Dual-Frequency Multi-Constellation (DFMC) service through BDSBAS-B2a signal for users in China and surrounding areas.

Further information on BDSBAS can be found via website (www.beidou.gov.cn).

6.4.3.4 MULTI-SATELLITE AUGMENTATION SYSTEM (MSAS)

In Japan, the Multi-Satellite Augmentation System (MSAS) is a SBAS similar to EGNOS and WAAS. MSAS has been commissioned for aviation use, with two GEO-links using the L1 band via dedicated satellites, shared with communications and meteorological missions. The system has been operational since 2007 and there are plans to add additional services in the future.

Further information on MSAS can be found via the website: (https://www.mlit.go.jp/koku/15_hf_000105.html).

6.4.3.5 GPS-AIDED GEO AUGMENTED NAVIGATION SYSTEM (GAGAN)

India has developed its own SBAS called GPS-Aided Geo Augmented Navigation system (GAGAN). The system was jointly developed by ISRO (Indian Space Research Organisation) and AAI (Airports Authority of India). The system provides GPS signal corrections primarily for aviation users over the Indian landmass and is the first to cover the equatorial region. Two GEOs simultaneously transmit the GAGAN signal in space. The GAGAN footprint extends from Africa to Australia and the system has the capacity for expansion to neighbouring countries. As the system conforms to ICAO standards it is interoperable with other SBAS and provides a link between EGNOS and MSAS.

Further information on GAGAN may be found at https://gagan.aai.aero/gagan

6.4.3.6 SYSTEM FOR DIFFERENTIAL CORRECTIONS AND MONITORING

Russia is developing an augmentation to provide corrections for GLONASS and GPS called the System for Differential Corrections and Monitoring (SDCM). This system will consist of 3 geostationary satellites, assigned PRN codes 125,140 and 141.

6.4.3.7 KOREA AUGMENTATION SATELLITE SYSTEM (KASS)

Republic of Korea is developing a Korea Augmentation Satellite System (KASS), which is an independent SBAS similar to WAAS and EGNOS. KASS includes 7 reference stations, 2 GEOs, 3 up-link stations, 2 control centres and 2 Processing stations. KASS is currently undergoing a series of system certification processes before its provision of safety of life (SoL) service in the aviation sector after 2023. Further information on KASS can be found via website www.kass-re.kr.

6.4.4 INTEGRITY OPTIONS

Augmentation systems check the data provided by each satellite and constellations, to ensure they are valid and operating within normal ranges. Any satellite or constellation found to be working outside of the norm, is marked as unhealthy and not used in the user's position estimate.

This check or test is known as integrity. GNSS integrity is defined as the measure of trust that can be placed in the correctness of the information supplied by the navigation system. There are two different approaches, system level and user level integrity.

System level integrity checks the operation of the system at a set, normally static, location – such as the reference stations used within marine radio beacon DGNSS and SBAS solutions. Such systems are able to identify system level failures, aspects such as erroneous satellite position data, clock errors or atmospheric effects. System level tests are unable to determine or capture any integrity errors at the users' location.

User level integrity is the name given to integrity checks that take place within the user's receiver as these can include not just system level failure effects, but also local effects such as interference and multipath near to the user receiver. It is anticipated that user level integrity and system level integrity will be required in the future as the reliance on PNT information grows.

6.4.4.1 RECEIVER AUTONOMOUS INTEGRITY MONITORING

Receiver Autonomous Integrity Monitoring (RAIM) is a technology developed to assess the integrity of GNSS signals, and therefore the user level integrity of GNSS-based positioning. This kind of integrity monitoring is autonomously realized within the user's receiver with special importance for safety critical applications, such as aviation and maritime navigation.

Range measurements are required from at least four GNSS satellites to enable the determination of position, velocity and time data. However, the application of RAIM in a navigation receiver requires redundancy in the range measurements. That is, when more satellites are available than needed to produce a position fix, the extra or redundant pseudoranges can be checked to ensure they are all consistent with the computed position.

Safety-critical RAIM algorithms might use only "Fault Detection" (FD) or "Fault Detection and Exclusion" (FDE), which enables the continuation of operation in the presence of a single GNSS satellite signal failures. To detect a faulty satellite, at least five range measurements are required, whereas to isolate and exclude a faulty satellite, at least six range measurements are required. While RAIM can detect many failure modes, it cannot detect some failures affecting multiple satellites.

The upcoming availability of various GNSS will increase the usable number of navigation signals for RAIM-based positioning. New and modernized GNSS supports the provision of GNSS signals in two or more frequency bands and therefore improves the capability of GNSS based ranging.

Future advancement in RAIM algorithms should improve the availability and continuity of RAIM based positioning.

Such enhanced RAIM techniques - called Advanced RAIM (ARAIM) - may become available to maritime users (https://gssc.esa.int/navipedia/index.php/ARAIM).

6.5 RADAR AIDS TO NAVIGATION

Radar Aids to Navigation are devices that provide returns to a ship's radar that help to locate and/or identify a navigation mark. The IMO carriage requirements contained in Chapter V, Regulation 19 of the SOLAS Convention 1974 (as amended), states all ships of:

- 300 gross tonnage and upwards are to carry a 9 GHz radar;

- 3,000 gross tonnage and upwards are to be fitted with a 3 GHz radar or, where considered appropriate by the Administration, a second 9 GHz radar.

Some administrations may impose other carriage requirements.

IMO Resolution MSC.192 (79) Adoption of the Revised Performance Standards for Radar Equipment (December 2004) states that 9 GHz radars should be capable of detecting radar beacons (Racons), SARTs and radar target enhancers. By omission, 3GHz radars are not required to detect radar beacons and SARTS. With the removal of the 3GHz radar Racon detection requirement, ship-owners are free to use higher performing solid-state radars (previously known as New Technology (NT) radars), discussed below.

9 GHz radars are also extensively carried by vessels not covered by SOLAS or local regulation. Due to this high rate of carriage, radar Aids to Navigation in the 9 GHz band are especially useful.

6.5.1 RADAR REFLECTORS

A radar reflector is a passive device designed to return the incident radar pulses of electromagnetic energy back towards the source and thereby enhance the response on the radar display. By design, a radar reflector attempts to minimise absorption and random scattering effects. A radar reflector is generally installed as a supplementary device at sites that would also be marked with a light. The main objectives are to enhance:

- target detection at long ranges (for example, for landfall navigation);
- target detection in areas of sea or rain clutter; and
- radar conspicuity of Aids to Navigation to reduce the risk of collision damage.

The performance of a radar reflector can be defined in terms of its effective radar cross section (RCS). This is a value determined by comparing the strength of radar signals returned by the radar reflector with the equivalent return from a radar reflective sphere of $1m^2$ reflecting area.

The range at which a radar reflector target can be detected is dependent on the heights of the radar antenna and the reflector, the reflector's RCS, and the characteristics of the transmitter, receiver and antenna of the radar. Meteorological incidences like heavy rain, snow and hail have also an impact on the probability of detection of a radar reflector. There are analogies to the geographical range of visual marks. The radar performance of corner cluster reflectors may vary considerably from one make to another.

Use of small radar reflectors can also be subject to multipath fading effects. Please see IALA Guideline No. 1010 on Racon Range Performance for a discussion on multipath fading.

Most radar reflectors are designed for use by 9 GHz radars. The reflectors can also be used with 3 GHz radars; however, the effective radar cross section is about an order of magnitude less.

A detailed description of radar reflectors and their use on AtoN can be found in Guideline G1174 on Radar Reflectors.

6.5.2 RADAR TARGET ENHANCERS

A Radar Target Enhancer (RTE) is an electronic and powered device that amplifies and returns the pulse from a ship's radar to give an enhanced image on the radar screen. The returned signal from an RTE is not coded. The RTE was designed primarily for buoys and small vessels that might normally carry a passive radar reflector. RTE testing has shown RTEs to have provided an effective radar cross section (RCS) of about 100m2, compared with an RCS of 20 to 30m2 for passive radar reflectors typically fitted to buoys.

To date, commercially available RTEs only operate in the 9 GHz band. RTE use is subject to multipath fading effects (please see Guideline 1010 on Racon Range Performance).

While passive radar reflectors do not need a power supply, Radar Target Enhancers are active devices that need to be powered by battery.

6.5.3 RADAR BEACONS

Radar beacons (Racons) are receiver/transmitter devices operating in the maritime radar frequency bands (9 and 3 GHz) that enhance the detection and identification of certain radar targets. As previously noted, IMO MSC.192 (79) has done away with the requirement for 3 GHz radar to detect Racons.

A Racon responds to the presence of a ship's radar by sending a characteristic pulse train. The response appears as a coded mark (or "paint") on the ship's radar display (refer Figure 31) that highlights the range and bearing of the Racon. The display paint can be fixed to a specified length or can be dependent on the radar range setting. It uses a Morse Code letter character for identification.

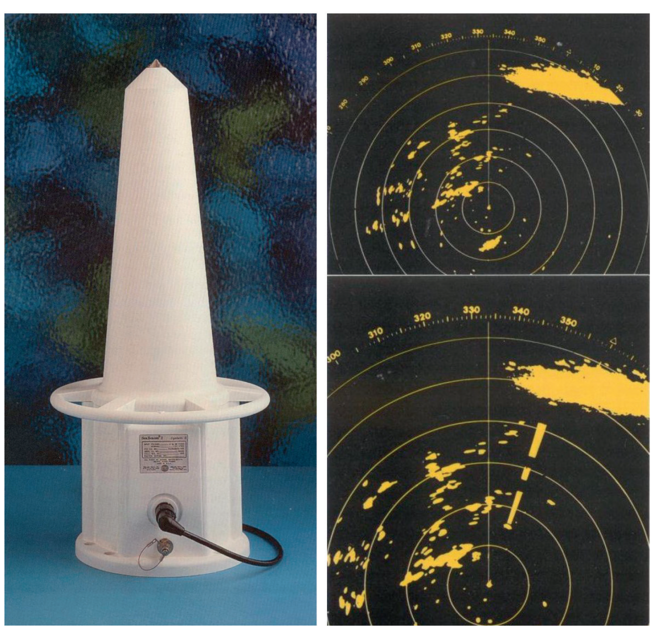


Figure 31. A Racon (left) and a Radar Display with and without the Racon character (right)

6.5.4 RACON APPLICATIONS

6.5.4.1 APPLICATIONS

A Racon is generally considered to be a supplementary Aid to Navigation installed at sites that would also be marked with a light. The number of vessels capable of making use of a Racon is effectively unlimited.

A Racon can be used for:

- ranging and identification of positions in ice conditions or on inconspicuous or featureless coastlines;
- identification of Aids to Navigation, both sea-based and land-based;
- landfall identification;
- indicating centre and turning points in precautionary areas or Traffic Separation Scheme (TSS);
- marking hazards;
- indicating navigable spans under bridges; and
- identifying leading lines.

6.5.4.2 FREQUENCY-AGILE RACON

A frequency-agile Racon responds on the frequency on which it is interrogated, and the response can be re-painted on each radar sweep. The purpose of frequency agility is to provide a signal to the radar that is within the receiver bandwidth of the radar.

Racons operate in the 9 GHz band with horizontal polarisation, and/or in the 3 GHz band, with horizontal and optional vertical polarisation.

Table 27. Preferred terminology for the description of Racon Operating Frequencies

Preferred Terminology	Alternatives		
9 GHz	9300 9500 MHz	X-BAND	3 CM
3 GHz	2900 3100 MHz	S-BAND	10 CM

6.5.5 RACON PERFORMANCE CRITERIA

The availability of a Racon is the principal measure of performance determined by IALA. In the absence of any specific considerations, IALA recommends that the availability of a Racon should be at least 99.8%.

6.5.5.1 RACON TECHNICAL CONSIDERATIONS

There are a number of technical considerations in the use of Racons to assist with the navigation of a ship:

- To avoid masking other features on the radar display, the Racon response is usually switched on and off on a pre-set cycle;
- The angular accuracy of the bearing between the ship and Racon depends entirely on the interrogating radar, while the accuracy of the range measurement depends on both the radar and Racon;
- When Racons are used in leading line applications, an alignment accuracy of about 0.3 degrees can be expected; and
- When a ship is very close to a Racon, side-lobes from the radar antenna can trigger the Racon. The resulting multiple responses on the radar display may be a distraction and can mask other targets. Side-lobe suppression techniques are standard features of frequency agile Racons.

6.5.5.2 USE WITH SOLID-STATE RADARS

All currently available and installed Racons are designed for use with high power pulse (magnetron) radars. In comparison, solid-state radars (previously referred to as New Technology or NT radar) use low power transmissions with long pulses. Due to the low received peak signal strength, long pulse at the Racon and modulation technique, current Racons may not detect solid-state radars and may not transmit a response usable by such radars. Studies have shown that pulsed solid-state radars are able to reliably trigger Racons at shorter ranges than would have been achieved with a magnetron pulsed radar. The IMO regulations regarding 9 GHz radars and Racons remain unchanged and although detection and triggering range might be reduced, it is the responsibility of manufacturers of 9 GHz solid-state radars meant to satisfy SOLAS carriage requirements to retain Racon functionality.

Despite changes to the IMO regulations relating to 3 GHz Racons, existing racons with 3 GHz capability will continue to be useful to 3 GHz pulse radars of both magnetron and pulsed solid-state variants. Advanced techniques of solid-state radars do not automatically mean that Racons are no longer useable. Some manufacturers are continuing to provide Racon compatibility in their solid-state 3 GHz radars.

Please refer to Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability for more information on solid-state radars.

6.5.6 RADAR REFERENCED POSITIONING

Algorithms may be developed to allow the radar display to be overlaid upon the electronic chart using detectable recognised navigational features (Racons, passive radar beacons or land edge patterns etc.). This technique, although unlikely to challenge the accuracy of a GNSS based position fix, might be adopted as part of a PNT integrity assessment and/or as a back-up in the event of GNSS service or equipment failure or corruption.

6.5.7 ENHANCED RADAR POSITIONING SYSTEM

A new system known as Enhanced Radar Positioning System (ERPS) has been under trial for many years and results have been presented at IALA conferences in 2014 and 2018. ERPS uses enhanced Racons (eRacons) that announce their location by encoding their identity and surveyed position into the response signals returned to radars. Enhanced Radars (eRadars) then use the encoded data to calculate position solutions. Dynamic position accuracies of better than 28 meters with availability better than 87% have been measured during trials. ERPS is independent of GNSS and can be used as a back-up system in support of resilient PNT.

Refer to IALA publications:

- Recommendation R0101 - Maritime Radar Beacons (Racons)
- Recommendation R0146 - Strategy for Maintaining Racon Service Capability
- Recommendation R0113 - The Marking of Fixed Bridges and other structures over Navigable Waters
- Guideline G1010 - Racon Range Performance
- Guideline G1147 – The use of enhanced radar positioning systems
- IALA Model Course C2007- - Aids to Navigation Technician Level 2 – Radar Beacon (Racon) Maintenance

6.6 NON-RADIO POSITIONING SYSTEMS

6.6.1 INERTIAL SYSTEMS

Many studies have been carried out on the integration of GNSS with Inertial Measurement Units (IMU) for maritime navigation. There exist various grades of IMU, from the very expensive navigation grade, through to tactical grade and low-cost units based on the Micro Electro Mechanics System (MEMS). The IMU grade characterizes the achievable performance of data provision covering velocities and orientations. A small IMU grade is associated with higher drift rates. Depending on the different drift rates, an IMU can provide contingency for various lengths of GNSS outages and support resilient PNT.

In combination with a GNSS compass, an IMU can provide accurate and stable heading data for longer GNSS outages. None of the currently available inertial systems is capable of maintaining all levels of navigation accuracy during a lengthy outage of GNSS. For ocean areas, both navigation and tactical-grade IMUs will give protection for appreciable outages over 15 minutes and navigation-grade IMUs for approximately 1 hour. For coastal areas, the required accuracy of 10 meter could be obtained for 3.5 minutes with a navigation-grade IMU and 1.5 minutes with a tactical-grade IMU.

6.6.2 ePELORUS

An electronic pelorus (ePelorus) is a device for taking bearings of visual marks and converting them to an electronic format for input to an electronic chart system. Such a device would enable the integration of visual AtoN with e-Navigation.

The feasibility of constructing a low-cost ePelorus from commercial off-the-shelf components is being investigated to demonstrate its effectiveness as a backup, and to evaluate the potential for integrating visual AtoN with e-Navigation.

6.7 AUTOMATIC IDENTIFICATION SYSTEM (AIS) - OVERVIEW

AIS was developed to provide automatic reporting between ships and also to shore, which contributes to the safety of navigation and facilitates traffic management by exchanging digital maritime information such as identity, position, time, course and speed; autonomously and continuously.

AIS is a 2 channel Digital VHF data broadcast and interrogation technology, which is Ship and shore-based, for monitoring and tracking. Data is exchanged automatically with other ships in radio range (not necessarily in sight) and VTS/AtoN centres. This data provides a ships identification; position; course and speed; ship type, dimensions, cargo and destination.

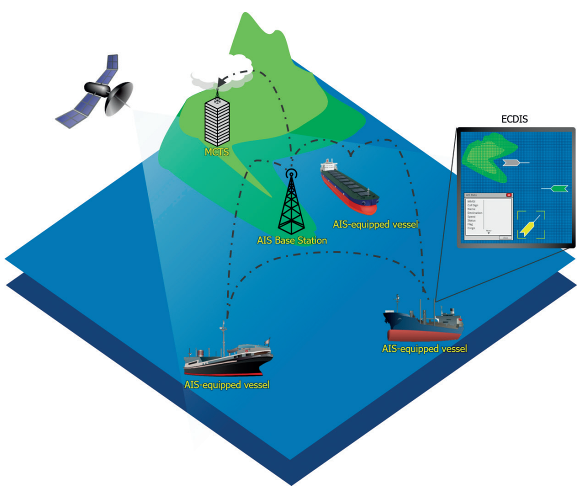


Figure 32. AIS overview

AIS might also be used for "mobile Marine AtoN" to mark temporary wrecks to comply with the Nairobi Convention.
AIS Communication aspects are further described in Chapter 9.

6.7.1 STRATEGIC APPLICATIONS OF AIS

AIS enhances situational awareness by providing information on vessels nearby: visible or just out of sight (around a bend in a navigational channel for example).

It improves safe and expeditious navigation and thereby supports the protection of the environment. It also enhances maritime efficiency by providing information for fleet management.

AIS also contributes to hazard avoidance and navigation assistance.

An important aspect for AtoN management is that Littoral States gain information about coastal traffic. This feature is essential to risk management and consequently for AtoN deployment. The diagram below shows vessel traffic from AIS data. The main shipping routes show the volume of traffic with a deeper colour signifying the greatest volume, for example in the Dover Channel and around many of the busiest ports the colour is red rather than green or yellow.

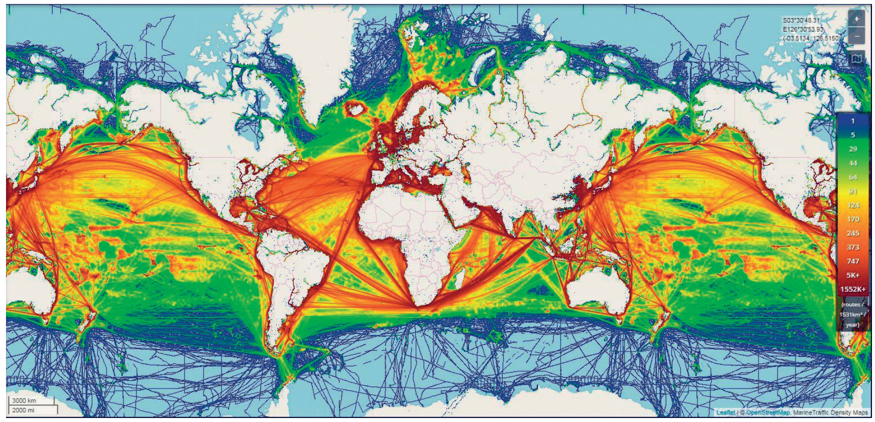
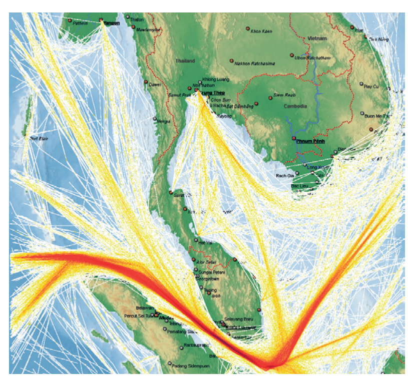


Figure 33. Examples of AIS tracks

The diagram showing the Malacca Straits also shows the volume of shipping traffic in this area. Appropriate software can further analyse the AIS tracks to determine the type of shipping, e.g. High speed craft (HSC), Pilot Vessels, Search and Rescue vessels, Tugs, Tankers with Hazardous cargo etc.

Furthermore, compliance with national and international regulations can be monitored (mandatory reporting; PSSA; TSS; MARPOL etc.).



6.7.2 IMO CARRIAGE REQUIREMENTS

IMO mandatory carriage requirement from Dec 2004 (SOLAS V. 19; 2.4) states that ships of 300GT and over must carry a Class A transceiver (AIS unit). The different classes of AIS units are explained later. SOLAS V.19 also advises Competent Authorities to provide AIS shore stations.

Smaller vessels (fishing/recreational) can voluntarily carry Class B units, but some States require Class B carriage.

Whatever class of unit is carried, all units must comply with ITU-R specification M.1371. This document is available for download from the ITU website.

A Minimum Keyboard Display (MKD) is essential but has significant limitations.

Post-2004 radars and ECDIS must display AIS targets using agreed symbols. The "target" may be a ship (of a certain class e.g. Cargo Ship, Dredger etc.) or an AtoN or shore station. The development of AIS is a good example of IMO/ITU/IEC and IALA cooperation.

6.7.3 SHIPBOARD AIS

- A Shipboard AIS unit will have automatic transmission of its' own data (identity, position, time, course and speed etc.) as well as automatic reception of AIS data from other ships and shore stations within its' VHF range.

The main components of the AIS unit comprise:

- VHF Transmitter;
- 2 x VHF Receivers;
- Processor;
- VHF DSC Receiver;
- GNSS Receiver;
- Comms interface to displays and sensors.

Figure 34. Examples of AIS data display

As already noted, a Minimum Keyboard Display (MKD: shown above on right) has significant limitations and AIS data is better displayed on radar and/or ECDIS (shown above on left).

The ship Information which is displayed includes:

- Fixed or static (i.e. ship or other target is at anchor or underway);
- Voyage related (i.e. destination, cargo etc.) ;
- Dynamic (i.e. course and speed); and
- Short safety Related message.

6.7.4 AIS AT SEA – CAUTIONS AND RISK CONTROL

All AIS users must be aware that vessels of less than 300GT vessels may not carry AIS. If no AIS is carried, no data is being transmitted/received and therefore that vessel will not appear on an ECDIS.

Consequently, AIS should not be used as a primary means of anti-collision.

AIS users must also be aware that not all crews of vessel set up their AIS correctly. Some of the data is entered into the AIS unit manually and there is the chance of incorrect information being entered or information not being updated.

One example of incorrect information might be "destination" where a vessel may report its destination to be a port to the west whereas the actual destination port may be to the east, giving an incorrect sense of sailing direction.

Port State Control can be used to target non-conformance.

6.7.5 SHORE-BASED AIS

SOLAS V 19 states that AIS shall provide and receive information from "appropriately equipped shore stations".

Competent Authorities should consider the requirement for AIS shore infrastructure to maximise its strategic benefits as outlined above. The clear implication following such a consideration is that Competent Authorities should provide shore-based AIS.

AIS is a vital tool for Vessel Traffic Service provision and obligatory risk assessment. AIS is also a valuable supplementary AtoN such as marking major lighthouses and buoys.

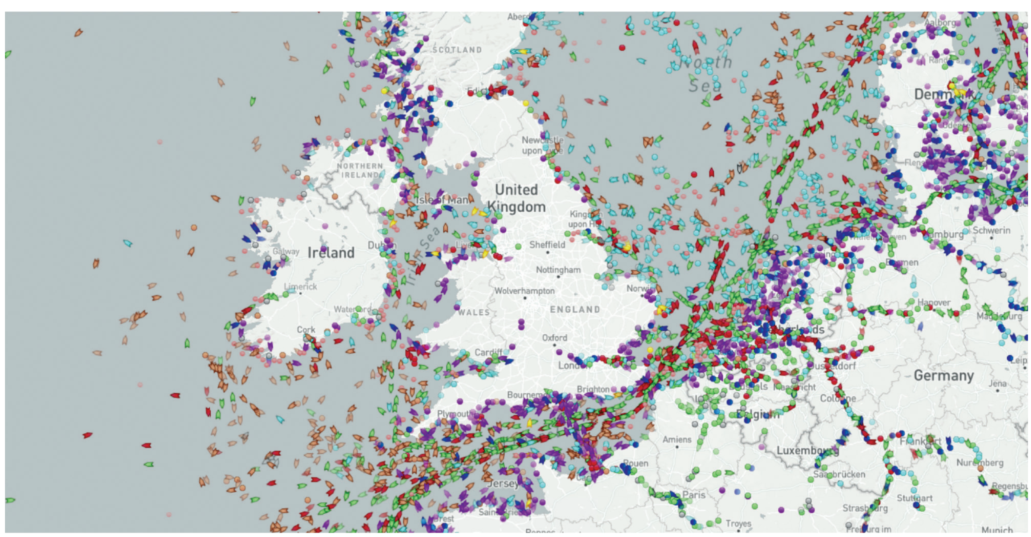


Figure 35. AIS information (types of ships, lighthouses, buoys etc.)

6.8 AIS AS A SHORT-RANGE AtoN

Special AIS units can be fitted to an AtoN (fixed or floating) which monitors and/or transmits a number of messages as follows:

- Identity: Message 21;
- Position from a GNSS/DGNSS sensor with buoy out of position warning (if appropriate): Message 21;
- AtoN performance monitoring: Message 21 or Message 6;

- AtoN condition (e.g. battery) and control: Message 6; and
- Meteorological and hydrological data: Message 6 (addressed) or Message 8 (broadcast).

These AIS AtoN can be used to mark a route, channel or an area. AIS is therefore a valuable supplementary short-range AtoN.

6.8.1 REAL, VIRTUAL AND SYNTHETIC AIS

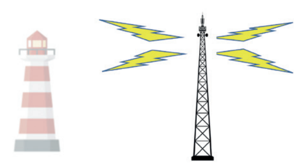
The use of AIS AtoN can vary from the provision of an actual unit on a physical (or 'real') AtoN to the transmission of a 'synthetic' or 'virtual' AtoN by an AIS base station, where they fall within the footprint of the base station.

6.8.2 REAL AIS AtoN

A Real AIS AtoN is an AIS unit which is located on an AtoN that physically exists. In this case, the Message 21 is transmitted directly from the AtoN.

6.8.3 VIRTUAL AtoN

The IALA definition states: "A virtual AtoN does not physically exist but is a digital information object promulgated by an authorised service provider that may be presented on navigational systems."



Digital information is broadcast via AIS which results in the Virtual AtoN being visible on MKDs and ECDIS, even though it does not physically exist. There are a number of scenarios where a Virtual AtoN would be deployed such as:

- Used to mark new dangers;
- Where it is impossible to deploy a physical AtoN (e.g. ice fields);
- Where an AtoN marking physical dangers are off station following a natural disaster or other event; and
- Route identification and dangers to deeper-draught vessels that must carry ECDIS.

A Virtual AtoN should only be deployed permanently where a physical AtoN would not be possible to deploy. However, this situation is under review by IALA/IMO. (Reference: IMO MSC.1-Circ.1473).

Virtual AtoN are used primarily where there is a time critical consideration, e.g. the need to quickly deploy Emergency Wreck Marking. However, they are not intended to replace physical AtoN.

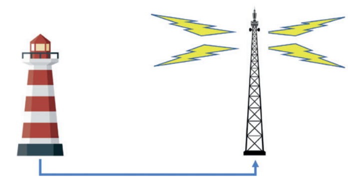
In order to alert users, the Virtual flag in Message 21 is set.

6.8.4 SYNTHETIC AIS AtoN

A Synthetic AIS AtoN is where the Message 21 is transmitted from an AIS station located remotely from the AtoN, e.g. from a nearby Base Station. The AtoN physically exists but does not transmit the AIS itself. There are two types of Synthetic AIS AtoN:

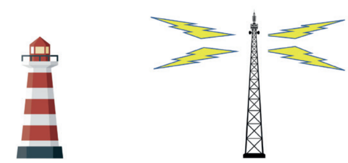
Synthetic (monitored) AIS AtoN

A "Monitored Synthetic AIS AtoN" is transmitted as a message 21 from an AIS Station that is located remotely from the AtoN. The AtoN physically exists and there is a communication link between the AIS Station and the AtoN. The communication between the AtoN and AIS confirms the location and status of the AtoN.



Synthetic (predicted) AIS AtoN

A "Predicted Synthetic AIS AtoN" is transmitted as a Message 21 from an AIS Station that is located remotely from the AtoN. The AtoN physically exists but the AtoN is not monitored to confirm its location or status.



A Predicted Synthetic AIS AtoN does not ensure the integrity of the Message 21, and therefore is not recommended for use on floating AtoN. The use of Predicted Synthetic AIS AtoN broadcasts for fixed AtoN is acceptable as the location will not change, but the status of the AtoN is not verified.

Refer to IALA Publications:

- Recommendation R0123 - Provision of Shore Based AIS
- Recommendation R0124 - The AIS Service
- Recommendation R0126 - Use of the AIS in Marine Aids to Navigation Services
- Recommendation R0143 - Provision of Virtual Aids to Navigation
- Recommendation R1016 - Mobile Marine Aids to Navigation (MAtoN)
- Guideline G1050 - Management and Monitoring of AIS Information
- Guideline G1062 - Establishment of AIS as an Aid to Navigation
- Guideline G1081 - Virtual Aids to Navigation
- Guideline G1082 - An Overview of AIS
- Guideline G1086 - Global Sharing of Maritime Data
- Guideline G1098 - On The Application of AIS - AtoN on Buoys

CHAPTER 7

VESSEL TRAFFIC SERVICES

7.1 INTRODUCTION

IALA Standard S1040 applies to Vessel Traffic Services. This Standard references normative and informative provisions, detailed in the listed IALA Recommendations, covering the following scope.

- VTS implementation
- VTS operations
- VTS communications
- VTS auditing and assessing
- VTS data and information management
- VTS technologies
- VTS additional services

This chapter provides a first point of reference, basic information and guidance on where more detailed guidance related to Vessel Traffic Services may be obtained.

7.2 BACKGROUND

SOLAS Chapter V Regulation 12 (Vessel Traffic Services) states, inter alia, that:
Vessel Traffic Services (VTS) contribute to safety of life at sea, safety and efficiency of navigation and protection of the marine environment, adjacent shore areas, work sites and offshore installations from possible adverse effects of maritime traffic.

Contracting Governments undertake to arrange for the establishment of VTS where, in their opinion, the volume of traffic or the degree of risk justifies such services. Contracting Governments planning and implementing VTS shall, wherever possible, follow the guidelines developed by the Organization. The current guideline is IMO Resolution A.1158(32), Guidelines for Vessel Traffic Services (VTS).

7.3 DEFINITION OF VTS

A VTS, as defined by IMO Resolution A.1158(32), Vessel traffic services (VTS) means services implemented by a Government with the capability to interact with vessel traffic and respond to developing situations within a VTS area to improve safety and efficiency of navigation, contribute to the safety of life at sea and support the protection of the environment.

7.4 PURPOSE OF VTS

The purpose of VTS is to contribute to safety of life at sea, safety and efficiency of navigation and the protection of the environment within the VTS area by mitigating the development of unsafe situations through:

- Provision of timely and relevant information on factors that may influence the ship's movements and assist onboard decision-making.
- Monitoring and management of ship traffic to ensure the safety and efficiency of ship movements.
- Responding to developing unsafe situations.

7.5 BENEFITS OF VTS

The benefits of implementing a VTS are that it allows identification and monitoring of vessels, strategic planning of vessel movements and provision of navigational information and assistance. It can also assist in prevention of pollution and coordination of pollution/ emergency response.

7.6 IALA VTS MANUAL

The IALA VTS Manual is acknowledged by the VTS community as being the most comprehensive guide to VTS as well as a point of reference for further detailed study.

The VTS Manual assists Contracting Governments, Competent Authorities and VTS providers in the harmonising the delivery of VTS worldwide by providing a comprehensive overview on all aspects relating to the provision of VTS. In particular, the Manual provides guidance on:

- The regulatory and legal framework for implementing and operating VTS;
- The obligations of Contracting Governments and Flag States; and
- IALA Standards relating to the implementation and operation of VTS and their associated Recommendations, Guidelines, and Model Courses.

The Manual is also aimed at a wide readership to encompass all who are in any way involved with the policy for provision, operation and effectiveness of VTS, including those with management responsibility at national level and those who deliver services to the mariner.

- The VTS Manual provides further information on, for example:
- Regulatory and legal framework of VTS;
- VTS Implementation;
- VTS Operations;
- VTS Communications;
- Auditing and Assessing in VTS;
- Additional Services;
- Data and Information Management;
- VTS Technologies; and
- Training and Assessment for VTS Personnel.

The VTS Manual is intended to complement IALA documentation relating to VTS. It is not intended to replicate the information and guidance in these documents or be prescriptive about the practices described within them. Rather, it provides a roadmap to assist authorities meet their obligations for the establishment and operation of VTS in a consistent manner.

The VTS Manual is available in digital format and will be updated regularly when new or revised documents have been approved. The latest version of the VTS Manual can be downloaded from the IALA website.

Refer to IALA Publications:

- IALA VTS Manual

Note there are many IALA publications relating to VTS. These are listed in the VTS Manual.

CHAPTER 8

TRAINING AND CERTIFICATION

8.1 INTRODUCTION

One of the aims of IALA is to foster the safe and efficient movement of vessels through the harmonisation of Marine Aids to Navigation services worldwide. SOLAS (2004 edition) Chapter V, Regulation 13, states that, 'in order to obtain the greatest possible uniformity in Aids to Navigation, Contracting Governments undertake to take into account the international recommendations and guidelines when establishing Aids to Navigation'. IALA defines international standards for the AtoN themselves through the publication of documents including Standards, Recommendations and Guidelines.

IALA Standard 1050 applies to Training and Certification. This Standard references normative provisions, i.e. provisions which shall be observed, detailed in the listed IALA Recommendations, covering the following scope.

- Training and assessment;
- Accreditation, competency, certification and revalidation and
- Capacity building.

The successful delivery of AtoN services depends upon competent and experienced personnel to implement and maintain such aids. The recruitment, selection, training and assessment of competant personnel are pre-requisites to the provision of professionally qualified and certified personnel capable of contributing to safe and efficient AtoN operations. Certification and revalidation of those personnel should be from accredited organisations.

In addition, Resolution 10 of the Standards of Training & Certification for Watchkeepers (STCW) code states that the contribution of vessel traffic service personnel contributes to the safety of life and property at sea and the protection of the marine environment.

IALA addresses the aim of appropriate training in several ways, one of which is to recommend that Marine Aids to Navigation Authorities and relevant Competent Authorities for VTS and VTS providers ensure their staff receive a high standard of training. To assist with this approach, IALA Recommendation E-141 on Training and Certification of Marine Aids to Navigation Personnel and R0103 (V-103) on Training and Certification of VTS Personnel, together with associated model courses and supporting Guidelines, were developed. Both the ARM and ENG Committees continue to develop the training requirements for AtoN Management and Engineering Personnel through the World-Wide Academy (WWA).

Competent Authorities should ensure that all employees have the knowledge, skills and training to perform their duties effectively, efficiently and with safety. As well as permanent staff, the term 'employees' includes newly hired, part time and temporary employees.

The ISO 9001 Quality Management standard places considerable emphasis on competence, awareness and training.

8.2 IALA WORLD WIDE ACADEMY

8.2.1 INTRODUCTION

The IALA World-wide Academy (WWA) is the vehicle by which IALA delivers Education, Training and Capacity Building. The objective of the Academy is not so much to deliver training by itself, but rather to develop and promote the use and delivery of IALA model courses world-wide. Many of the IALA model courses are delivered through a global network of Accredited Training Organisations (ATOs) with the support of the IALA World-Wide Academy.

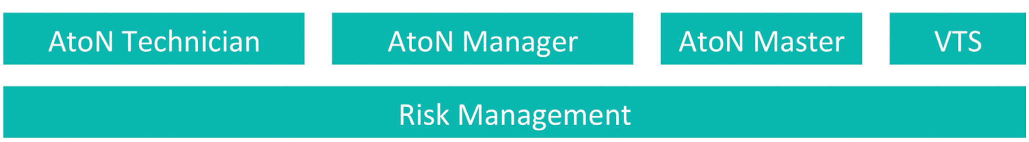
8.2.2 ACCREDITED TRAINING ORGANISATIONS

Accredited training organisations (ATO) have been subject to audit by a Competent Authority in accordance with the IALA Accreditation Scheme to ensure that they have the necessary quality and training management systems in place to deliver high quality training in accordance with the IALA standards.

The Academy delivers a range of courses itself, particularly those which are not being delivered by any accredited training organisations or where demand exceeds the existing capacity in a given region or language.

8.2.3 TRAINING PROGRAMMES

Based on the IALA model courses, a series of training programmes have been developed as illustrated below:



- The AtoN Technician programme provides a framework for the training and education of personnel tasked with conducting the installation, servicing, maintenance or replacement of marine Aids to Navigation and their components.
- The AtoN Manager programme covers fundamental principles of effective management, with a significant emphasis on the implementation of IALA standards, to enable coastal States have suitably qualified professionals to effectively discharge their obligations under the SOLAS Convention.
- The AtoN Master programme covers more in depth principles of effective management with emphasis on good governance and strategy.
- The Vessel Traffic Service programme covers the aspects of delivering a Vessel Traffic Service described in the C0103 series of model courses. The IALA VTS C0103 model courses are delivered by a global network of accredited training organisations.
- The Risk Management programme provides training on the use of the IALA Risk Management Tools, including SIRA, PAWSA, IWRAP and simulation.

8.2.4 WWA MODEL COURSES

The content of all Model courses takes into account IALA Recommendations and Guidelines and the NAVGUIDE Manual. Those describing technical functions for Level 2 technician training can also be used for Level 1 manager training if appropriate.

The Model Courses are designed to produce universally common standards. It is for the relevant Competent Authority to approve the AtoN courses undertaken at accredited training organisations. The model courses are developed by the IALA technical committees and approved by the IALA Council for publication. The Academy works closely with the committees; their Working Groups, and where appropriate with IALA Industrial Members, to ensure that model courses and other training documentation are maintained in the most efficient manner for the benefit of IALA Members, potential Members and the accredited training organisations.

Aids to Navigation service providers should base their technician training on these model courses. In some cases the courses can be developed further to address particular topics related to the maintenance and operation of specific systems and equipment used by the AtoN service provider.

The Academy does generally not deliver these model courses directly. The courses are delivered in English, French and Spanish with Arabic and Portuguese programmes under longer-term development. The range of languages is continuously under review and other languages may be available upon request, drawing on the expertise of the global network of accredited training organisations.

8.2.5 WWA CAPACITY BUILDING

Many coastal States have a need to develop and/or reinforce their national and institutional capacity to deliver Marine Aids to Navigation services to international standards. Therefore, the Academy undertakes capacity building by:

- Conducting workshops and seminars to raise the awareness of high-level decision makers with respect to their international obligations;
- Undertaking analytical missions to identify gaps between current practices and international standards and provides advice on how to bridge these gaps;
- Arranging follow-up activities to review progress made towards conformance with international standards; and
- Providing opportunities for individuals to participate in training and IALA events to raise their level of expertise and interact with other Marine Aids to Navigation professionals.

Further information on the IALA World-Wide Academy is available on the WWA website at https://academy.iala-aism.org/wwa/.

8.3 TRAINING AND CERTIFICATION OF MARINE AIDS TO NAVIGATION PERSONNEL

National AtoN Competent Authorities are encouraged to adopt IALA Recommendation R0141 - Training and Certification of Marine AtoN Personnel together with the associated model courses as the basis for mandatory training in a manner consistent with their domestic legal framework.

The objectives of Recommendation R0141 are to provide a basis:

- for AtoN Authorities when recruiting potential AtoN staff;
- for model courses used to develop a training programme on the specific knowledge, skills and attitude requirements necessary to qualify AtoN personnel;
- to ensure that AtoN personnel gain the appropriate level of competency to enable them to perform the tasks required;
- to assess regularly the ability of AtoN personnel to perform to established and recognised standards;
- to provide a basis for a structured progression for AtoN personnel;
- to foster professionalism and pride in AtoN personnel;
- to support, as far as is practicable, the consistent application of AtoN standards world-wide; and
- for AtoN Authorities to meet their international obligations.

8.3.1 MARINE AIDS TO NAVIGATION TECHNICIAN

The IALA Marine Aids to Navigation Technician series of model courses provides a framework for the training and education of personnel tasked with conducting the installation, servicing, maintenance or replacement of Marine Aids to Navigation and their components. An overview document further describes the objectives of this training.

The 30+ model courses for Level 2 AtoN Technician Training cover a range of subject areas, including:

- Introduction to Aids to Navigation
- Introduction to Aids to Navigation buoyage
- Buoy moorings, handling and cleaning
- Power supplies
- Lights and marine lanterns
- Sound signals
- Painting and coatings
- AtoN service craft and buoy tenders
- Radar beacons (RACONS)
- Automatic Identification Systems (AIS)
- Radionavigation and Differential Global Navigation Satellite Systems (DGNSS)
- Remote monitoring and control
- Structures, materials and AtoN maintenance

These L2 model courses are not intended to be used directly as course material but are guides that can be adapted to enable course design to be matched to the requirements of individual AtoN Competent Authorities.

Refer to IALA Publications:

- Recommendation R0141 – Training and certification of Marine AtoN Personnel
- Guideline G1020 – Training related to AtoN
- Guideline G1169 – Training and certification of Marine Aids to Navigation personnel
- IALA Model Course C2000 – Aids to Navigation Technician Level 2 – Model Course Overview
- IALA Model Courses (as detailed further above)
- Recommendation R0149 – Accreditation of training organisations
- Guideline G1100 – Accreditation and approval process for AtoN personnel training

8.3.2 AIDS TO NAVIGATION MANAGER TRAINING

Training for Aids to Navigation Managers is set out in the following IALA model course:

- IALA Model Course C1001 – Marine Aids to Navigation - Manager Training

This paid training is intended for those responsible for the operational management and implementation of AtoN services. Candidates may be employed by Competent Authorities charged with the provision of AtoN services as well as port authorities, AtoN manufacturers and consultants.

Training is available through a global network of Accredited Training Organisations and by means of distance learning.

The course consists of three modules:

- **Module One – Nautical Aspects**
  Introduces the marine environment and AtoN as well as maritime knowledge required by an AtoN manager.
- **Module Two – Technical aspects**
  Focuses on the technical and operational knowledge of visual, radio and audible AtoN and Vessel Traffic Services required by an AtoN manager.
- **Module Three – AtoN Management**
  Focuses on theoretical and practical aspects of AtoN provision, design and management.

Candidates will be given access to on-line tutorial material for module 1 and 2 while module 3 may be a residential course. Accompanying text books are available for each module.

Training in the use of the IALA Risk Management tools is set out in the following IALA model course:

- IALA Model Course C1003 – Aids to Navigation Manager Level 1 - Use of the IALA Risk Management Tools

This training is intended for those responsible for ensuring the provision of appropriate and evidence based safety of navigation risk management as required by SOLAS Chapter V Regulation 12 and 13. Training is available through the IALA World-Wide Academy at venues world-wide and also by means of distance learning.

The course comprises 4 modules:

Each module involves case studies, small-group discussions with international experts, individual topic investigation and hands-on exercises, and ensures that participants gain an operational knowledge of waterway risk management. The Risk Management Programme is modular in nature. Participants will be required to undertake the introductory module (M0) on the concepts and obligations of risk management, and the capabilities of each risk management tool, before moving on to the more advanced modules. Following this introductory module (M0), participants can elect to take the advanced courses on the use of one or more of the IALA risk management tools.
Other AtoN Manager courses are also available.

Refer to IALA Publications:

- IALA Model Course C1004 – Aids to Navigation Manager Level 1 - Global Navigation Satellite Systems and e-Navigation
- IALA Model Course C1005 – Aids to Navigation Manager Level 1 - Historic Lighthouse Projects
- The GNSS course and the Historic Lighthouse projects course are delivered by the Academy on demand.
- IALA Model Course C1003 – Aids to Navigation Manager Level 1 - Use of the IALA Risk Management Tools

These L2 model courses are not intended to be used directly as course material but are guides that can be adapted to enable course design to be matched to the requirements of individual AtoN Competent Authorities.

8.3.3 MASTER OF MARINE AIDS TO NAVIGATION TRAINING

Training for Master of Marine Aids to Navigation Management is set out in the following IALA model course:

- IALA Model Course C1002 - Master of Marine Aids to Navigation Management

The WWA offers this Master of Marine Aids to Navigation Management qualification which addresses key aspects of AtoN governance from a strategic perspective and is aimed at senior management personnel concerned with AtoN service provision or its supervision. This training is intended for those with responsibility for the strategic management and implementation of AtoN services. Training is available through the IALA World-Wide Academy in cooperation with a global network of Accredited Training Organisations and by means of distance learning.

This course consists of two modules:

M1 – Strategy and Governance → M2-Group task: Strategic Analysis

Module one

Covers areas of knowledge in which senior AtoN managers are required to have knowledge and skill related to governance and strategic management.

Module two

A group task to produce a specific strategic analysis of an AtoN authority.

8.3.4 SUPPLEMENTARY SHORT COURSES

In addition to the IALA model course programmes, IALA delivers supplementary short courses on demand, based on IALA publications and lectures from the Academy model course programmes. Listed below are some of the potential short courses available (the numbers after the course names refer to the relevant IALA publications):

- Maritime Buoyage System (R1001)
- Contracting out Aids to Navigation Services (G1005)
- Categorisation and availability objectives for short range AtoN (R0130)
- Level of service (G1004)
- Recording of Aids to Navigation positions (R0118)
- Virtual Aids to Navigation (G1081)
- Selection of rhythmic characters and synchronization of lights for (marine) Aids to Navigation (G1116)
- "How to" series of Marine Aids to Navigation procurement courses including topics such as preparing a business case, managing stakeholders, writing specifications and appraising tenders.

8.4 TRAINING AND CERTIFICATION OF VTS PERSONNEL

A major factor in the effective delivery of a Vessel Traffic Service (VTS) is the competence and experience of its personnel to:

- provide timely and relevant information on factors that may influence the transit of a ship and to assist on-board decision making;
- monitor and manage traffic to ensure the safety and efficiency of ship movements; and
- respond to developing unsafe situations to assist the on-board decision-making process.

IMO Resolution A.1158(32) Guidelines for vessel traffic services states, inter-alia, that:

a) The level of safety and efficiency in the movement of maritime traffic within an area covered by a vessel traffic service is dependent upon close cooperation between those operating the vessel traffic service and participating ships.

b) The Contracting Government should appoint and authorize a Competent Authority for VTS.

c) The Competent Authority for VTS should ensure that VTS training is approved and VTS personnel are certified.

d) The VTS provider should ensure that VTS facilities are adequately staffed and that VTS personnel are appropriately trained and qualified.

IALA Recommendation R0103(V-103) provides the framework to assist Competent Authorities and VTS providers recruit, train and assess VTS personnel to ensure the harmonised delivery of vessel traffic services world-wide.

Refer to IALA Publications:

- Recommendation R0103 (V-103) – Training and certification of VTS personnel
- Guideline G1156 - Recruitment, training and certification of VTS Personnel
- Guideline G1014 - Accreditation of VTS Training Organisations and Approval to deliver VTS model courses
- Guideline G1027 - Simulation in VTS Training
- Guideline G1103 - Train the Trainer
- Guideline G1017 - Assessment of prior training exemption for VTS model courses
- IALA Model Course C0103-1 (V-103/1) Vessel Traffic Service Operator training
- IALA Model Course C0103-2 (V-103/2) Vessel Traffic Service Supervisor training
- IALA Model Course C0103-3 (V-103/3) Vessel Traffic Service On-the-Job training
- IALA Model Course C0103-4 (V-103/4) Vessel Traffic Service On-the-Job Instructor
- IALA Model Course C0103-5 (V-103/5) The Revalidation Process for VTS Qualifications and Certification

For further information on VTS issues, please refer to IALA VTS Manual, available on the IALA website.

8.5 EXAMPLES OF OTHER TRAINING OPPORTUNITIES FOR ATON AND VTS PERSONNEL

On-the-job (OTJ) training is instruction for employees that takes place at their workplace. This usually involves a combination of observing others, combined with hands-on experience completing work. OTJ training is normally conducted under the supervision of a training manager, co-worker or outsourced professional trainer.

During OJT, personnel learn the processes and procedures their employer uses. Personnel may also learn how to operate any equipment, tools or machinery required for their function. The instruction and hands-on practice completed as part of the training can help develop the skills, competencies and knowledge needed to carry out tasks at the company or organisation. Part of OJT may include job shadowing or observing an experienced employee perform certain job tasks.

Job shadowing is a form of on-the-job learning that allows interested employees to closely follow, observe, and at times perform tasks of another more experienced employee performing the role.

Mentorship is the influence, guidance, or direction given by a mentor. A **mentor** is someone who teaches or gives help and advice to a less experienced and often younger person. In an organisational setting, a mentor influences the personal and professional growth of a mentee. Most traditional mentorships involve having senior employees' mentor more junior (or newly joined) employees, but mentors do not necessarily have to be more senior than the people they mentor. What matters is that mentors have experience that others can learn from. This is usually a more formal type of training opportunity than On the Job training or job shadowing.

A "**Toolbox talk**" is a short presentation on a single aspect of health and safety. The talk usually takes place prior to the start of work. Toolbox talks are quick, simple, and easy to understand safety discussions. A toolbox talk is ideally an informal discussion of about 5-10 minutes with workers to chat about awareness of health and safety risks associated with their tasks. An effective toolbox talk helps promote a culture of safety in the workplace and facilitates a sharing of knowledge and safety best practices among workers.

Examples of Toolbox talks are:

- Preventing Slips, Trips, and Falls
- Working at Height Safely
- Working near or over water
- Manual Handling
- Hazardous Substances such as:
    a. Asbestos awareness
    b. Mercury awareness
- Electrical safety
- Fire Safety
- Environmental awareness.

Formal **specialised training** may be required by certain employees to become certified to operate specific equipment such as Crane Driver, Forklift operator, welder etc. This certification may need to be updated on a regular basis.

Safety training should be undertaken before employees access certain sites or work-stations. This may be a requirement under local regulations and may need to be updated on a regular basis.

CHAPTER 9

DIGITAL COMMUNICATION TECHNOLOGIES

9.1 DIGITAL COMMUNICATIONS SYSTEMS

IALA Standard S1060 applies to Digital Communication Technology. This Standard references normative and informative provisions, detailed in the listed IALA Recommendations, covering the following scope.

- Wide and medium bandwidth systems
- Narrow bandwidth systems
- Harmonised maritime connectivity

In this era of near-instantaneous communication, digital technologies are gradually being integrated into the maritime environment. Limitations in communication, such as transmission range, data speed, and access cost, are steadily being addressed and overcome.

In the upcoming years, it is expected that the availability of robust, cost-effective maritime digital communication systems to rise. IALA has played a significant role in the development of such systems, with key contributions to technologies like AIS and, more recently, VDES.

9.2 THE IALA MARITIME RADIO COMMUNICATIONS PLAN (MRCP)

Maritime Radio Communication Plan (MRCP) is a comprehensive framework designed to facilitate efficient and coordinated use of radio communication systems in the maritime domain from the perspective of IALA.

The MRCP aims to ensure seamless communication between various stakeholders, such as ships, coastal stations, and port authorities, by standardizing radio frequencies, operational procedures, and equipment. This, in turn, enhances navigational safety, environmental protection, and overall efficiency of maritime operations.

9.3 AIS (COMMUNICATIONS ASPECTS)

An overview of the Automatic Identification System (AIS) was introduced in a previous chapter 6.7. To recap, it is a VHF maritime mobile system designed as a tool to argument navigation data for ship-to-ship collision avoidance and VTSs, and, as a means for littoral States to obtain information about ships and their cargo. AIS also allows for the exchange of safety related data between ships, from ship to shore and from shore to ship. There are numerous types of AIS devices, known as stations, which are identified by a unique Maritime Mobile Service Identity (MMSI) and use the AIS international open standard to communicate. AIS enables the automatic exchange of shipboard data from vessel sensors (dynamic data), as well as manually entered static and voyage related data, between one vessel and another and between a vessel and a shore authority using terrestrial or satellite communications. AIS has been mandated as a shipboard carriage requirement for vessels under the revised Chapter V of the International Convention for the Safety of Life at Sea, 1974 (as amended)(SOLAS 74) section 19.2.4. In addition, some administrations require AIS carriage on non SOLAS vessels. The main benefits of AIS are summarized below:

- Data exchange, such as identification and course, between vessels within VHF range of each other, increasing situational awareness;

- Data exchange between a vessel and shore authorities, such as a VTS, to improve traffic management in waterways, coastal and remote areas where AIS is sometimes the only mean to exchange data;
- Automatic reporting in areas of mandatory and voluntary reporting;
- Exchange of safety related information between vessels, and between vessels and shore station(s).

The development of AIS has broadened to encompass devices such as AIS for Aids to Navigation (AIS AtoN), AIS on search and rescue aircraft, and AIS search and rescue transmitters (EPIRB-AIS, AIS-SART, and AIS-MOB). The success of AIS has led to its increased adoption and expansion, raising concerns about the system's reliability as it becomes overloaded. As a result, the International Maritime Organization (IMO) issued Resolution MSC.347(91) Annex 15 to protect AIS. This concern also served as a driving factor for the development of the VHF Data Exchange System (VDES), which is discussed in the next section (8.4).

Moreover, the use of Autonomous Maritime Radio Devices (AMRD) on AIS frequencies has been restricted by the IMO and the International Telecommunication Union (ITU) to only those devices that enhance navigational safety. These devices are referred to as AMRD group A. For equipment that does not meet the criterion of improving navigational safety, AMRD group B, a new channel (2006) was allocated at the World Radiocommunication Conference 2019 (WRC-19), where AIS technology can be utilized. The relevant documents addressing AMRDs include IMO Resolution MSC.441(99) and ITU recommendations ITU-R M.1371-5 and ITU-R M.2092.

IALA Guideline G1082 provides a comprehensive overview of AIS and an extensive listing of all AIS related documentation from various international organisations in its Annex.

It is important to note that AIS does not provide any cyber security protection.

9.4 VDES

The VHF Data Exchange System (VDES) is a radio communication system that operates in the VHF Maritime Mobile band. The VDES consists of 4 components:

- The AIS uses channels AIS 1, AIS 2, CH75 and CH76. AIS 1 and AIS 2 are for terrestrial communications while satellite uplinks can use all channels, AIS 1, AIS 2, CH75 and CH76;
- The Application Specific Messages (ASM) component of VDES uses channels ASM 1 and ASM 2, for both terrestrial communications and satellite uplinks.
- The VHF Data Exchange Terrestrial (VDE-TER) component of VDES uses channels 1024, 1084, 1025, 1085, 2024, 2084, 2025 and 2085 for terrestrial communications.
- The VHF Data Exchange Satellite (VDE-SAT) component of VDES uses channels 1024, 1084, 1025, 1085,1026, 1086, 2024, 2084, 2025, 2085, 2026 and 2086, for both satellite uplink and downlink communications.

The sections below provide a short introduction to each VDES component other than AIS which was already discussed above. There are 3 IALA documents that provide additional information on VDES and its sub-systems.

- Recommendation R1007 – The VHF Data Exchange System (VDES) for Shore Infrastructure
- Guideline G1117 - VHF Data Exchange System (VDES) Overview
- Guideline G1139 – The Technical Specification of VDES will be superseded by ITU.R M.2092-1
- Additionally, these ITU documents provide important technical information for VDES:
- ITU-R M.2092, Technical characteristics for a VHF data exchange system in the VHF maritime mobile band.
- Report ITU-R M.2231, Use of Appendix 18 to the Radio Regulations for the maritime mobile service
- Report ITU-R M.2435-0 [VDE-SAT]

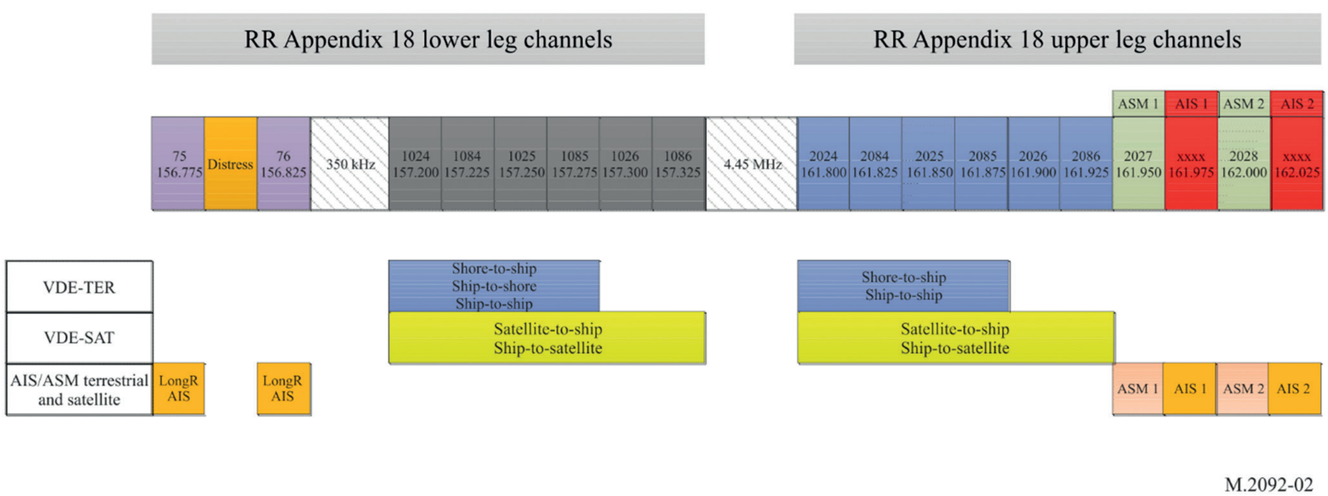


Figure 36. VDES frequency usage

9.4.1 WHY VDES INCLUDES AIS?

VHF Data Exchange System (VDES) comprises a suite of channels in the VHF Maritime mobile band and forms a contiguous block of frequencies that includes both international AIS frequencies as shown in the figure above. For this reason, the VDES was designed in such a way to simplify radio equipment complexity allowing a single "smart" radio box to perform all VDES functionalities, including AIS. Anchored in VDES design is the protection of AIS and the situational awareness it provides to mariners and shore authorities. As such, all AIS functionalities are a part of VDES just as they would be available on an independent AIS device. In principle, a VDES unit could replace the AIS equipment using the same antenna, power and connectivity. For shore authorities to make use of the full capabilities of VDES, improvements to the infrastructure might be necessary.

9.4.2 ASM COMPONENT OF VDES

The Application Specific Message component of VDES uses 2 channels (ASM1 and ASM2). The purpose of ASM is to offload the AIS channels from the growing use of various messages to exchange data that is safety related, but not directly relevant to collision avoidance. The deployment of ASM across the globe should relieve AIS frequencies from such usage and ensure the availability of AIS for collision avoidance and safety purposes, increasing its effectiveness. Examples of ASM data that are currently carried over AIS frequencies include meteorological / hydrological data, waterways obstructions, recommended routes, etc. The ASM channels use a more efficient signal modulation than the original AIS frequencies which allows for more data, almost twice, to be carried in the same time slot/ frame. Existing AIS messages could be simply reused on ASM or VDE channels.

IALA maintains a list of all available Application Specific Messages on all physical links (AIS, VDES-ASM and VDES-VDE) that have been created and are used across the world for ASM purpose. The list can be found on the IALA website https://www.iala-aism.org/asm/ and where also new proposed ASMs can be registered. It is important to note that VDES does not provide any cyber security protection and has to be implemented as ASM.

9.4.3 VDE-TER COMPONENT OF VDES

The purpose of the VDE-TER component is to provide a communication system capable of supporting e-Navigation growing requirements within VHF range (approx. 40 to 60 km). It is expected that ASM will not be able to meet the native transfer requirements of the S-100 suite (S-1xx, S-2xx, S-4xx, etc) of data products. As e-Navigation standardize on S-100 data products, the maritime safety data will be in need of a communication system with expanded capacity to carry this information to and from ships in waterways and coastal areas. This is the gap that is filled with VDE-TER.

VDE-TER uses 4 duplex channels to achieve 100kHz of bandwidth available to carry data from ship-to-ship, shore-to-ship and ship-to-shore. The maximum total capacity of the channel is approximately 230kbps that is divided amongst the users (ship or shore stations) of the system in a specific area. For example, there could be one shore station and 5 ships using VDE-TER simultaneously to exchange data, each getting about 38kbps of throughput.

VDE-TER is providing much more capacity than AIS and ASM, but it is still an order of magnitude slower than other commercial communication systems such as cellular 3G/4G/5G. This limitation will require VDES to be carefully managed by shore authorities to make sure priority is given to safety related data pertinent to the ship's context.

9.4.4 VDE-SAT COMPONENT OF VDES

The purpose of the VDE-SAT is to extend VDE coverage beyond the shore-based coverage of VDE-TER and offer global coverage. As such VDE-SAT is an essential supplement to terrestrial VDE coverage provided by VDE-TER in support of e-Navigation services.

VDE-SAT use 2x150kHz, of which 2x100kHz are shared with VDE-TER and 2x50kHz are identified for VDE-SAT only. The VDE-SAT downlink support data rates ranging from about 2 kbps to 48 kbps, depending on link quality. The VDE-SAT uplink support data rates ranging from about 1 kbps to 95 kbps, depending on link quality and interference environment observed by the satellite. These data rates are total system rates for a 50 kHz channel of which can be allocated to and shared between 1 and 6 users.

VDE-SAT is capable of supporting the same services envisioned for VDE-TER. However, the reduced data rates and inherent store and forward operations mode of VDE-SAT may not be suitable for all services. As for VDE-TER the resources available in VDE-SAT should be carefully managed by the satellite operators to ensure priority is given to the appropriate services.

9.5 R-MODE

As GNSS signals are not always reliable and subject to jamming and spoofing, it is desired to have alternative means of maritime navigation. One approach for that is to equip communication systems on the shore with the option to transmit ranging signals (R-Mode), which vessels can use to determine their position when within range of these stations. The VHF Data Exchange System (VDES), which is currently in standardisation, can be utilized for this R-Mode application.

The demand for a resilient positioning, navigation and timing (PNT) solution was reflected by the ACCSEAS project and is being further developed by the R-Mode Baltic Project which investigates in the MF and in the VHF band additional ranging sequences.

The proposal for such an alternative system is termed Ranging-Mode (R-Mode). R-Mode intends to utilize the shore-based communication infrastructure, like DGPS (IALA beacons), Automatic Identification System (AIS) or VDE base stations [2] [9] with the existing housing infrastructure.

The accuracy of ranges between the base station on land and the vessel at sea, measured by means on the received radio signal, depends on the utilized bandwidth and of the received signal power versus the power of other noise sources.

9.6 LTE-M AS A COMMUNICATIONS INFRASTRUCTURE

The objective of LTE-Maritime or (LTE-M) is to provide high data rates in the order of megabits per second within the communication coverage of 100km from the shoreline.

In 2017, in order to confirm the feasibility of LTE technology on maritime field, a testbed was developed in the Republic of Korea and several field experiments were conducted. The experiment results show that, although there exist the interference issues with other communication signals, LTE-Maritime can provide the data rates over Mbps and the communication coverage around 100km.

9.6.1 LTE-M

LTE-M is based on LTE technology that is a promising solution for wireless maritime network.

To support the requirements of various data services, the maritime communications providing high-speed data rates and extended communication coverage need to be developed. Unfortunately, the conventional communication systems of maritime field such as VHF, MF/HF were operated on the terrestrial radio frequency specified on the maritime missions of GMDSS convention. In case of satellite like Inmarsat, the channel capacity and operative cost are not reasonable for the private user purpose. They could be a good communication system on GMDSS missions globally but not a good solution to be used as a communication system for the various services like e-Navigation, especially in specific local water requiring high data rates for their own services.

LTE is capable of providing increased data rate, capacity, and spectral efficiency even in dynamic propagation environments with the support of advanced techniques such as multiple-input multiple-output (MIMO) and carrier aggregation (CA). Furthermore, it has the potential to provide the communication coverage about 100 km depending on the cell environments, though LTE for commercial mobile communication is designed with a relatively short cell coverage. This superiority of LTE makes us develop a single-hop network enabling ship-to-shore data communication based on LTE technology.

In general, the wireless mesh networks are vulnerable to link failures caused by radio interference and they could not assure reliability. Contrary to existing maritime networks for extending the communication coverage with multi-hop transmission, LTE-Maritime enables ships to directly communicate with onshore BSs and it could improve reliability. Therefore, it is more suitable especially for the safety related maritime services that require high reliability as well as low latency.

9.7 LOW POWER COMMUNICATION SYSTEMS

There are proprietary and Internet Protocol Suite (TCP/IP) based systems (mostly in low earth orbits (LEO) available and partly GMDSS approved.

Especially LEO satellite constellations offer high bandwidth communication coverage for wide sea and coastal areas. This is able to cover a lot of communication requirements. By providing sufficient bandwidth suitable cyber security protection can be implemented. It is already be used for fleet monitoring, predictive maintenance and applications like chart updates. Standards for provision of Maritime Safety Information (MSI) are under development.

9.8 LOW POWER COMMUNICATION SYSTEMS

Low power communication systems, such as LoRa (Long Range), Sigfox, and NB-IoT (Narrowband IoT), are emerging technologies that have the potential to significantly impact maritime communication. These systems are designed to provide long-range, low-power wireless connectivity, making them ideal for various IoT (Internet of Things) applications in the maritime sector.

IALA recognizes the importance of exploring and evaluating the potential of low power communication systems for maritime use. These technologies could be employed for various purposes, such as tracking and monitoring assets, environmental monitoring, and enhancing safety and efficiency in port operations.

IALA could encourage its members and the maritime community to study and assess the feasibility of these technologies for maritime applications. Additionally, IALA could facilitate collaboration among its members, industry partners, and other relevant organizations to identify best practices, develop standards, and promote interoperability of low power communication systems within the maritime domain.

9.9 AUTONOMOUS MARINE RADIO DEVICES

There are numerous maritime radio devices that operate autonomously. These include but are not limited to: devices on towed or unpowered ships and barges, "man overboard" devices, diver locating, alerting and radiotelephony devices, fishing net marker buoys, oil spill tracking buoys, oceanographic, and other drifting buoys.

Some types of autonomous maritime radio devices (AMRD) use AIS or digital selective calling (DSC) technology. They can also transmit synthetic voice messages or employ a combination of these technologies. These devices have been developed for and are operating in the maritime environment, with their numbers expected to grow.

Certain devices do not enhance the safety of navigation or serve the purpose of communication between coast stations and ship stations, or between ship stations, or between associated onboard communication stations, or survival craft stations and emergency position-indicating radio beacon stations. Nevertheless, they occupy the spectrum and identities of the maritime mobile service.

There is a need to categorize and regulate the usage of autonomous maritime radio devices. In 2019, the ITU adopted the preliminary draft definition of AMRD. The categorization of AMRD and relevant information are contained in the draft new recommendation ITU-R M.2135 and will operate on a new channel (2006). In principle, these devices will use AIS technology but are not limited to it. The new recommendation could be published in 2022.

The generally agreed IMO position states that:

- the integrity of AIS and the Global Maritime Distress and Safety System (GMDSS) should be protected;
- autonomous maritime radio devices which enhance the safety (of navigation) should be regulated for the use of frequencies and identities of the maritime mobile service; and
- for autonomous maritime radio devices which do not enhance the safety (of navigation), regulation of the use of frequencies, and technical and operational characteristics, should benefit both the user of devices as well as maritime safety.

9.9.1 AMRD GROUP A

This group consists of Mobile Aids to Navigation (MAtoN) and Man Over Board Class M (MOB). Their technical and operational characteristics are described in the most recent versions of Recommendations ITU-R M.1371 and ITU-R M.493.

Mobile AtoN and MOB should use the numbering scheme defined in ITU-R M.585 "Identities in the maritime mobile service," i.e., for MAtoN, it is 99MIDXXXX.

9.9.2 AMRD GROUP B

All other AMRDs that do not enhance the safety of navigation are categorized as AMRD Group B. The characteristics of AMRD Group B were further developed and are contained in two annexes, one for devices using AIS technology and the other for devices using other technologies.

The AMRD Group B numbering scheme is still under consideration. The identity 979YYYYYY (not including the manufacturer ID) is proposed for the revised ITU-R M.585-7. However, further work is needed and will be carried forward to the ITU WP 5B meetings.

9.10 3GPP

IALA has a focus on evaluating various communication technologies for maritime use. Some of the technologies assessed include 3GPP, LTE-M, and others.

IALA cooperates with 3GPP as one of the vertical industries and contributes to its development by sharing maritime viewpoints. However, IALA acknowledges that it cannot represent the entire maritime industry. This collaboration helps bridge the gap between the maritime sector and telecommunications, ensuring that the specific needs of the maritime environment are considered in the development of 3GPP standards.

One of IALA's primary interests is the satellite component of 3GPP, which has the potential to significantly change the maritime communication environment by addressing coverage issues in remote and offshore areas. This advancement will enable seamless connectivity and improved communication capabilities for the maritime domain.

Additionally, IALA is also interested in exploring side link technologies within the 3GPP framework, which can facilitate direct communication between devices without relying on network infrastructure. These technologies can enhance safety and operational efficiency in various maritime scenarios.

IALA's position is that communication based on 3GPP (currently 4G) technology is an emerging technology for IALA and the maritime domain.

It may be beneficial to describe IALA members' 5G requirements, identify other larger segments with similar requirements, join forces with the custodians of these segments, and work jointly with 3GPP and CIRM, as appropriate, to adopt the requirements.

9.10.1 WHAT IS 3GPP?

The use of mobile communications has been increasingly recognized as a valuable means of communication for ships at sea.

3GPP (3rd Generation Partnership Project) was created in 1998 with the signing of "The 3rd Generation Partnership Project Agreement." 3GPP unites seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC), known as "Organizational Partners." It provides their members with a stable environment to produce the reports and specifications that define 3GPP technologies.

The original scope of 3GPP was to produce technical specifications and technical reports for a 3G Mobile System based on evolved GSM core networks and the radio access technologies they support (i.e., Universal Terrestrial Radio Access (UTRA) in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes). The scope was later expanded to include the maintenance and development of Global System for Mobile communication (GSM) Technical Specifications and Technical Reports, including evolved radio access technologies.

The project covers cellular telecommunications network technologies, encompassing radio access, core transport networks, and service capabilities such as codecs, security, and quality of service. It provides complete system specifications, also offering hooks for non-radio access to the core network and interworking with Wi-Fi networks.
More detailed information about 3GPP can be found in http://www.3gpp.org/about-3gpp.

9.11 DIGITALIZATION OF MARINE VHF VOICE CHANNELS

The digitalization of marine VHF voice channels is a significant development in the maritime communication landscape. This transformation aims to enhance communication clarity, increase channel capacity, and improve overall communication efficiency. There are several options to implement voice over VHF, including:

- digital Private Mobile Radio (dPMR) that uses Frequency Division Multiple Access (FDMA) and
- Digital Mobile Radio (DMR) that uses Time Division Multiple Access (TDMA) technology.

IALA has assessed that digital voice over VHF, using the example of dPMR, is a suitable candidate for consideration in meeting the needs of IALA members. However, a suitable vocoder needs to be identified as a standard for maritime use to ensure interoperability.

IALA could be actively support and promote the transition to digital voice communication, while ensuring that the chosen technology aligns with the needs of its members and the wider maritime community. To achieve this, IALA may work towards fostering collaboration among its members, relevant organizations, and industry partners to identify and adopt suitable vocoder standards, as well as facilitate the smooth integration of digital voice technologies into existing maritime communication infrastructure.

9.12 DIGITAL HIGH FREQUENCY RADIO

The data transfer of files and e-mails at a reasonable cost for the mariner is now possible with the digitalisation of the HF frequencies which has been study at ITU-R WP5B. The available HF data transfer protocols currently used in the maritime mobile service (MMS) for the exchange of data and electronic mail on MF/HF frequencies are described in the Recommendation ITU-R M.1798 (Characteristics of HF radio equipment for the exchange of digital data and electronic mail in the maritime mobile service). Three HF electronic mail systems and one wideband HF data exchange system for point-to-point communication are proposed in this Recommendation.

9.13 EMERGING TECHNOLOGIES

IALA acknowledges the importance of staying informed about emerging technologies that could be beneficial to its members and the maritime industry. As a proactive organization, IALA has developed a guideline, G1153, titled "A Template for the Review of Emerging Technologies for Possible Use by IALA Members," to systematically review and assess these technologies in terms of their advantages, limitations, and applicability to the maritime domain.

The objective of this guideline is to encourage the identification of existing or emerging technologies that may be of interest to IALA members. By evaluating these technologies, IALA aims to ensure that its members are aware of the latest developments and can make informed decisions about their adoption and implementation.

The G1153 guideline provides a structured framework for assessing new technologies and considering their potential impact on user requirements and the needs of IALA membership. It serves as a valuable resource for IALA members who are looking to stay updated on the latest advancements in maritime technology and explore potential opportunities for innovation and improvement in their operations.

9.13.1 EXAMPLES OF EMERGING TECHNOLOGIES

Emerging technologies that IALA has been examining include:

- Low Power Wide Area Networks (LP-WAN) - These systems enable long transmission with limited power consumption. They have potential applications in tracking and monitoring systems for lightweight boats and experimental studies of transmission over seawater.
- Low Earth Orbit (LEO) Satellite Constellations - With the growth of digital communication capabilities from different low earth orbiting satellites, LEO constellations offer promising opportunities for maritime communication.
- Alternative Data Transmission Systems - IALA is also monitoring developments in alternative data transmission systems presented at various international organisations, including the IMO and ITU.
- Light-based Wireless Communication - Technologies such as LiFi, which is based on Visual Light Communication (VLC) and uses LEDs to network a wireless system, offer unique opportunities for maritime communication.

9.14 DIGITAL COMMUNICATIONS IN VTS

The adoption of digital communications in Vessel Traffic Services (VTS) is on the rise as a means to improve communication quality and reduce misunderstandings caused by mishearing or language barriers between ship-to-shore and ship-to-ship communications.

VTS have been implementing various digital communication systems, such as satellite, internet, and mobile phone networks, to communicate not only with vessels but also with other stakeholders. For instance, some VTSs use Integrated Maritime Services (IMS) to provide centralized communication services, including digital selective calling (DSC), satellite communications, and email.

Moreover, there is a growing interest in adopting emerging digital communication technologies like VHF Data Exchange System (VDES), alternative data transmission systems, and 5G networks for maritime communications. These technologies offer the potential for higher data rates, lower latency, and better coverage, which can further enhance the efficiency and effectiveness of VTS operations.

The increasing use of digital communications in VTS is expected to facilitate more efficient information exchange, provide better situational awareness, and support the development of future e-Navigation services.

9.15 IALA AND GMDSS MATTERS

IALA takes an active interest in maritime mobile services, including the Global Maritime Distress and Safety System (GMDSS) and radio determination services. The organization closely follows the ongoing GMDSS modernization efforts led by the International Maritime Organization (IMO), aiming to adapt the system to the evolving needs of the maritime industry and incorporate new technologies and innovations.

As part of these efforts, IALA emphasizes the development of the VHF Data Exchange System (VDES), VDE-SAT (Satellite VDES), AIS, and Autonomous Maritime Radio Devices (AMRD) operating in the maritime VHF mobile band. These technologies are expected to significantly enhance communication capabilities, data exchange, and the overall efficiency of the GMDSS.

The GMDSS modernization plan, initiated by IMO, covers various aspects such as incorporating new satellite systems, updating the functional requirements for GMDSS equipment, revising the operational guidelines, and incorporating new digital communication technologies. These updates aim to ensure that the GMDSS remains relevant, effective, and capable of meeting the needs of the modern maritime industry.

By actively participating in GMDSS-related matters and staying informed about its modernization efforts, IALA supports its members and the broader maritime community in leveraging the latest advancements in maritime communication technologies and services.

CHAPTER 10

INFORMATION SERVICES

10.1 INTRODUCTION

The e-Navigation initiative, led by the International Maritime Organization (IMO), aims to enhance safety and efficiency in the maritime sector by providing harmonized electronic information to navigational systems on board ships, as well as streamlining the exchange of information among maritime authorities, agencies, and stakeholders ashore. This initiative encompasses multiple disciplines and seeks to create a more integrated and standardized approach to the use of electronic navigational tools.

The development of e-Navigation began in 2006 when seven IMO Member States proposed the creation of a strategic vision for the utilization of navigational tools, particularly electronic ones, in a holistic and systematic manner. The proposal was driven by concerns that a lack of coordination in the introduction of new technology could lead to increased complexity and a lack of standardization on board vessels, potentially jeopardizing safety.

In response to this proposal, the IMO collaborated with other international organizations such as IALA and IHO to develop a strategy for e-Navigation in 2008. This strategy was further refined with the completion of the Strategy Implementation Plan (SIP) in 2014 and its subsequent review and update in 2018.

e-Navigation's ultimate goal is to reduce navigation-related accidents and improve safety and incident prevention in the maritime sector. By providing seamless, customized, and efficient access to electronic information, e-Navigation enables better-designed navigational systems on board ships and streamlines the way maritime authorities and stakeholders gather and exchange information. The continued development and implementation of e-Navigation will play a crucial role in enhancing safety and efficiency in the maritime industry moving forward.

A plan to implement the strategy, termed the Strategy Implementation Plan (SIP), was completed in 2014 (NCSR1/28 Annex 7). This was reviewed and updated in 2018 (MSC.1/Circ.1595).

10.2 IMO'S STRATEGY FOR THE DEVELOPMENT AND IMPLEMENTATION OF e-NAVIGATION

The IMO strategy for e-Navigation (MSC 85/26/Add.1, Annex 20) states that about 60% of collisions and groundings are caused by direct human error. Despite advances in bridge resource management training, it seems that the majority of watch-keeping officers make critical decisions for navigation and collision avoidance in isolation. This is partly due to a general reduction in manning, it states.

The IMO strategy also states that in human reliability analysis, the presence of someone checking the decision-making process improves reliability by a factor of 10. If e-Navigation can assist in improving this aspect, through well-designed on-board systems and closer cooperation with vessel traffic management (VTM) systems ashore, the risk of collisions and grounding (and their inherent liabilities and costs to administrations) can be dramatically reduced.

The IMO vision for e-Navigation includes the following general expectations for on-board, ashore and communications elements.

10.2.1 e-NAVIGATION DEFINITION

The IMO strategy defines e-Navigation as the *"harmonised collection, integration, exchange, presentation and analysis of maritime information on-board and ashore by electronic means to enhance berth-to-berth navigation and related services, for safety and security at sea and protection of the marine environment."*

In other words, e-Navigation means:

- The harmonised exchange and presentation of navigational information in electronic formats;
- Harmonised data exchange and improved communications;
- Creation of a "wide area navigation team", which allows the Officer of the Watch (OOW) and the Vessel Traffic Services (VTS) Operator to share tactical and planning information; and
- Improved design of navigational and communication equipment.

10.2.2 ON-BOARD AND ASHORE

Navigation systems that benefit from the integration of own ship sensors, supporting information, a standard user interface and a comprehensive system for managing guard zones and alerts. Core elements of such a system will include actively engaging the mariner in the process of navigation, to carry out their duties in the most efficient manner, while preventing distraction and overburdening.

The management of vessel traffic and related services from ashore, enhanced through better provision, coordination and exchange of comprehensive data in formats that will be more easily understood and utilized by shore-based operators in support of vessel safety and efficiency.

10.2.3 COMMUNICATIONS

An infrastructure providing authorized seamless information transfer on board ship, between ships, between ship and shore and between shore authorities and other parties with many related benefits.

10.2.4 WHAT DOES THE 'e' IN e-NAVIGATION STAND FOR?

It is generally accepted that the IMO concept of e-Navigation can be thought of as a brand, without the need for 'e' to be specifically defined. The concept of e-Navigation was first proposed by seven IMO Member States in 2006 as a process for the harmonisation, collection, integration, exchange and presentation of maritime information. As such, the 'e' could have stood for 'enhanced' or 'electronic' (just like the 'e' in e-commerce), but this would limit what could be done within e-Navigation. It must be noted that the generic term electronic marine navigation already exists in many forms. It should not be confused with this particular IMO initiative.

10.2.5 KEY ELEMENTS

The key elements of the IMO strategy for e-Navigation, based on user needs include:

- Architecture
- Human element
- Conventions and standards
- Position fixing
- Communication technology and information systems
- Electronic Navigational Charts (ENC)
- Equipment standardisation
- Scalability

According to the strategy, the implementation of e-Navigation should be a phased, iterative process of continuous development, taking into account the evolution of user needs and the lessons learned from the previous phase(s).

As part of the basic requirements for the implementation of e-Navigation, it was agreed that e-Navigation should be based on user requirements and needs and not technology-driven.

10.2.6 e-NAVIGATION SOLUTIONS

The centrepiece of the current (2018) SIP is the following five e-Navigation solutions:

- S1: improved, harmonised and user-friendly bridge design;
- S2: means for standardized and automated reporting;
- S3: improved reliability, resilience and integrity of bridge equipment and navigation information;
- S4: integration and presentation of available information in graphical displays received via communication equipment; and
- S5: improved Communication of VTS Service Portfolio (not limited to VTS stations).

Solutions S1 and S3 promote the workable and practical use of the information and data on board. As regards S1, IMO finalised:

- Guideline on Software Quality Assurance and Human-Centred Design for e-navigation (MSC.1/Circ.1512)
- Guidelines for the standardisation of user interface design for navigation equipment (MSC.1/Circ.1609)
- Interim Guidelines for the Harmonised Display Of Navigation Information Received Via Communication Equipment (MSC.1/Circ.1593)
- Guidelines for the presentation of navigation-related symbols, terms and abbreviations, (SN.1/Circ.243/Rev.2)
- Amendments to the Performance standards for the presentation of navigation-related information on shipborne navigational displays (resolution MSC.191(79))
- Guidance on the definition and harmonisation of the format and structure of maritime services in the context of e-navigation (IMO Resolution MSC.467 (101)).

Solutions S2, S4 and S9 focus on efficient transfer of marine information and data between all appropriate users (ship-ship, ship-shore, shore-ship and shore-shore).

The process at IMO lead to the specification of Maritime Services in the Context of e-Navigation.

10.3 IALA'S WORK ON DIGITAL COMMUNICATION TECHNOLOGIES, INFORMATION SERVICES AND e-NAVIGATION MATTERS

IALA has so far focussed on three broad streams:

Digital Information Systems

- Developing guidance on the description and implementation of "Maritime Services in the Context of e-Navigation".
- Facilitating harmonisation in the development of data models, technical services and platforms.
- Defining concepts, procedures, services and platforms for new initiatives such as identity management.

Emerging Digital Technologies

- Evaluation of new technologies relevant to e-navigation, in particular digital maritime communications
- Maritime Autonomous Surface Ships (MASS)
- Single Window Data Exchange

Digital Communication Systems

- IALA's Maritime Radio Communication Plan
- The technical characteristics and operation of the VHF Data Exchange System (VDES)
- Autonomous Maritime Radio Devices (AMRD), Automatic Identification System (AIS) and other digital communication technologies

10.4 MARITIME SERVICES IN THE CONTEXT OF e-NAVIGATION

IALA Standard S1070 applies to Information Services. This Standard references normative and informative provisions, detailed in the listed IALA Recommendations, covering the following scope.

- Data models and data encoding
- Data exchange systems
- Terminology, symbology and portrayal

10.4.1 BACKGROUND

The primary goal of e-Navigation is to provide harmonized information in electronic formats to better-designed navigational systems on board and streamline communication and data exchange among maritime authorities, agencies, and stakeholders. There are 16 digital maritime services recognized by the IMO at the moment, forming the core of navigation services in the coming years. These services include three VTS services (information, traffic organization, and navigational assistance), a chart service, and Maritime Safety Information (MSI). IALA is trying to update the VTS services and add the Marine Aids to Navigation service in the list of maritime services.

10.4.2 TERMINOLOGY AND DIRECTIVES

Maritime Services in the context of e-Navigation refer to the provision and exchange of maritime-related information and data in a harmonized, unified format. IMO Resolution MSC.467(101) provides guidance on the definition and harmonization of the format and structure of maritime services in the context of e-Navigation. IALA, in collaboration with IMO, is recognized as a coordinating body for the development of Maritime Service on VTS.

10.4.3 HARMONIZATION OF THE FORMAT AND STRUCTURE OF MARITIME SERVICES

In accordance with IMO Resolution MSC.467(101), all Maritime Services must adhere to the S-100 standard as a baseline. IALA offers recommendations and guidelines for the development and evaluation of harmonized platforms that provide Marine Aids to Navigation (AtoN) Services, including VTS, within the context of e-Navigation.

Recommendation R1019 acknowledges ongoing advancements in the field of Maritime Services, outlining general requirements for these services in the context of e-Navigation. This recommendation serves as a directive for creating new guidance documents on the topic.

Guideline G1161 offers information for evaluating harmonized and suitable platforms for delivering Marine Aids to Navigation (AtoN) Services, including VTS, within the context of e-Navigation, as suggested by R1019. As the e-Navigation domain continues to evolve with new digital platform solutions, a common understanding of requirements is essential. This document assists IALA members and the industry in identifying appropriate platforms and encourages platform providers to align their solutions with shared requirements.

Refer to IALA Publications:

- Recommendation R1019 - Provision of Maritime Services in the context of e-Navigation in the domain of IALA
- Guideline G1161 – Evaluation of Platforms for the Provision of Maritime Services in the context of e-Navigation.

10.4.4 TECHNICAL SERVICES

A Technical Service comprises a set of technical solutions, based on an agreed data model and communications means, to provide a Maritime Service as per IMO MSC.467 (101). Based on the concepts of service-oriented architectures, a Technical Service also refers to a set of related software functionalities that can be reused for different purposes, together with policies that govern and control their use. Therefore, harmonization and interoperability of data models and interfaces of Technical services play a key role in the realization of Technical Services.

Technical Services should also be designed modularly. In this way, services offered by one electronic device can directly be used by another electronic device without any modification. Often, Operational Services are implemented by electronic devices or software components that rely on one or more Technical Service.

IALA is working on developing the operational and technical aspects of maritime service on the Marine Aids to Navigation including VTS.

IALA Guideline G1128 on the specification of e-Navigation technical services enables service providers, consumers and regulatory authorities to have a common understanding of a technical service and its implementation. The Guideline differs between the actual service specification (functionality and interfaces), technical designs (technology specific considerations) and instance descriptions (specific setup of a single service instance). All sections of the guideline are characterized by a fixed scheme. This enables the standardized specification of services in a Service Oriented Architecture.

A Technical Service should be formally specified and documented, as described by IALA Guideline G1128. At the time of writing, this guideline aims at improving the visibility and accessibility of available Technical Services and information provided by them. Data models of Technical Services should be implemented using the S-100 Universal Hydrographic Data Model.

10.4.5 ARCHITECTURES FOR e-NAVIGATION

The maritime domain is a complex ecosystem of multiple stakeholders and a mix of new and existing digital infrastructures. Secure, reliable, and efficient architectures are required to fulfil the requirements of a harmonized network of technical services. The Maritime Architecture Framework (MAF) is a framework for the design of maritime architectures. It can be used to describe the context of e-Navigation digital architectures and implement them.

In recent years, platform solutions for connecting decentralized services and databases have been established in a large part of the transportation and other sectors. IALA recognizes platforms as an essential building block to implement the e-Navigation strategy, as they can facilitate harmonization, interoperability, and collaboration between different service providers and support Service Oriented Architectures (SOA). SOAs enable services to interact with other services and, furthermore, make it possible to build services based on existing services. Additionally, IP-based communication and web services open possibilities for efficient and more fine-grained communication. However, as this introduces a relatively new way of interacting with Maritime Services in a digital context, there are new requirements and risks that service architects and developers should be aware of. IALA is currently developing a Guideline to address these issues (G1161: Guideline on Platforms to support the provision of Maritime Services in the context of e-Navigation).

As for the content of NAVGUIDE, certain sections remain pertinent and can be integrated into e-Navigation architecture discussions. These sections touch on crucial aspects such as technical infrastructure, data exchange, and communication protocols, all of which are vital for the successful implementation and operation of e-Navigation systems.

By combining the insights from the MAF, existing platform solutions, and relevant sections of the NAVGUIDE, a comprehensive understanding of the architectures for e-Navigation can be developed. This knowledge will enable the maritime community to design and implement effective digital infrastructures that enhance safety, efficiency, and collaboration among stakeholders in the maritime domain.

10.5 A LAY PERSON'S DESCRIPTION OF e-NAVIGATION

e-Navigation is based on the principles of data exchange as used in the apps that operate on smart phones.

For example, a weather app provides information to a user, this could be called a "Weather Service". This weather service satisfies the user's need for information about the weather. Similarly, a Maritime Service, in the context of e-Navigation, satisfies a user need for information concerning vessel navigation and other maritime considerations including safety, efficiency and the protection of the marine environment. Our weather service app has to communicate with a server that runs software that can provide weather information.

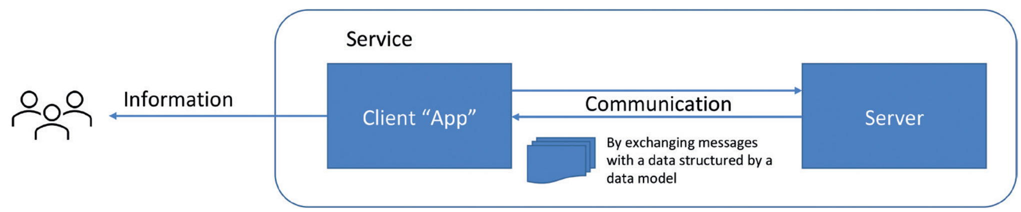


Figure 37. The Concept of a Client-Server based Maritime Service

The interaction between the app and the server is defined by a technical service specification, which describes the exchange of standardised messages and the language that is used in the message contents. The language is described by a data model.

The software running on the server hardware is described as being an instance of the technical service.

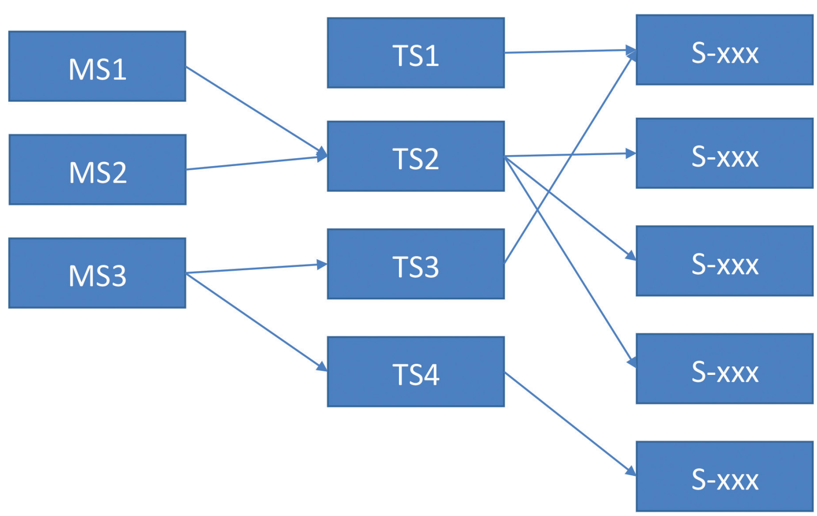


Figure 38. The relationship between specifications of Maritime Services, Technical Services and data models in e-Navigation

If somebody wants to develop an app that is able to communicate with the server or develop a server to be used by the app, then the developer must refer to the technical service specification and the referenced data models.

Similarly, an e-Navigation Maritime Service draws together information through a combination of one or more running instances of a technical services. A technical service facilitates the exchange of data, by receiving messages, processing the data, and sending a result. The data is formatted according to the Common Maritime Data Structure, which is based on the IHO S-100 series of data models, thus ensuring harmonisation and interoperability.

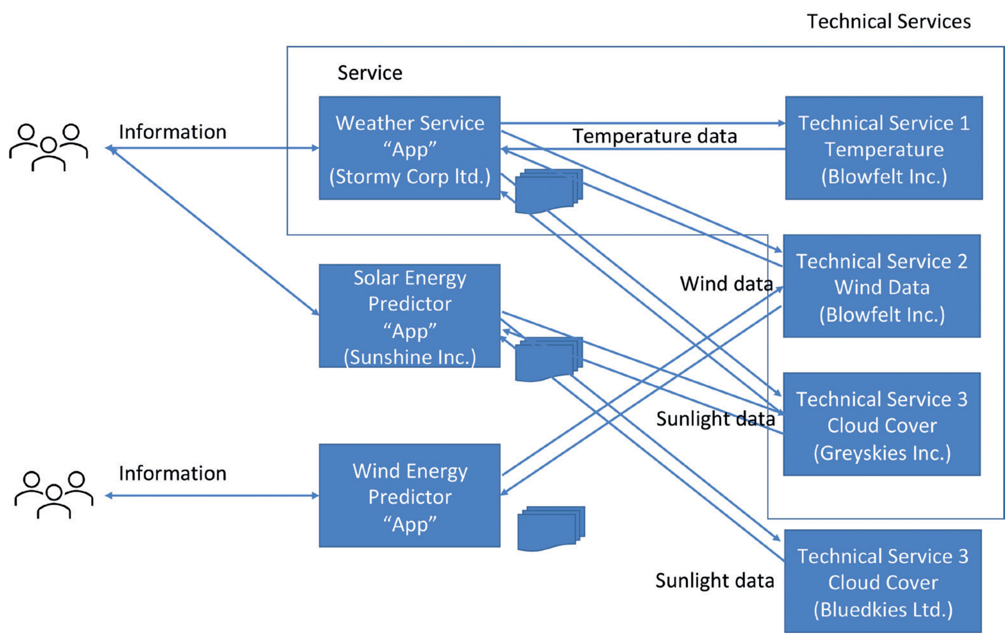


Figure 39. The dataflow between Maritime Services, Technical Services and data exchange

The relationship between Maritime Services, Technical Services, and Data Models can be further analyzed with reference to Figure 11, which elaborates on the example of a Weather Service App. In this scenario, the weather service app is assumed to be part of a set of e-Navigation Maritime Services, drawing parallels with Figure 10. The Maritime Weather Service App, developed by Stormy Corp Ltd., comprises several Technical Services. Each Technical Service communicates with servers containing various weather-related data, such as temperature, wind, and cloud cover. These datasets are collected from sensors dispersed across a geographical region and stored in databases. Technical Services are responsible for extracting relevant data based on the user input in the Weather Service app interface.

The Weather Service app connects to instances of Technical Service 1 for temperature, Technical Service 2 for wind, and Technical Service 3 for cloud cover (or sunlight). Upon examining the architecture presented in Figure 11, several characteristics can be observed:

- A single Maritime Service can utilize multiple Technical Services, exemplifying a 1:N relationship between Maritime Services and Technical Services.
- Instances of Technical Services can be deployed by either one organization or multiple organizations. For instance, BlowFelt Inc. hosts a Temperature Technical

Service on their servers and provides their temperature data. They also offer a Wind Technical Service with their wind database. However, StormyCorp Ltd.'s Weather Service App opts to use cloud cover data from GreySkies Inc. BlowFelt and GreySkies servers may be geographically distant.

- Instances of Technical Services can be reused by other Maritime Services. Figure 11 depicts a Maritime Service that estimates the amount of harvestable solar energy using the Solar Energy Predictor App, developed by SunShine Inc. Users can input a geographical location in the app's interface to determine the energy harvesting potential of a remote, solar-powered autonomous ship at its current location. SunShine's App could utilize the same instance of GreySkies' Cloud Cover Technical Service as employed by StormyCorp's Weather App or choose the one hosted by BlueSkies. Decisions regarding which service provider's technical service instance to use may depend on factors such as perceived data quality, subscription costs, or other considerations.

10.5.1 AN EXAMPLE OF AN IALA NATIONAL MEMBER'S VISION

In 2019, the Australian Maritime Safety Authority released Navigation Services in Australian Waters—outlook to 2030. This work provides an insight to the provision of navigation services (not just Aids to Navigation) in the coming years. It outlines the emerging trends and drivers in navigation technology and communications. It also describes the anticipated impacts these will have on the maritime industry. Importantly, it lists AMSA's policy responses to these changes.

It can be found here:

https://www.amsa.gov.au/safety-navigation/navigation-systems/navigation-services-australian-waters-outlook-2030

10.5.2 PLANNING AND REPORTING OF TESTBEDS IN THE MARITIME DOMAIN

Several projects (completed and underway) have made noteworthy inroads in developing aspects of e-Navigation. The IALA website (https://www.iala-aism.org/technical/planning-reporting-testbeds-maritime-domain/) provides more detail on known testbeds and their results.

IMO and IALA have guidelines to assist with the reporting of testbed results

- Guidelines on Harmonisation of Testbed Reporting (MSC.1/Circ.1494)
- IALA Guideline G1107 – Planning and reporting of testbeds in the maritime domain

10.6 MARITIME RESOURCE NAMES

The Maritime Resource Names (MRN) is a unique identifier system developed by IALA to support e-Navigation initiatives. MRNs are designed to facilitate the identification, management, and exchange of digital resources in the maritime industry. The MRN structure is based on the Uniform Resource Name (URN) concept, which is part of the Internet Engineering Task Force (IETF) standards.

In the maritime sector, there are already numerous identification systems in place, such as the IMO number for ships, the Maritime Mobile Service Identity (MMSI) for vessel communication, and the Aid to Navigation (AtoN) number. While these identification systems serve their specific purposes, they are often limited in scope and do not provide a comprehensive solution for identifying all types of maritime resources.

The MRN system addresses this issue by offering a global, unified approach to identifying various maritime resources, regardless of their nature or purpose. By adopting the URN concept from IETF, the MRN system ensures that the identifiers are globally unique, persistent, and location-independent, which is critical for efficient communication and collaboration among various maritime stakeholders, such as ship operators, port authorities, coastal states, and service providers.

The MRN consists of several components that follow a hierarchical structure, similar to the URN:

- Namespace Prefix: This is a short code that represents the standardization organization responsible for maintaining the MRN system. For IALA, the prefix is 'urn'.
- Domain: This component indicates the specific organization or authority that is responsible for the resource. Examples include 'mmsi' for Maritime Mobile Service Identity, 'imo' for International Maritime Organization, or 'ais' for Automatic Identification System.
- Subdomain: This is an optional component that further specifies the type of resource within the domain. For example, within the 'ais' domain, there could be subdomains like 'message' or 'report' to differentiate between different types of AIS resources.
- Resource Identifier: This is a unique alphanumeric code that distinguishes the resource from others within the same domain and subdomain. The resource identifier is usually generated by the responsible organization or authority.

By implementing the MRN system, the maritime industry can streamline data exchange, avoid confusion or miscommunication, and improve the overall safety and efficiency of maritime operations. The MRN is a key component of the Maritime Connectivity Platform (MCP), an open and vendor-neutral communication framework that supports the seamless exchange of information between maritime actors in a secure and reliable manner.

For more information on MRNs, URNs, and their practical applications, you can consult the IALA website, explore IETF's RFC documents, or review guidelines and best practices related to e-Navigation.[1]

10.7 IHO'S S-100 UNIVERSAL HYDROGRAPHIC DATA MODEL

The IHO S-100 Standard is a comprehensive framework document designed for the development of digital products and services within the hydrographic, maritime, and GIS

1 Maritime Resource Name (MRN) see: http://mrnregistry.org

communities. It comprises multiple parts based on ISO geospatial standards. IHO has developed the S-100 Universal Hydrographic Data Model (UHDM) to meet future demands for digital products and services.

The S-100 Geospatial Information Registry hosts online databases of concepts, features, portrayal information, attributes, metadata, and other resources pertinent to communities developing S-100 based products and services. A centralized registry facilitates harmonization between product specifications in the maritime sector.

10.7.1 S-100 ROLE IN e-NAVIGATION

IMO oversees the e-Navigation concept, which aims to enhance safety and security in commercial shipping through improved organization of data on ships and onshore, as well as better data exchange and communication between them.

IHO had already established a system of standardized methods for codifying, encapsulating, transferring, and distributing hydrographic and charting data through its S-57 Electronic Navigational Chart standard. This concept can be integrated into the entire e-Navigation concept by ensuring that the foundational standards are in place from the outset through the S-100 family of product specifications and centralized information registry. The IHO maintains control only over its own standards. The principles are outlined in IHO publication S-99, Operational Procedures for the Organisation and Management of the S-100 GI Registry, available at www.iho.int. It is planned to introduce finalized S-100 products in the coming years, initially with the simultaneous usage of S-57 products. Later, a complete transition to S-101 and other S-100 products is planned.

10.7.2 S-100 DEPENDENT PRODUCT SPECIFICATIONS

To manage the development of S-100 based products and minimize duplication while encouraging conformity, the IHO Hydrographic Services and Standards Committee (HSSC) allocates S-XXX numbers for the development of S-100 dependent products. The HSSC has allocated the following Product Specification numbers:

- International Hydrographic Organization (IHO) (S-101 to S-199)

Some examples are:

- S-101 Electronic Navigational Chart (ENC)
- S-102 Bathymetric Surface
- S-104 Water Level Information for Surface Navigation
- S-111 Surface Currents
- S-121 Maritime Limits and Boundaries
- S-122 Marine Protected Areas (MPAs)
- S-123 Marine Radio Services
- S-124 Navigational Warnings
- S-125 Marine Navigational Services
- S-126 Marine Physical Environment
- S-127 Marine Traffic Management

- S-128 Catalogue of Nautical Products
- S-129 Under Keel Clearance Management (UKCM)

IALA (S-201 to S-299)

Some examples are

- S-201 Aids to Navigation Information
- S-211 Port Call Message Format
- S-212 VTS Digital Information Service
- S-230 Application Specific Messages
- S-240 DGNSS Station Almanac
- S-245 eLoran ASF Data
- S-246 eLoran Station Almanac
- S-247 Differential eLoran Reference Station Almanac

Joint Technical Commission for Oceanography and Marine Meteorology (WMO/IOC JCOMM)(S-411 to S-414)

- S-401 Inland ENC
- S-402 Bathymetric Contour Overlay for Inland ENC
- S-411 JCOMM Ice Information
- S-412 JCOMM Weather Overlay
- S-413 Weather and Wave Conditions
- S-414 Weather and Wave Observations

10.7.3 IALA AND S-100 DEVELOPMENT

IALA plays a significant role in the development of the IHO S-100 standard by contributing to its refinement, testing, and implementation. IALA collaborates closely with IHO to ensure that the standard meets the needs of the maritime community, particularly regarding aids to navigation and related services.

IALA focuses on creating guidelines and recommendations for S-100-based products and services to promote technical interoperability, harmonization, and the secure, reliable, and efficient exchange of maritime information. Consequently, IALA participates in the development and testing of new proposals for S-100, addressing any issues or challenges that may arise.

This collaborative effort between IALA and IHO ensures that the S-100 standard meets the evolving needs of the maritime community and supports the broader goals of e-Navigation.

The current edition of S-100 includes a section for online data exchange. IHO is actively working to refine S-100 to incorporate the concept of online communications. The initial challenges raised during the testing of the first proposal, contributed by IALA have been addressed.

As the S-100 standard becomes increasingly important for exchanging maritime information, it is essential to ensure the secure, reliable, and efficient exchange of S-100 data. Standardizing a common Web Service interface (based on IP technology) for the exchange of S-100-based products will enable greater technical interoperability, allowing the same service interface to be used for information exchange, regardless of operational use, and making it common for various Maritime Services. As a result, IALA is actively working on developing a guideline for S-100-based Web Services, known as G1157 Web Service-Based S-100 Data Exchange. The guideline offers a general introduction to the topic and an overview of existing standardization and guidance documents.

10.8 CYBER SECURITY

As the IALA domains are undergoing rapid changes with regards to digitalisation, as well as the maritime domain as a whole, cyber security becomes an important aspect. Cybercrime and the associated risks have expanded from IT environments to Operational Technology like AtoN, VTS and vessels. Therefore, cyber security must be taken into consideration for all maritime domains to provide resilience for safety, continuity and for reliability of systems and data.

Cyber security is not only a technological topic. Human behaviour is as important. Also, cyber security should not be considered a feature or an add-on to a (digital) technology, but incorporated from the first development throughout the technology's entire lifetime. This is what is commonly known as "security by design".

It is a good practice to secure everything unless this is explicitly unwanted for a valid reason. This will make a technology more resilient to evolving (and yet unknown) risks in the future. With "secure", at least encryption and validation of data authenticity should be considered. Furthermore, it is recommended to select a suitable normative standard for cyber security to apply to the development or use of a technology.

IALA has created recommendation R1024. The document provides valuable information for developers and users of digital technologies in the IALA domains and includes references to the most applicable normative standards that may be applied to technology for AtoN, VTS and maritime services.

NOTES FOR CHAPTER 10

[1] A registry is simply a bookkeeping device where definitions/specifications are kept in organised locations known as registers. The registry eases the tasks of development of new things, by providing a centralised source for finding definitions/ specifications

[2] GPS Performance Standards, 2008

[3] United Nations Office for Outer Space Affairs, "Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentations Systems", 2011

[4] At the time of writing, further information on BeiDou may be found on the internet hhttp://www.en.beidou.gov.cn/csnclist.html

[5] Further information on Galileo can be found at the following website: http:/ / ec. europa. eu/ growth/ sectors/ space/ galileo/

[6] A 1kW transmitter will generally allow position fixing to better than 10 metres over a radius of about 200 Nautical Miles

[7] United Nations Office of Outer Space Affairs

ABBREVIATIONS

AIS	Automatic Identification System
AISM	Association Internationale de Signalisation Maritime (Title of IALA in French)
AMRD	Autonomous Maritime Radio Devices
ASM	Application Specific Message
ATO	Accredited Training Organisation
AtoN	Marine Aid to Navigation
CA	Competent Authority
CIE	International Commission on Illumination (CIE from French title, the Commission Internationale de l'Eclairage)
COLREGS	International Regulations for Preventing Collisions at Sea
CTI	Continuity Time Interval
dGNSS	Differential Global Navigation Satellite System
dGPS	Differential Global Positioning System
DRI	Detection, Recognition, Identification
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
EGNOS	European Geo-stationary Navigation Overlay Service
ENC	Electronic Navigation Chart
EWMB	Emergency Wreck Marking Buoy
GALILEO	Global Navigation Satellite System (EU)
GIS	Geographic Information Systems
GLONASS	Global Navigation Satellite System (Russia)
GNSS	Global Navigation Satellite System
GPA	Global Positioning System (USA)
GSM	Global System for Mobile communication
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IHO	International Hydrographic Organization
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organisation
IPSL	Integrated Power System Lantern
ISO	International Standards Organization
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union – Radiocommunications Bureau
LOP	Lines of Position
LORAN	Long Range Navigation

LOS	Level of Service
MARPOL	International Convention for the Prevention of Pollution from Ships
MAtoN	Mobile Aid to Navigation
MBS	(IALA) Maritime Buoyage System
MKD	Minimum Keyboard Display
MOB	Man overboard
MRCP	IALA Maritime Radio Communications Plan
MSC	(IMO) Maritime Safety Committee
MTBF	Mean time between failures (in hours)
MTBO	Mean time between outages
MTSR	Mean time to service restoration
MTTR	Mean time to repair (in hours)
NM	Nautical Mile
PDL	Precision Directional Light
PNT	Positioning, Navigation and Timing
PSSA	Particularly Sensitive Sea Area
Racon	Radar transponder beacon
RAIM	Receiver Autonomous Integrity Monitoring
RTE	Radar Target Enhancer
RTK	Real Time Kinematic
SAR	Search and Rescue
SBAS	Satellite Based Augmentation System
SOLAS	Convention on the Safety of Life at Sea 1974
SRS	Ship Reporting System
TSS	Traffic Separation Scheme
UTC	Universal Time Co-ordinated
Vdes	VHF Data Exchange System
VHF	Very High Frequency (radio in the 30-300 MHz band)
VTM	Vessel Traffic Management
VTS	Vessel traffic service or vessel traffic services (dependent on context)
WAAS	Wide Area Augmentation System
WGS-84	World Geodetic System 1984
WWA	World Wide Academy
WWRNS	World Wide Radio Navigation System
ZOC	Zone of Confidence

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

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