NAVGUIDE 2018

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AIDS TO NAVIGATION AND LIGHTHOUSE AUTHORITIES

NAVGUIDE

AIDS TO NAVIGATION MANUAL

2018

EIGTH EDITION

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Navguide: Foreword

The NAVGUIDE has been a signature document and information source for IALA members and users for now many years. The 2018 edition of the Guide continues on with this proud tradition and sees it updated with the latest information and developments in the field of Marine Aids to Navigation technology and application.

The Guide is a product of four years collaboration by the world's leading experts on Marine Aids to Navigation, produced by the four primary Committees, AtoN Requirements and Management (ARM), AtoN Engineering and Sustainability (ENG), e-Navigation (ENAV) and Vessel Traffic Services (VTS). The ARM Committee has the primary oversight for its editing and production.

The Guide plays an important role within the IALA information suite and is regarded as a primary source of information for Marine Aids to Navigation practitioners around the world, along with the other IALA Standards, Recommendations, Guidelines, Manuals and other publications.

As one of the essential publications for Marine Aids to Navigation practitioners, the Guide also has recently been included as one of the key guidance documents in the Aids to Navigation Management training syllabus for IALA's World-Wide Academy. The Guide has been translated into many languages and IALA encourages this practice and is keen to work with members to assist in this process and its dissemination into all regions of the world where English is not the primary working language.

The 2018 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 information sources available to our members and users of Marine Aids to Navigation. I encourage readers of this Guide to also consult the website for other information references that may assist you in your day-to-day work in the field of Marine Aids to Navigation. As always, IALA is receptive to feedback on how the Guide may further be developed for future editions and welcomes suggestions for improvements (contact@iala-aism.org).

In closing, I would like to thank the IALA membership for helping to produce this 2018 edition of the NAVGUIDE and reflect on the unique nature of IALA that allows professionals from around the world to contribute their expertise to assist the international maritime community in improving and harmonizing Marine Aids to Navigation.

Francis Zachariae, IALA Secretary-General,

November 2017

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Navguide: Chapter 1 - An Introduction to IALA – AISM

1.1 Purpose and Scope

The purpose of this manual is to assist Marine Aids to Navigation (AtoN) authorities in the harmonization of AtoN by providing a first point of reference on all aspects of providing an AtoN service. The manual also provides references to more detailed guidance from related international organizations on specific topics.

1.2 Background

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

IALA is a non-profit, international technical association devoted to the harmonization of Marine Aids to Navigation. IALA was formed in 1957 to provide a framework for aids to navigation authorities, manufacturers and consultants from all parts of the world.

The aim of IALA is to foster the safe and efficient movement of vessels through the improvement and harmonization of Marine Aids to Navigation worldwide, and by other appropriate means, for the benefit of the maritime community and the protection of the marine environment. The Strategic Vision for 2018-2026 sets out two main goals:

- Marine Aids to Navigation are harmonized through international cooperation and the provision of standards.
- All coastal states have contributed to an efficient global network of Marine Aids to Navigation through capacity building and the sharing of expertise.

1.3 Membership

IALA has four types of members:

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

Associate Membership: Applicable to any other service, organization or scientific agency concerned with aids to navigation or related matters.

Industrial Membership: Applicable to manufacturers and distributors of Marine Aids to Navigation equipment for sale, or organizations providing aids to marine navigation services or technical advice under contract.

Honorary Membership: 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.

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Figure 1 - IALA National Members (The shaded countries are IALA Members)

1.4 Governance arrangements

1.4.1 General Assembly

The General Assembly brings together members from all the membership categories every four years and usually convenes in conjunction with the four-yearly Conference.

National members attending the General Assembly 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.

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1.4.2 The Council

IALA is administered by a Council of up to twenty-one elected and three non-elected Councilors. 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 Councilors from different parts of the world to achieve a broad representation on the Council.

The main functions of the Council are to:

- implement the overall policy as defined by its aims or by the General Assembly;
- decide membership matters
- establish Committees relevant and/or facilitates other such bodies as may be appropriate and their terms of reference;
- approve Recommendations, Guidelines, Manuals and other appropriate papers;
- approve submissions to other organizations;
- decide the venue and the year of the next Conferences and symposia;
- establish rules for participation in Conferences and symposia;
- convene General Assemblies;
- approve the annual budget and accounts;
- determine the rate of subscriptions;
- decide upon the location of the Headquarters and registered office of IALA.

1.5 Advisory Bodies

1.5.3 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 harmonization of 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 to provide a collegiate delivery of the various work plans with the Secretariat.

== 1.5.2 Legal Advisory Panel (LAP) The Legal Advisory Panel (LAP) is a group that comprises a chairperson and vice chairperson (both as appointed by the Council), IALA National members with interest in legal affairs, representatives of relevant international organizations (as approved by the Secretary-General), and experts (as appointed by the Secretary-General).

The role of LAP is to:

1. Provide legal support to the Council as required;
2. Respond to issues and concerns that may be raised through the Secretariat;
3. Respond to requests from Committees and other IALA bodies for legal advice;
4. Provide 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;
5. Prepare draft documentation/guidelines on items of common concern;
6. Identify where external legal advice may be needed and assisting with the preparation of requests/briefs for such advice, as appropriate;
7. Review, updating, advising and reporting to the Council on the Risk Registers;

1.6 Committees

Committees are established by the Council to study a range of issues, as determined by the General Assembly, with the aim of preparing recommendations and guidelines for the members. In addition, the Committees prepare submissions to International Organizations. A committee may also be asked to provide continuous monitoring of elements of subjects that could influence decisions concerning the provision of Marine Aids to Navigation, including Vessel Traffic Services. Committees meet regularly and are important to the work of IALA because they keep abreast of developments, including technological developments, relating to their area of expertise and prepare, review and revise relevant publications in accordance with their approved Work Programme. The programmes for the Committees generally cover a 4-year study period, from one Conference to the next.

The documents created by the Committees address topics relating to management, operations, engineering, emerging technologies and training, and must be approved by the Council.

All members are invited to participate in the Committees which include:

- AtoN Requirements and Management (ARM);
- AtoN Engineering and Sustainability (ENG) including the Heritage Forum;
- e-Navigation (ENAV);
- Vessel Traffic Services (VTS).

1.7 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, and it focuses on the second goal set out in IALA's strategic vision, which is about ensuring that all coastal states contribute to an efficient global network of marine aids to navigation, and services, for the safety of navigation. The functions of the Academy are:

- Education and training
- Capacity-building
- Research and development

The Academy is dedicated to assist coastal states with continuous and sustainable improvement of their marine aids to navigation services, including VTS. While its education and training activities are intended for all coastal states, capacity-building activities are aimed at those states who are struggling with fulfilling their international obligations related to marine aids to navigation, as detailed in IALA Standards, Recommendations and Guidelines. The research and development activities of the Academy are aimed at identifying topical knowledge gaps within the IALA domain, and encouraging research in these topics, worldwide. The Academy maintains an overview of its activities in a Master Plan and an associated Action Plan, which can be found on the Academy website – www.academy.iala aism.org.

1.7.1 IALA Model Courses and the IALA Accreditation Scheme

IALA has developed a number of model courses covering the contents of its Standards, Recommendations and Guidelines. These model courses, which can be found on the Academy website, can in principle be delivered by anyone, but only those training organizations who have been accredited by a competent authority (an IALA national member), can claim to be delivering IALA model courses. These are called Accredited Training Organizations (ATO's), and the accreditation scheme aims at ensuring the quality of their delivery of IALA model courses. There are now several ATO´s around the world, delivering both AtoN and VTS related model courses.

Refer to IALA publications:

- Recommendation V-103 on Standards for Training and Certification of VTS Personnel;
- Recommendation E-141 on Standards for Training and Certification of AtoN Personnel.

- Recommendation O-149 on Accreditation of Training Organisations
- Guideline 1014 on Accreditation of VTS training courses
- Guideline 1100 on the Accreditation and approval process for Aids to Navigation personell training

While the AtoN model courses have two levels, Level 1 for AtoN managers and Level 2 for AtoN technicians, the VTS model courses encompass the training of VTS operator, VTS supervisor and VTS training in

1.9 Conferences, Symposia and Exhibitions

19th IALA Conference 2018
Incheon, Republic of Korea

IALA holds a general Marine Aids to Navigation Conference every four (4) years. These 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 organizes an Industrial Exhibition in conjunction with the Conference.

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

1.9 Workshops and Seminars

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

Workshops are special meetings convened for the purpose of making maximum use of the technical expertise of participants to further the work of the Association on a specified subject or topic. They also enable skills and comprehension 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 on the subject or topic followed by question and answer sessions. IALA has developed guidelines on the preparation of a Workshop or a Conference/Symposium. Approval to convene a Workshop or Seminar may be given by the Council on the recommendation of the Secretary General.

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1.10 Other meetings

In order to promote exchange of information and coordination of AtoN provision, IALA arranges a number of other meetings where members and other interested parties can meet to discuss specific topics.

1.6 IALA Publications

IALA is responsible to its membership for production of a comprehensive set of publications that have the primary objective of facilitating a uniform approach to Marine Aids to Navigation worldwide.

The types of publications include:

IALA Standards:
An IALA Standard is a part of a framework, the 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 Recommendations:
An IALA recommendation specifies what practices shall be carried out in order to comply with that Recommendation, and may be referenced, in full or in part, in an IALA Standard.

IALA Guidelines:
An IALA guideline describes how to implement practices normally specified in a Recommendation.

IALA Manuals:
An IALA manual provides an overall view of a large subject area. Whilst aimed at introducing a subject to a widely varied readership, reference is also made to IALA guidelines and IALA recommendations, as well as other related international documents, as an indicator of further study.

IALA publications are governed by a set of principles including:

Usability – The system should be as intuitive as possible, be inclusive for all IALA documents while maintaining the existing numbering scheme for Recommendations.

Visibility - Presentation of documents should present a 'common look and feel', providing a visual indication of a document, as well as a visual clue as to the type of IALA document.

Validity - The date of issue and date of amendment/edition should be clearly visible to ensure that members have the most up-to-date information available.

Availability - Documentation related to the safety of navigation should ideally be provided to all who have need of the information – i.e. available, in electronic form, at no charge for download from the website.

Other documentation available from IALA on request includes:

- Conference Proceedings;
- Reports (symposia, meetings, workshops, seminars, etc.);
- IALA Bulletin (a magazine which appears twice a year);

1.12 Related Organizations

IALA works in close cooperation with the International Maritime Organization and the International Hydrographic Organization and have a number of formal cooperation agreements with other international maritime organizations to further its objective of harmonizing AtoN.

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Navguide: Chapter 2 - Concepts and accuracy of navigation

Competent aids to navigation authorities are generally established to provide a navigational safety regime that facilitates trade and economic development. The primary services are therefore directed towards the needs of commercial trading vessels. In some areas, authorities may provide additional services for ferries, fishing and recreational vessels and specialised maritime activities. This chapter looks at the methods of navigation and accuracy requirements from the perspective of commercial trading vessels.

2.1 Navigation Methods

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."

It is recommended that whenever possible the reliance on a single method of determining position be avoided.

The principal methods of marine navigation are briefly described as follows:

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

Celestial or Astronomical Navigation: navigation using observation of celestial bodies (ie sun, moon, planets and stars) to determine position.

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 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.

Radionavigation: navigation using radio signals to determine a position or a line of position (e.g. eLORAN, GNSS, DGNSS etc).

2.2 Accuracy Standards of Navigation

IMO Resolution A.915(22) established accuracy standards for maritime navigation.

Table 3 presents the relevant standards adopted in Appendixes 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) mentions 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 100 m with a probability of 95%."

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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

Table 3 - Minimum Maritime User Requirements

2.3 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.

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.

2.3.1 Ocean Navigation

In this phase, the vessel is typically:

- beyond the continental shelf (200 metres in depth) and more than 50 nm from land;
- in waters where position fixing by visual reference to land, charted fixed offshore structures, or to fixed or floating aids to navigation, is not practical;
- 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 3) the minimum navigational requirements for the Ocean Phase are considered to be a predictable accuracy of 2 to 4 nm, 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.

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2.3.2 Coastal Navigation

In this phase, the vessel is typically:

- within 50 nm from shore or the limit of the continental shelf (200 meters in depth);
- 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;
- 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 3), 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 0.25 nm, 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 a 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. GPS and DGPS (and 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

2.3.3 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;
- 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 ship will generally be within:

- the coverage areas of aids to navigation of varying complexity (including lights, racons, leading lights and sector lights);
- pilotage areas;
- 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.

GPS and DGPS (and 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.

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2.3.4 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 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;
- 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 GPS/DGPS (and in the future enhanced Loran (eLORAN)) and Electronic Chart Systems (ECS) or Electronic Chart Display Information System (ECDIS) technology.

Photo Courtesy of Wasser und Schifffahrtsdirektion (Germany)

2.4 Measurement Errors and Accuracy

Good practice in both navigation and 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.

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Faults and Mistakes: Errors of this type 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, the **Absolute** and **Predictable Accuracy** are the principal concerns.

Repeatable Accuracy: This 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) are 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 4 shows the typical accuracy (95% probability) achieved using common navigational instruments or techniques.

Process	Typical accuracy (95%probability)	Accuracy at 1 NM (metres)
Magnetic compass bearing on a light or landmark	±3º The accuracy may deteriorate in high latitudes	93
Gyro-compass bearing on a light or landmark	0.75º X secant latitude (below 60º of latitude)	< 62
Radio direction finder	±3º to ±10º	93 - 310
Radar bearing	±1º 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)	1-3 m	
Dead Reckoning (DR)	Approximately 1 nautical mile for each hour of sailing	

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Table 4 - Fixing Processes and Systems

2.5 Hydrographic Considerations

2.5.1 Charts

The IMO definition[1] 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.

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 aids to navigation.

The principal international organisation on charting matters is the International Hydrographic Organisation (IHO).

The IHO is an intergovernmental consultative and technical organization that was established in 1921 to support the safety in navigation and the protection of the marine environment.

The object of the IHO is to bring about the:

- coordination of the activities of national hydrographic offices;
- greatest possible uniformity in nautical charts and documents;
- adoption of reliable and efficient methods of carrying out and exploiting hydrographic surveys;
- development of the science of hydrography and the techniques employed in descriptive oceanography.

IMO is the body responsible for determining international standards for the quality of hydrographic surveys and chart production.

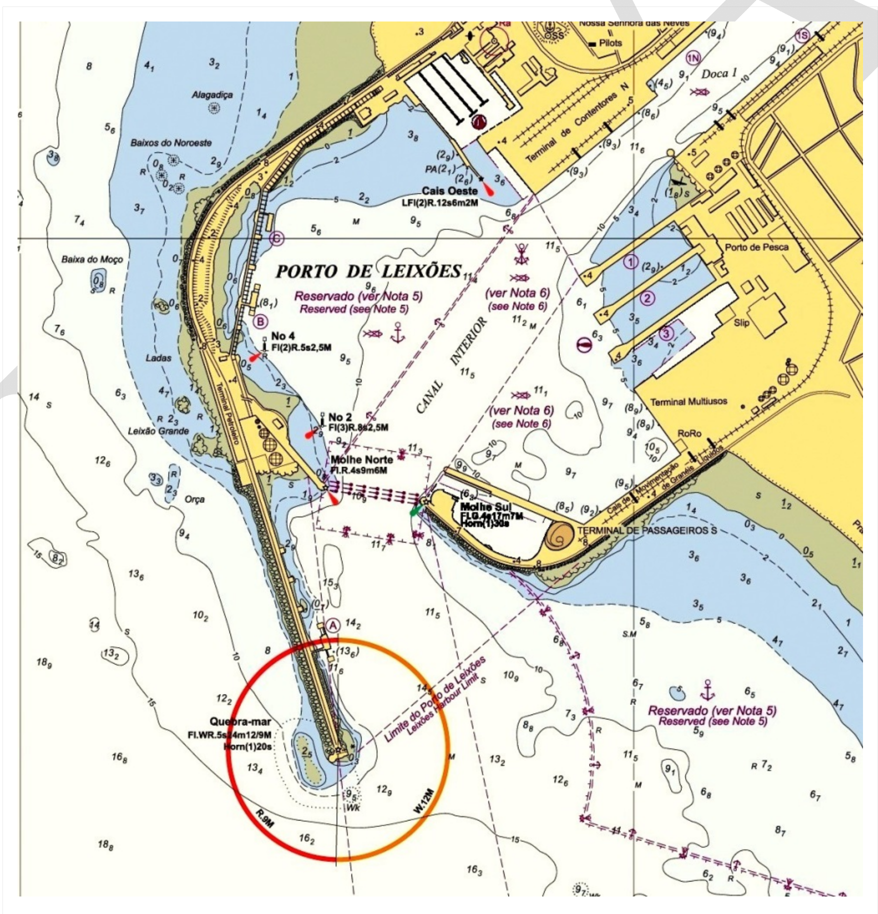

Figure 3 - Nautical Chart (Instituto Hidrográfico - Portugal)

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[2] 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 chart still carry a legend referring to a local datum, for instance, Ellipsoid Hayford or International – Datum Potsdam, Paris or Lisbon.

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).

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)[3];
- clearance heights for bridges are generally referenced to Highest Astronomical Tide.

These levels are depicted in Figure 4.

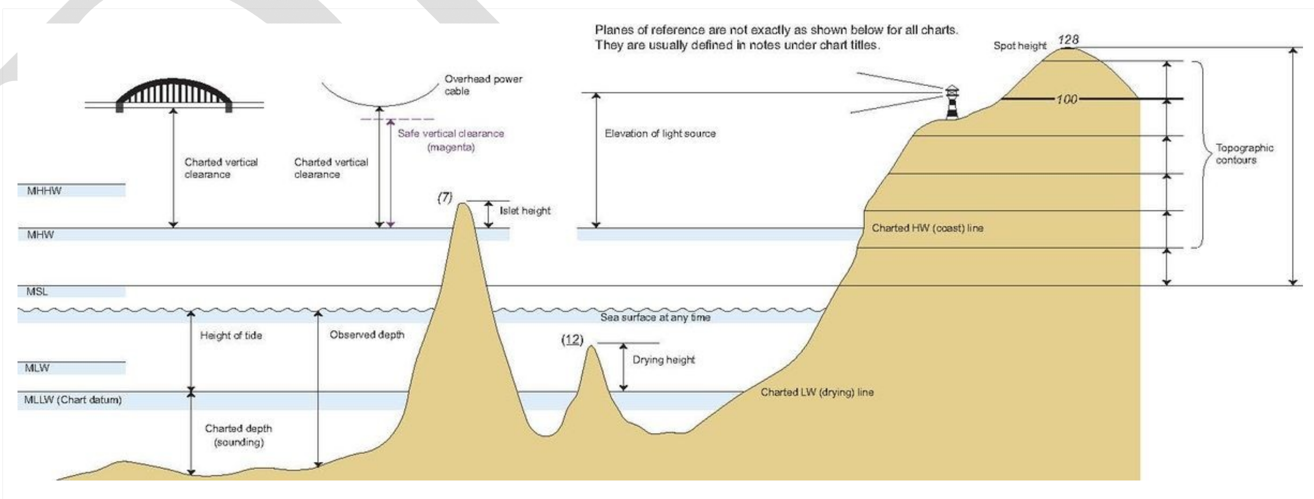

Figure 4 - Levelling or Vertical Control Datum (IHO)

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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 a 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)	MHWS
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, 3156)	MSL
Mean Low Water Springs: the average height of the low waters of spring tides. This level is used as a tidal datum in some areas. Also called spring low water. (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 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 defines 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

Table 5 – Levels Relevant to Aids to Navigation in Coastal and Restricted Waters

Chart Datum Issues

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

The now widely used GNSS positioning uses an earth centred datum referred to as World Geodetic System[4] 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 DGNSS stations using the ITU-R M.823/1 signal format.

The 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;
- 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[5] are shown in Figure 5.

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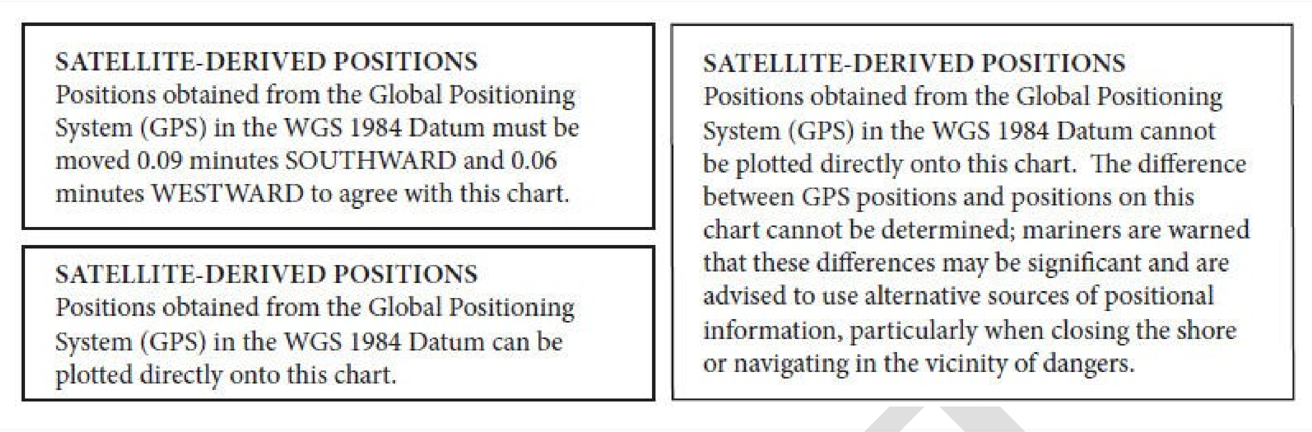
SATELLITE-DERIVED POSITIONS
Positions obtained from the Global Positioning System (GPS) in the WGS 1984 Datum must be moved 0.09 minutes SOUTHWARD and 0.06 minutes WESTWARD to agree with this chart.

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 5 – Examples of GNSS Notes on Charts

2.5.3 Accuracy of Charts

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

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

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

1	2	3	4	5
ZOC[6]	**Position Accuracy**[7]	**Depth Accuracy**[8]	**Seafloor Coverage**	**Typical survey Characteristics**[9]
A1	±5 m + 5% depth	=0,50+1%d Depth (m) / Acurracy (m) 10 / ±0,6 30 / ±0,8 100 / ±1,5 1000 / ±10,5	Full area search undertaken. All significant seafloor features detected[10] and depths measured.	Controlled systematic survey[11] 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.
A2	±20 m	=1,00+2%d Depth (m) / Acurracy (m) 10 / ±1,2 30 / ±1,6 100 / ±3,0 1000 / ±21,0	Full area search undertaken. All significant seafloor features detected and depths measured.	Controlled systematic survey achieving position and depth accuracy less than ZOC A1 and using a modern survey echosounder[12] and a sonar or mechanical sweep system.
B	±50 m	=1,00+2%d Depth (m) / Acurracy (m) 10 / ±1,2 30 / ±1,6 100 / ±3,0 1000 / ±21,0	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 accurades than ZOCA2, using a modern survey echosounder, but no sonar or mechanical sweep system.

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C	±500 m	=2,00+5%d Depth (m) | Acurracy (m) 10 | ±2,5 30 | ±3,5 100 | ±7,0 1000 | ±52	Full area search not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as sounding on passage.
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.			

Table 6 –Zones of Confidence (IHO)

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 7.

Chart scale	**Corresponding need for accuracy**	**Aproximate pencil width (0,5 mm) equivalence (metres)**	**Application**
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

Table 7 – Chart Scales[13], Applications[14] and Related Accuracy Considerations

2.5.4 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

[1] SOLAS Chapter V, Regulation 2.

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

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

[4] 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 A860(20)).

[5] Examples taken from Australian Charts.

[6] 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

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the chart production process. [Note: the rest of footnote 1 does not apply to paper charts and is therefore omitted from S-4].

[7] 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.

[8] 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.

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

[10] 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.

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

[12] Modern survey echosounder - a high precision single beam depth measuring equipment, generally including all survey echosounders designed post 1970.

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

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

Navguide: Chapter 3 - Aids to navigation

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. However these are covered in separate chapters due to their increasingly significant role in contributing to navigation safety.

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 shorebased aspects of the conceptual framework and systems architecture for e-Navigation. Chapter 4 of the Navguide covers e-Navigation. Radionavigation systems form a key element of the e-Navigation infrastructure and are therefore covered in Chapter 4.

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3.1 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.

3.2 Visual and Audible Aids to Navigation Design Theory

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 unlit if daytime navigation is sufficient.

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

- a radar reflector, and the navigating vessel has a radar;
- retro-reflecting 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 (lit or unlit), 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);
- 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, retro-reflective features; letters and numbers;
- lit/unlit; signal character; light intensity; sectors; inclusion of subsidiary aids;
- fixed structure; floating platform; construction materials;
- location; elevation; relationship to other aids to navigation and observable features.

Refer to IALA publications:

- Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation;
- Guideline 1035 on Availability and Reliability of Aids to Navigation.

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Photo - Courtesy of Danish Maritime Authority

3.2.1 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.

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.

3.2.1.1 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 use a five-colour system comprising white, red, green, yellow and blue, as defined in IALA Recommendation E-200 Part 1. 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. [1] , with small variances in some of the boundaries.

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[2].

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- Orange and fluorescent red, yellow, green or orange may be used for special purposes requiring high conspicuity.

Refer to IALA publications:

- Recommendation E-106 for the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System;
- Recommendation E-108 for the Surface Colours Used as Visual Signals on Aids to Navigation;
- Guideline 1015 on Painting Aids to Navigation Buoys (including reference to the practical guide on surface colours).

The CIE standard on the measurement of colours (colorimetry) is based on three reference colours (ie. 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).

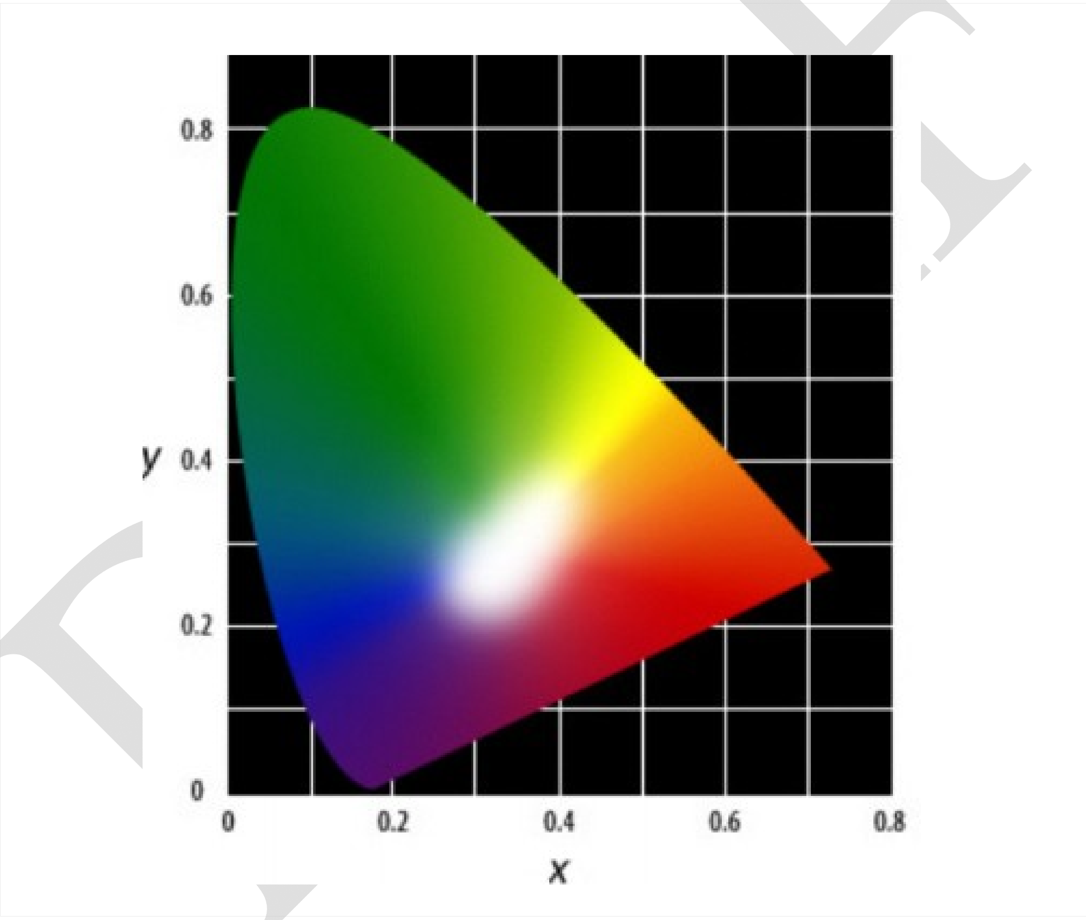

Figure 6 - Illustration of the Colour Zones on the 1931 CIE Chromaticity Diagram - Please note that the colour rendering is only indicative and should not be taken as fully accurate

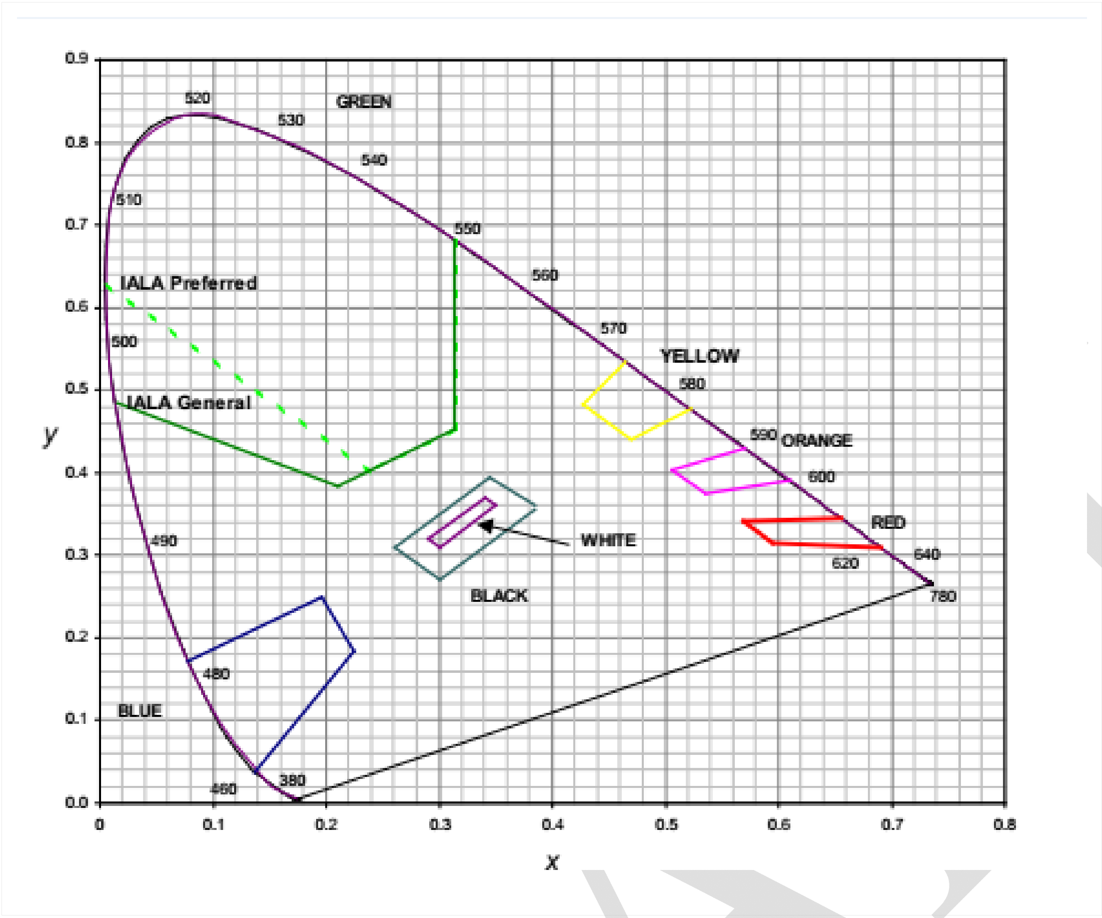

Figure 7 - IALA Chromaticity Areas of Ordinary Surface Colours - As plotted on the 1983 CIE Chromaticity diagram - courtesy of CIE

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 E108 on the surface colours used as visual signals on aids to navigation. Information for light signal colours is shown in IALA Recommendation E200/1 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]

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3.2.1.2 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.

Photo Courtesy of Australian Maritime Safety Authority.

3.2.1.3 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 26% of the light is "lost" 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;
- better matched to local conditions and user requirements.

3.2.1.4 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.

3.2.1.5 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:

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

where:

C = contrast

L_B = luminance of background (cd/m^2)

L_O = 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.

3.2.1.6 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;
- 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.

3.2.1.7 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 Figure 8.

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Observer Eye Heigth Metres	Elevation of Mark/metres										
	0	**1**	**2**	**3**	**4**	**5**	**10**	**50**	**100**	**200**	**300**
1	2.0	4.1	4.9	5.5	6.1	6.6	8.5	16.4	22.3	30.8	37.2
2	2.9	4.9	5.7	6.4	6.9	7.4	9.3	17.2	23.2	31.6	38.1
5	4.5	6.6	7.4	8.1	8.6	9.1	11.0	18.9	26.9	33.3	39.7
10	6.4	8.5	9.3	9.9	10.5	11.0	12.8	20.8	26.7	35.1	41.6
20	9.1	11.1	12.0	12.6	13.1	13.6	15.5	23.4	29.4	37.8	44.2
30	11.1	13.2	14.0	14.6	15.2	15.7	17.5	25.5	31.4	39.8	46.3

Table 8 - Graphical Range Table in Nautical Miles

The values in Table 8 are derived from the formula:

$$R_g = 2.03 \times \left(\sqrt{h_o} + \sqrt{H_m} \right)$$

where: R_g = geographical range (nautical miles)
h_o = elevation of observer's eye (metres)
H_m = 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.

3.2.2 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.

3.2.2.1 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 lit or unlit;
- intensity and character.

Refer to IALA publications:

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- Recommendation E-106 for the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System.
- Recommendation E-108 for the Surface Colours Used as Visual Signals on Aids to Navigation.

3.2.2.2 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 below.

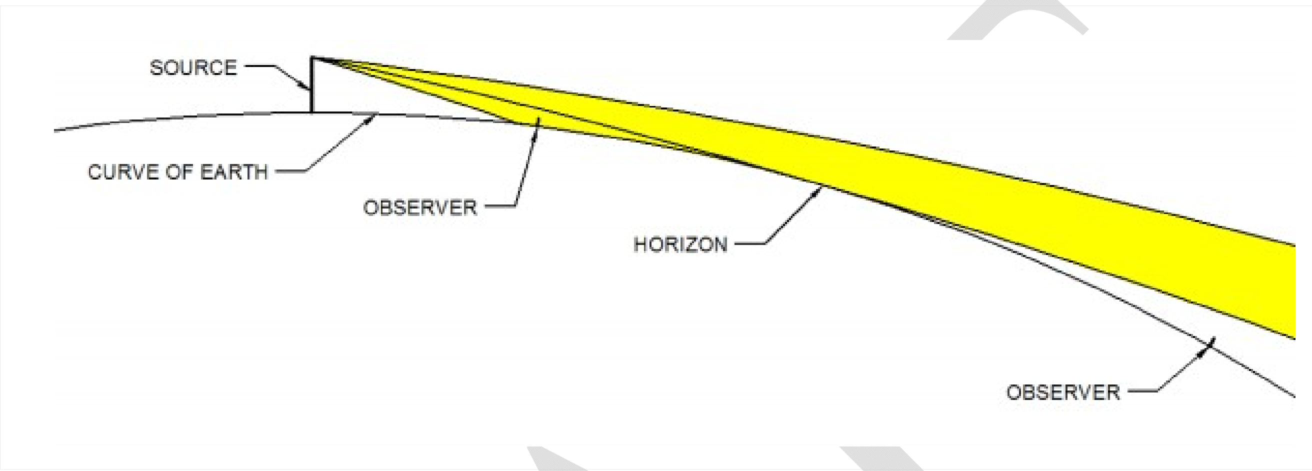

Figure 8 - Effect of Exceeding Geographical Range

3.2.3 Lights

3.2.3.1 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.

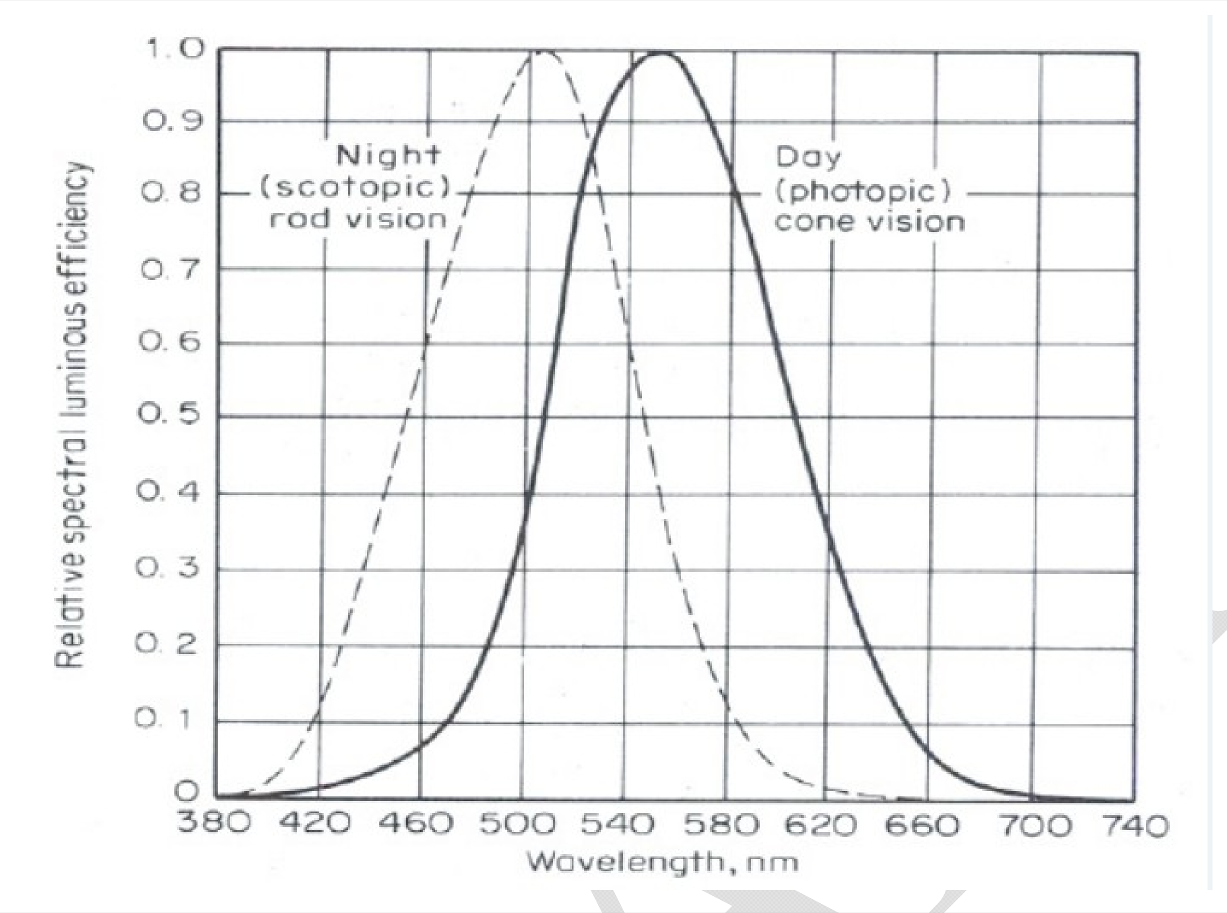

Figure 9 - Spectral Sensitivity Distributions or V(λ) and V'(λ) Curves for the Human Observer.

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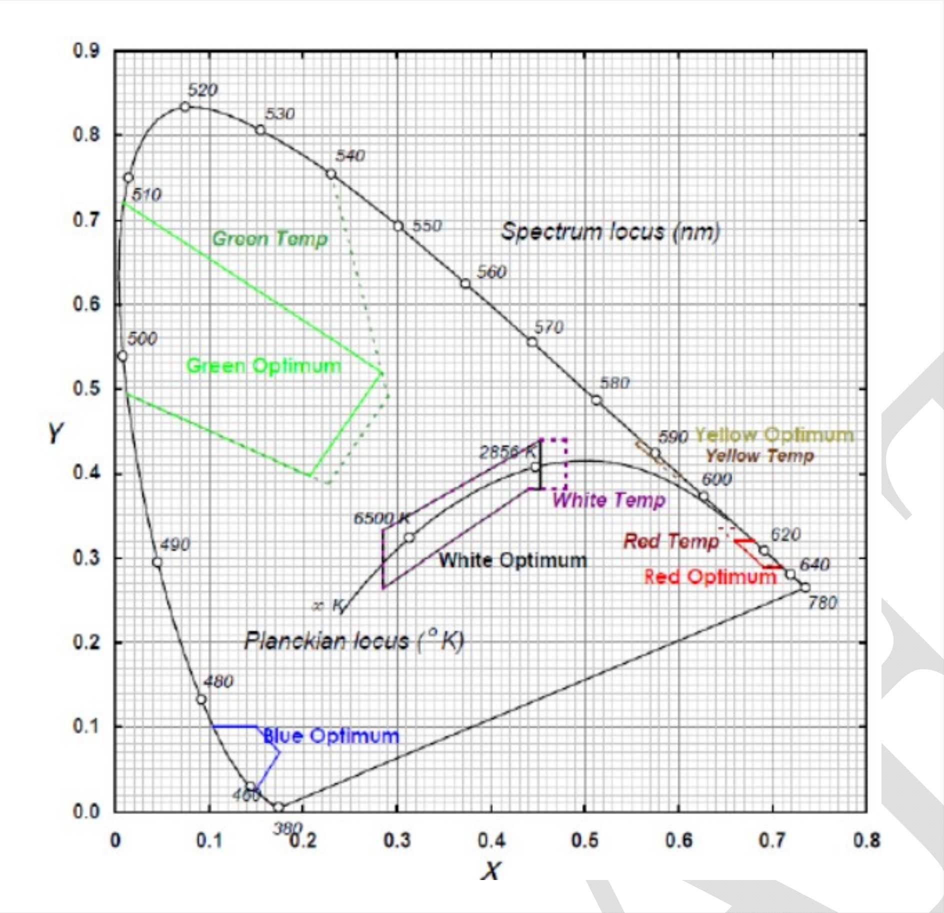

Figure 10 - Chromaticity Regions of the Recommended IALA Colours for Lights

IALA Optimum boundaries are represented by solid lines while IALA Temporary boundaries are represented by dashed lines.

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 instrument 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 spectradiometer, 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.

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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;
- 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 11.

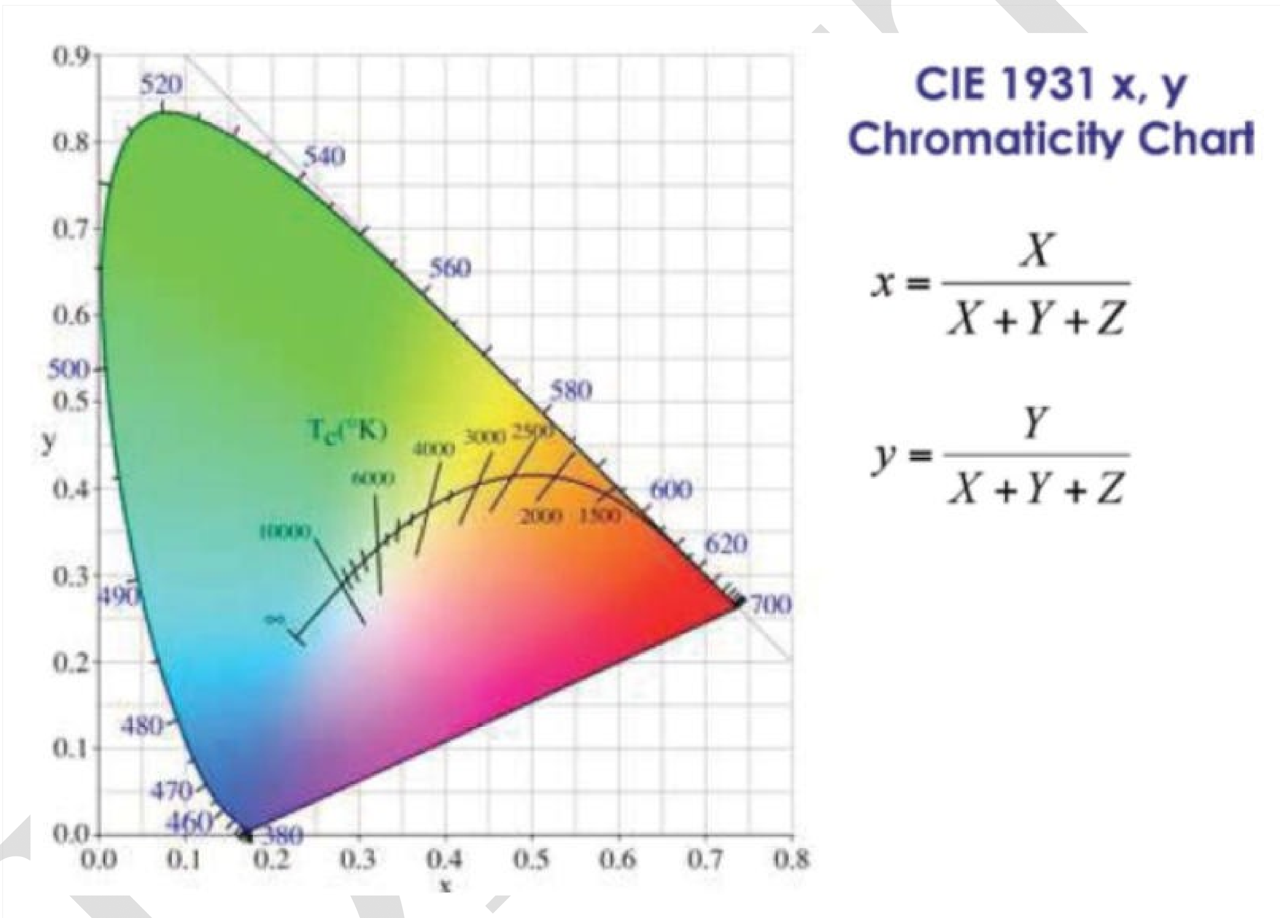

Figure 11 - CIE 1931 x,y Chromaticity Chart

Units of Measurement

Term	Description	Unit	Abbreviation
Luminous flux	This is the total light emitted from the source (ie. 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 680 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 [15])	candela	cd
Luminance (Brillance)	This is the portion of the luminous flux emitted in a specific direction by the surface area of a luminous body. Luminance is an important term for rating the brightness impression of light sources and illuminated objects.	candelas per square meter and also as candelas per square centimeter	cd/m2 cd/cm2
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

Table 9 –Photometric Units of Measurement

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 µlux 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 µlux 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 E200 series and its associated guidance provides 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.

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.

Inverse Square Law

Light emitted from a source radiates out in all directions. For a point source, the wave fronts of light can be imagined to generate a series of spherical surfaces. As shown in Figure 12, 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.

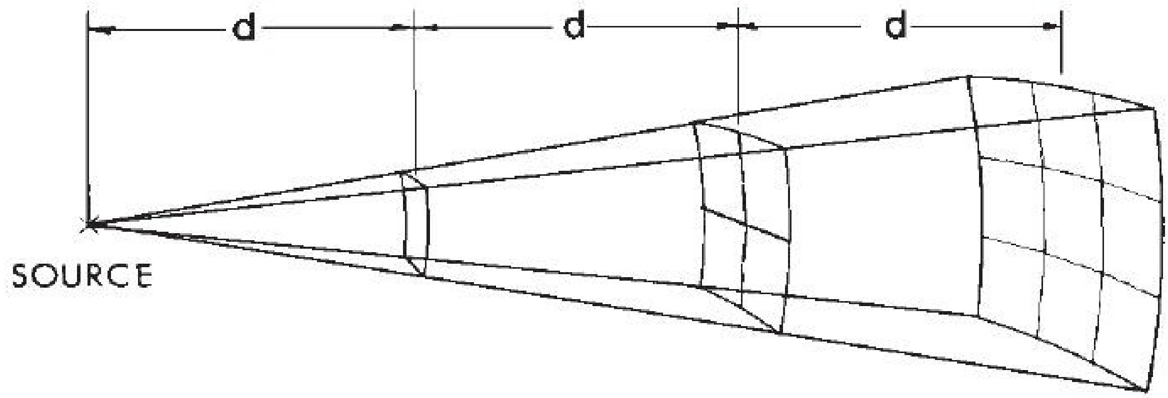

Figure 12 - Illustration of the Inverse Square Law Concept.

Allard's Law

The illuminance of a light source reaching an observer's eye determines whether the light is 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:

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

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

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

Refer to IALA publication:

- Recommendation E-200-2 on Marine Signal Lights - Part 2 - Calculation, Definition and Notation of Luminous Range

3.2.3.2 Rhythms and Characters

IALA has produced a recommendation on the characters for light on aids to navigation. The tables of classifications and specifications of aid to navigation characters are provided in Table 10.

Refer to IALA publication:

- Recommendation E-110 for the rhythmic characters of lights on aids to navigation.

The Rhythmic Characters of Lights are provided in Table 11.

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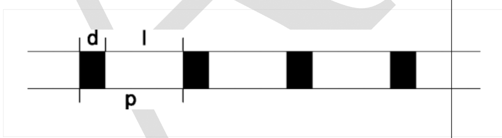
	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
1	FIXED LIGHT	F	A light showing continuously and steadily.	A single fixed light should be used with care because it may not be recognized as an aid to navigation light. 	A single fixed light shall 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  $l \geq 3d$ $p \geq 2s$ Example: l = 3 s; d = 1 s; p = 4 s	A single occulting White light indicates a safe water mark.
2.2	Group occulting light	Oc(#) eg. 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.	A group occulting Yellow light indicates a special mark.

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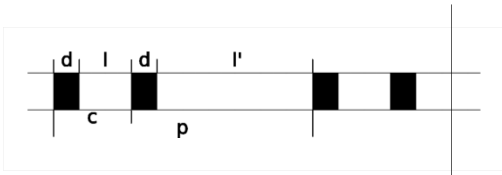
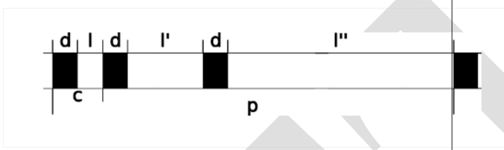
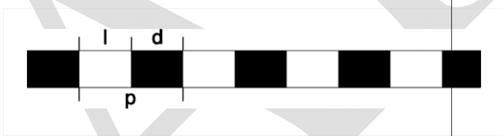
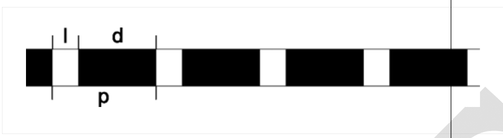
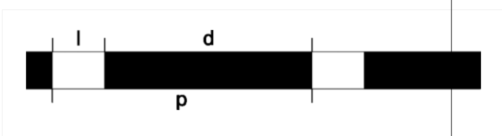
				 l' ≥ 3 d l ≥ d (c = d + l) ≥ 1 Example: l'=6s; l=2s; d=1s; c=3s; p=10s	
2.3	Composite group occulting light	Oc(# + #) eg.Oc(2 + 1)	A light similar to a group occulting light except that successive groups in a period have different numbers of eclipses.	This class of light character is not recommended because it is difficult to recognize.  l ≥ d l' ≥ 3l l'' ≥ l' (c = d + l) ≥ 1s Example: l''=9; l'=3s; l=1s; d=1s; c=2s; p=16s	
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 ≥ 2s Example: l = d = 2s; p=4s	An isophase White light indicates a safe water 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 ≥ 3l p ≥ 2s Example: d = 3s; l = 1s; p=4s	A single flashing Yellow light indicates a special mark.
4.2	Long flashing light	LFI	A single flashing light in which an appearance of light of not less than 2 s duration (long flash) is regularly repeated.	d ≥ 3l p ≥ 2s Example: d = 8s; l = 2s; p = 10s	A long flashing White light with a period of 10 s indicates a safe water mark.
4.3	Group flashing light	Fl(#) eg. 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' ≥ 3d d ≥ l (c = l + d) ≥ l Example: d' = 6s; d = 2s; l = 1s; p = 10s	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

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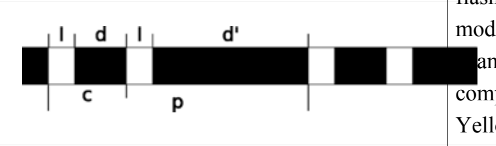
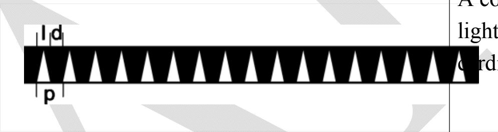
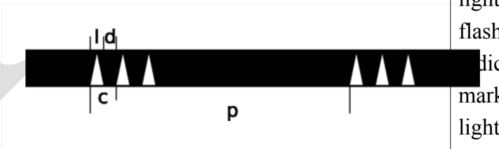
4.4	Composite group flashing light	Fl(# + #) eg Fl(2 + 1)	A light similar to a group flashing light except that successive groups in a period have different numbers of flashes.	Light characters should be restricted to (2 + 1) flashes in general, and should be (3 + 1) flashes only as an exception. Fl(2+1)  Fl(2*1) d'' ≥ d' ; d' ≥ 3d ; d ≥ l ; (c = l + d)≥ 1s ; Example: d'' = 9s; d' = 3s; d = 1s; l = 1s; c = 2s; p = 16s	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 (or 50) flashes per minute. The higher rate of flashing is preferred.	
5.1	Continuous quick light	Q	A quick light in which a flash is regularly repeated.	 d ≥ 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.
5.2	Group quick light	Q(#) eg Q(3) eg Q(9) eg 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)  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. A group quick White light with a group of nine flashes, in a period of 15 s, indicates a west cardinal mark. 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.

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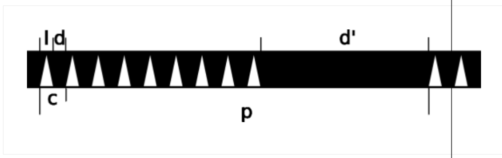
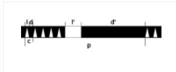
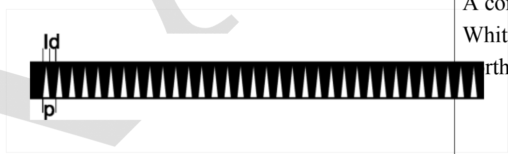
				Q(9)  d ≥ l d'>d 1 s ≤ c ≤ 1.2 s Q(6)+LF1  d' ≥ 3 l'; l' ≥ 2 s; d ≥ l; 1 s ≤ c ≤ 1.2 s; Example: d' = 7 s; l' = 2 s; l = d = 0.5 s; c = 1 s; p = 15 s.	
6	VERY QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 80 flashes per minute but less than 160 flashes per minute.	A light in which identical flashes are repeated at the rate of 120 (or 100) flashes per minute. The higher rate of flashing is preferred.	
6.1	Continuous very quick light	VQ	A very quick light in which a flash is regularly repeated.	 d ≥ l; 0.5 s ≤ p ≤ 1.6 s; Example: l = d = 0.25 s; p = 0.5 s	A continuous very quick White light indicates a north cardinal mark.
6.2	Group very quick light	VQ(#) eg VQ(3) eg VQ(9) eg 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' ≥ 1,5 s; d ≥ l; 0.5 s ≤ c ≤ 0.6 s; Example: d' = 3.75 s; l = d = 0.25 s; c = 0.5	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.

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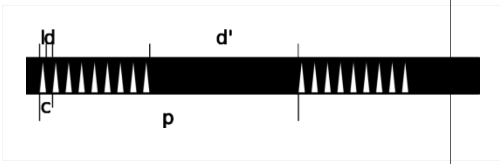
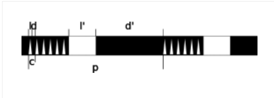
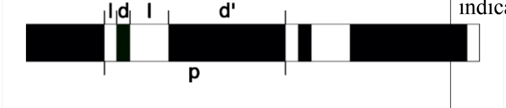
				VQ(9)  d' ≥ 1.5 s; d ≥ l; 0.5 s ≤ c ≤ 0.6 s; Example: d' = 5.75 s; l = d = 0.25 s; c = 0.5 VQ(6)+LF1  d' ≥ 1.5 l'; l' ≥ 2 s; d ≥ l; 0.5 s ≤ c ≤ 0.6 s; Example: d' = 5 s; l' = 2 s; l = d = 0.25 s; c = 0.5 s; p = 10 s	
7	ULTRA QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 160 flashes per minute.	A light in which flashes are repeated at a rate of not less than 240 flashes per minute and not more than 300 flashes per minute.	
7.1	Continuous ultra quick light	UQ	An ultra quick light in which a flash is regularly repeated.		
8	MORSE CODE LIGHT	Mo(#) eg. 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' ≥ 3l; d ≥ l; l = 0,5s; Example: l' = 1,5s; l = 0,5s; d = 0,5s; d' = 4,5s; p = 7s	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.

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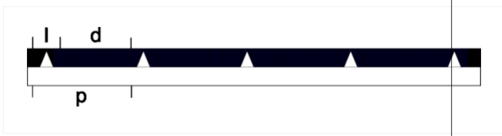
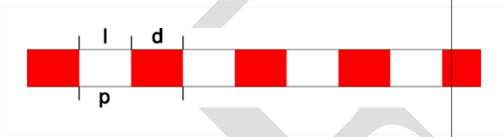
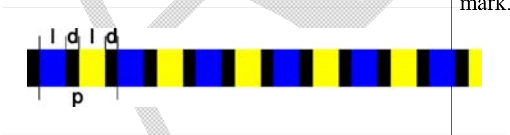
9	FIXED AND FLASHING LIGHT	FFl	A light in which a fixed light is combined with a flashing light of' higher luminous intensity.	This class of light character should be used with care because the fixed component of the light may not be visible at all times over the same distance as the rhythmic component.  d ≥ 3 l l ≤ 1 s Example: d = 3 s; l = 1 s; p = 4 s	
10	ALTERNATING LIGHT	Al## eg A1WR	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 = 2s; p = 4s	
10.1 New	OCCULTING ALTERNATING LIGHT	OAL	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.  OAL l = 1s d = 0,5s p = 3s Example: lb = 1s; d = 0,5s; ly = 1s; d = 0,5s; p = 3s	An Occulting-Alternating Blue and Yellow light indicates an Emergency Wreck Marking Buoy mark.

Table 10 - Classification of the Rythmic Characters of Lights

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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 16 s	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 5 s. (b) Group quick light with a group of three flashes, in a period of 10 s.	
South cardinal	(a) Group very quick 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. (b) Group quick 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.	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 10 s. (b) Group quick light with a group of nine flashes, in a period of 15 s.	
ISOLATED DANGER	(a) Group flashing light with a group of two flashes, in a period of 5 s. (b) Group flashing light with a group of two flashes, in a period of 10 s.	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 1 s and not more than 1.5 s. The duration of a flash together with the duration of the eclipse within the group should be not less than 2 s and not more than 3 s.
SAFE WATER	(a) Long flashing light with a period of 10 s. (b) 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 10 s. (c) Group flashing light with a group of four, five or (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 20 s, is assigned to Ocean Data Acquisition Systems (ODAS) buoys.
EMERGENCY WRECK MARKING BUOY	Occulting Alternating light with a period of 3s	Only the colours Blue and Yellow are used

Table 11 - Rhythmic Characters[4] of the Lights in the IALA Maritime Buoyage System[5]

Maximum Periods for Light Characters

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

Table 12 - Maximum Period for Rhythmic Characters of Aids to Navigation Lights

Refer to IALA publication:

- Recommendation E-110 for the rhythmic characters of lights on aids to navigation.

Timing of Astronomical Events

The nighttime 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.

Event	Condition	Typical 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 detail 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.

Table 13 - Timing of Astronomical Events

Switch-on / Switch-off Light Levels

For lighted aids to navigation that only operate at night, the ambient light levels at which an AtoN light switches on should be chosen so that the AtoN light switches on while the ambient light level is 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 publications:

- Guideline 1038 on Ambient Light Levels at which Aids to Navigation Should Switch On and Off.

Night Operations

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Nominal Range and Luminous Intensity

Table 14 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.

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

Table 14 - IALA Conversion Table for Luminous Intensity and Nominal Range for Night Observations

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

3.2.3.3 Background Lighting

Nominal range at night is calculated with no allowance for glare from background lighting. Excessive background lighting, from street lights, 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.

3.2.3.4 Glare

Glare can be caused by bright lights emitted from the shore, such as car headlights, 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;
- should be reduced to 0.01 lux if the background is very dark.

Refer to IALA publications:

- Recommendation E-112 for Leading Lights (including excel program);
- Guideline 1023 for the Design of Leading Lines.

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

- raise 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;

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- reducing the size of the optic;
- masking the optic with, for example, perforated metal sheet;
- screen unnecessary arcs of the light;
- use 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.

3.2.3.5 Intensity Losses

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 intersection.

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 publication:

- Recommendation E200-5 on Estimation of the Performance of Optical Apparatus.

3.2.3.6 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);
- 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 publication:

- Recommendation E200-2 on Service Condition Factors.

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3.2.3.7 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 E200-2 On Marine Signal Lights Part 2 – Calculation, Definition and Notation of Luminous Range;
- Recommendation E-111 on Port Traffic Signals.

Figure 13 and Table 15 are extracts of Recommendation E200-2 On Marine Signal Lights Part 2 – Calculation, Definition and Notation of Luminous Range (December 2008) and provides a conversion between nominal daytime range and luminous intensity.

The Luminous Range Diagram, shown in Figure 13 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 (refer to Table 16).

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

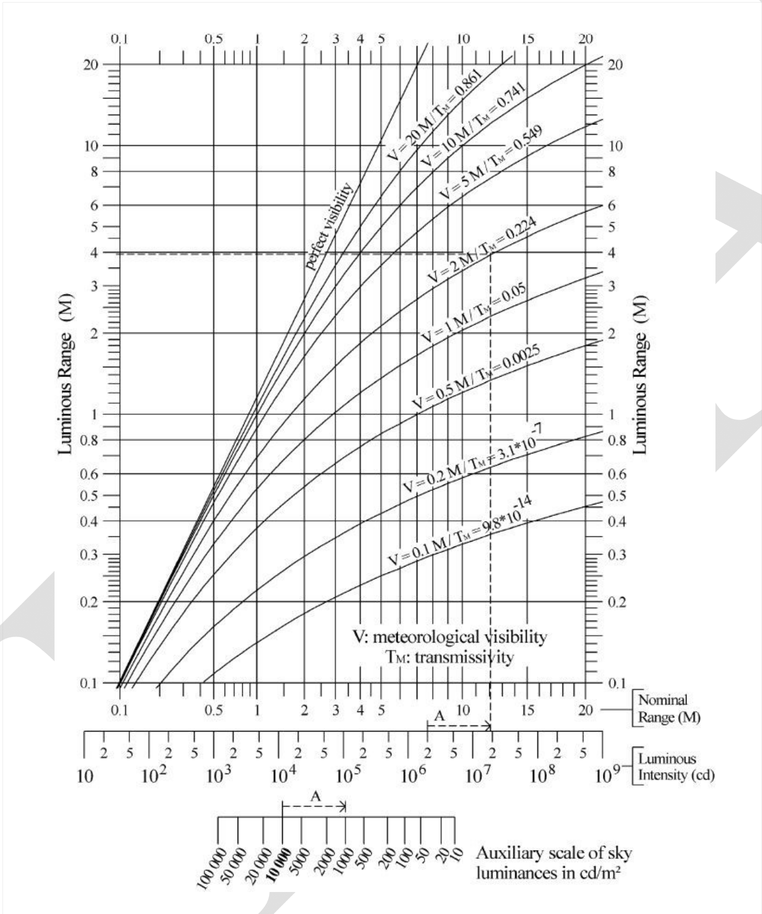

Figure 13 –Daytime Luminous Range Diagram

The graph has been drawn for a sky luminance of 10 000 cd/m². For other values of sky luminance mark off along the scale of abscissae the distance between the luminance of 10 000 cd/m² 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/m²).

Measure the distance A separating graduations 10 000 cd and 1 000 cd on the auxiliary scale. Transfer this distance to the scale of abscissae from the graduation corresponding to 2 000 000 cd ($2x10^6$ cd) in the same sense. 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 to meet the curve for 2 nautical miles visibility. Read off the luminous range on the vertical scale against the point so obtained. It should read approx. 4 nautical miles.

Luminous intensity	**Nominal range (rounded)**	**Luminous intensity**	**Nominal range (rounded)**
kilocandelas (10^3 cd)	**Nautical miles (M)**	**Megacandelas (10^6 cd)**	**Nautical miles (M)**
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
		199 – 299	18
		300 – 449	19
		450 – 669	20
		670 – 993	21
		994 – 1460	22

Table 15 – IALA Conversion Table for Luminous Intensity and Nominal Daytime Range

Meteorological condition	**Luminance in cd/m²**	**Required illuminance Et in 10^{-3} lx**
Very dark overcast sky	100	0.013
Dark overcast sky	200	0.024
Ordinary overcast sky	1 000	0.107
Bright overcast sky or clear sky away from the direction of the sun	5 000	0.506
Bright cloud or clear sky close to the direction of the sun	10 000	1
Very bright cloud	20 000	1.98
Glaring cloud	50 000	4.91

Table 16 – Required Illuminance in Varying Meteorological Conditions

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3.2.3.8 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:

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

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:

$$T = 0.05^{1/V} \quad \text{or} \quad T^{V} = 0.05$$

3.2.3.9 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.

3.2.3.10 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.

3.2.3.11 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.

3.2.4 Miscellaneous

This section includes information on audible signals and other options for increasing the conspicuity of aids to navigation structures.

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3.2.4.1 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 E-109 for the Calculation of the Range of a Sound Signal;
- Guideline 1090 on the Use of Audible 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 subjeced to a noise as defined in IALA Guideline 1090. 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.

3.2.4.2 llumination of Structures

Illumination of structures can provide an important AtoN function. Illumination of fixed structures is frequently called flood-lighting 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 publications:

- Guideline 1061 Light Applications - Illumination of Structures.

3.2.4.3 Retroreflective Materials

The use of retroreflective 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, retroreflective material is a cheap and effective way to obtain high level of night time conspicuity.

The use of retroreflecting material for aids to navigation is particularly in the case of unlighted aids where by the projection of a light, which may range from a hand-held spotlight to a powerful searchlight, an aid can more easily be located and sometimes identified.

Refer to IALA publication:

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- Recommendation R0106 - Retroreflecting Material on Aids to Navigation Marks with IALA Maritime Buoyage System..

3.3 Visual Aids to Navigation Technology

Until the first application of electricity for lights late in the nineteenth century, all artificial light was produced by fire. Illuminants progressed from pyres of wood (used up until the 1800's), to oil wick lamps, vaporised oil and gas burners, then electric arc and tungsten filament lamps. Optical devices matched these developments, first with reflector systems and later with lenses.

It is interesting to note that the efforts to understand the human perception of light, to improve the efficiency and effectiveness of aids to navigation illuminants and optical apparatus, were at the forefront of scientific endeavours for many years.

The glass lens design pioneered by Augustine Fresnel around 1820 remains a principal element of the modern aid to navigation light, although present day lenses are often made of plastic rather than glass.

A few countries still use aids to navigation lighting systems that burn acetylene or propane gas. They are typically preferred for their robustness and simplicity of operation. However, the majority of aids to navigation lighting systems use electricity of various types as their power source. Electricity is generally more efficient than gas. Increasingly, electric AtoN lights are powered by renewable energy sources such as solar, wind or wave power.

Lamps used in electric light systems have been specifically designed for aids to navigation applications. However, lamps selected from the enormous range of commercial products have also been used or adapted for aids to navigation. The use of Light Emitting Diode (LED) technology as an alternative to filament lamps in Aids to Navigation is rapidly expanding and in some countries now makes up the majority of all lighted AtoN.

3.3.1 Daymarks

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 17.

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

Table 17 – Typical Operational Range of Daymarks

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Guidance on the impact of background lighting and meteorological conditions on light intensity required to achieve a particular range is provided in Table 18.

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
Visability (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							

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26	1,120,000								
27	1,630,000								
28	2,360,000								
29	3,420,000								
30	4,940,000								

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

Table 18 – Night and Day with Background.

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

3.3.2 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 LED's are now widely used. Table 19 compares the performance and other characteristics of the various light sources.

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

Table 19 - Light source performance and other characteristics

Light Emitting Diode (LED)

Coloured LED

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 lamp 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.

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.

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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;
- Signs and signals formed by arrays of LEDs in the shape of letters, numerals, signs etc.

Technical data:

- Power: Single LED: 1milliWatt to over 32 Watts, Cluster LED: 1 to 60 Watts of 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;
- Easy to cluster LEDs.

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;
- Lamp 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 is covered in IALA Guideline 1043.

Refer to IALA publication:

- Guideline 1043 on Light Sources Used in Visual Aids to Navigation.

3.3.3 Integrated Power Supply Lanterns

Integrated Power Supply Lanterns (IPSL) have 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

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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 1064 on Integrated Power Systems Lantern.

3.4 Maritime Buoyage System and other Aids to Navigation

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. 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 uses 7 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[6];
- Cardinal Marks;
- Isolated Danger Marks;
- Safe Water Marks;
- Special Marks;
- Emergency Wreck Marking Buoy;
- Other Marks.

The General Principles and Rules of the IALA Maritime Buoyage System can be found in Annex D.

3.4.1 Marking New Dangers

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.

Refer to IALA publications:

- Maritime Buoyage System (with supporting guidelines);
- Guideline 1046 on a Response Plan for the Marking of New Wreck.

IALA also has a consolidated recommendation and guidelines 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.

3.4.2 Other Marks

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

3.4.2.1 Leading Lines/Ranges

Transits / Leading (Range) Lines

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

Leading (Rear Range) Light - Photo Courtesy of the Canadian Coast Guard

A simple transit can be used to:

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

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.

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[7] or do not satisfy the accuracy requirements for safe navigation;

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- define a safe approach bearing to a harbour or river entrance, particularly where there are cross currents;
- separate two-way traffic (ie. when passing a bridge).

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;
- 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 E-112 for Leading Lights (including excel program);
- Guideline 1023 for the Design of Leading Lines;
- Recommendation for a Definition of Nominal Daytime Range of Maritime Signal Lights Intended for Guidance of Shipping by Day.

3.4.2.2 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;
- 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 14 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.

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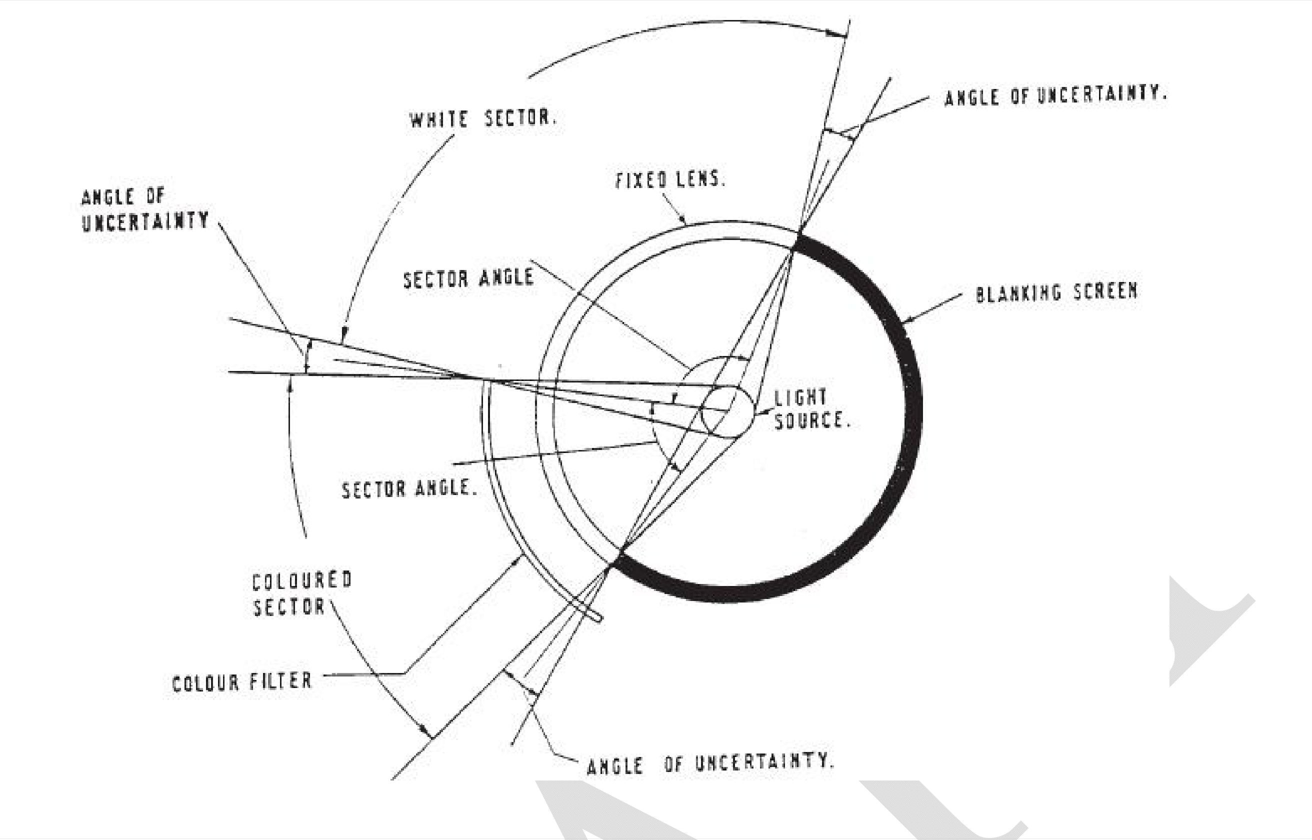

Figure 14 – Angle of Uncertainty

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 (ie. 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 0.25o 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;
- 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)[8].

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.

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.

Applications

LED Sector Projector Light - Photo Courtesy of Cybernetica AS

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;
- 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);
- define different rhythms over adjacent sectors.

Examples

Some examples of sector lights applications are illustrated in Figure 15 and Figure 16.

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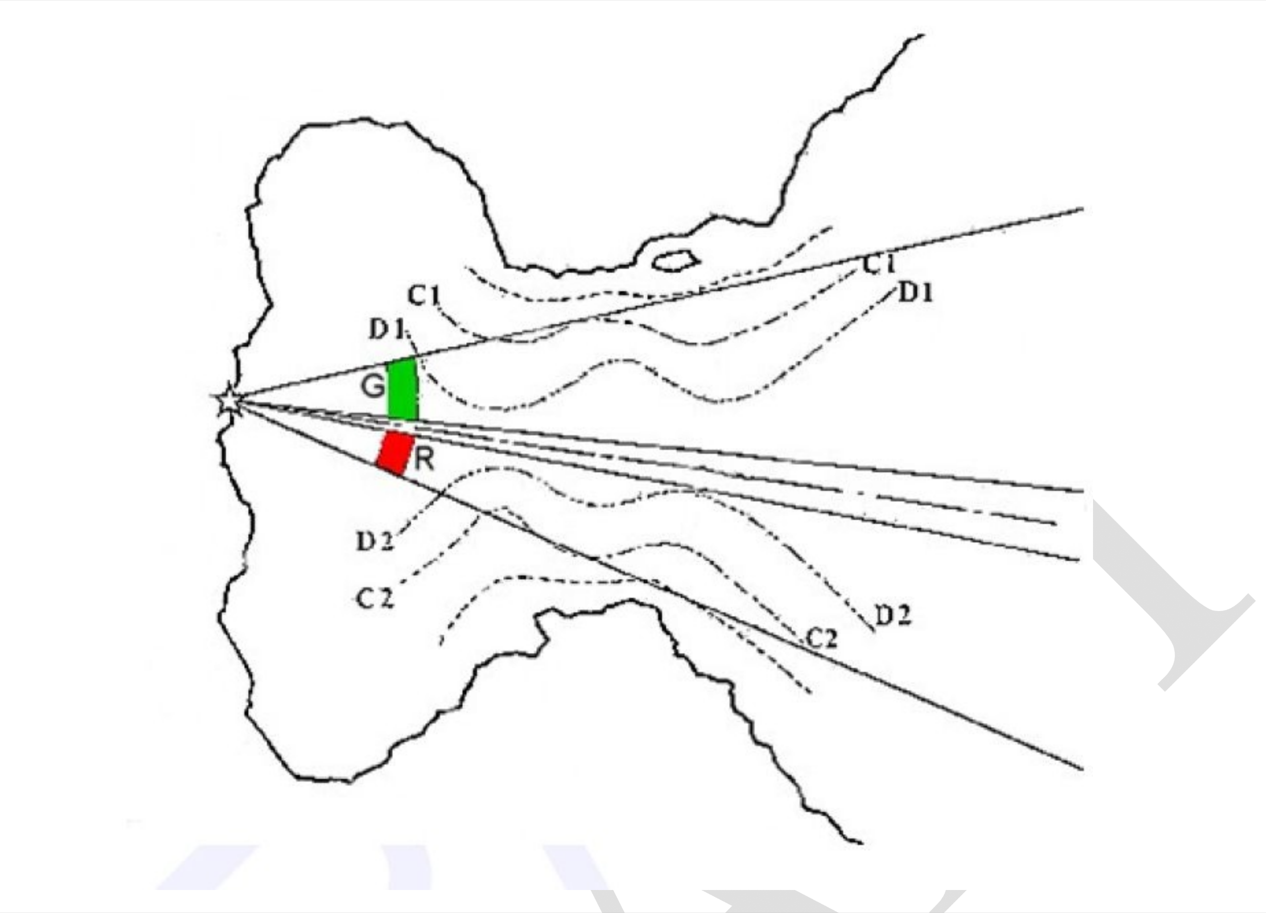

Figure 15 - Sector Light Application

This illustration 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.

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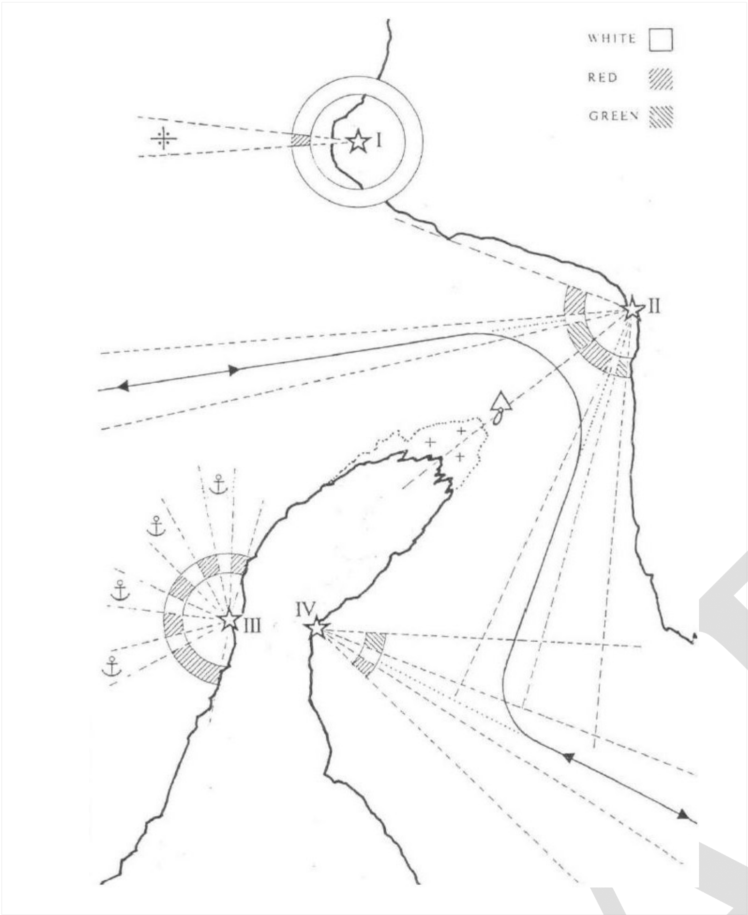

Figure 16 - Various Applications for Sector Lights

The function of each light in Figure 16 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.

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

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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.

Refer to IALA publication:

- Guideline 1041 on Sector Lights.

3.4.2.3 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;
- 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[9].

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;
- 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 DGNSS;
- coastwatch or coastguard functions;
- VTS functions;
- base for audible (fog) signals;
- collection of meteorological and oceanographic data;
- radio and telecommunication facilities;
- tourist facilities.

3.4.2.4 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 (eg. 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.
- a seasonal mark is required.

Buoys: Buoys are defined as minor floating aids and whilst it is normal that they are lit 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 AtoNs, and remote monitoring units are sometimes installed in addition to a light;
- audible signals are used on buoys in some countries.

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 AtoNs 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;
- are not specifically covered by the IALA Maritime Buoyage System.

Refer to IALA publication:

- Recommendation O-104 for 'Off Station' Signals for Major Floating Aids to Navigation.

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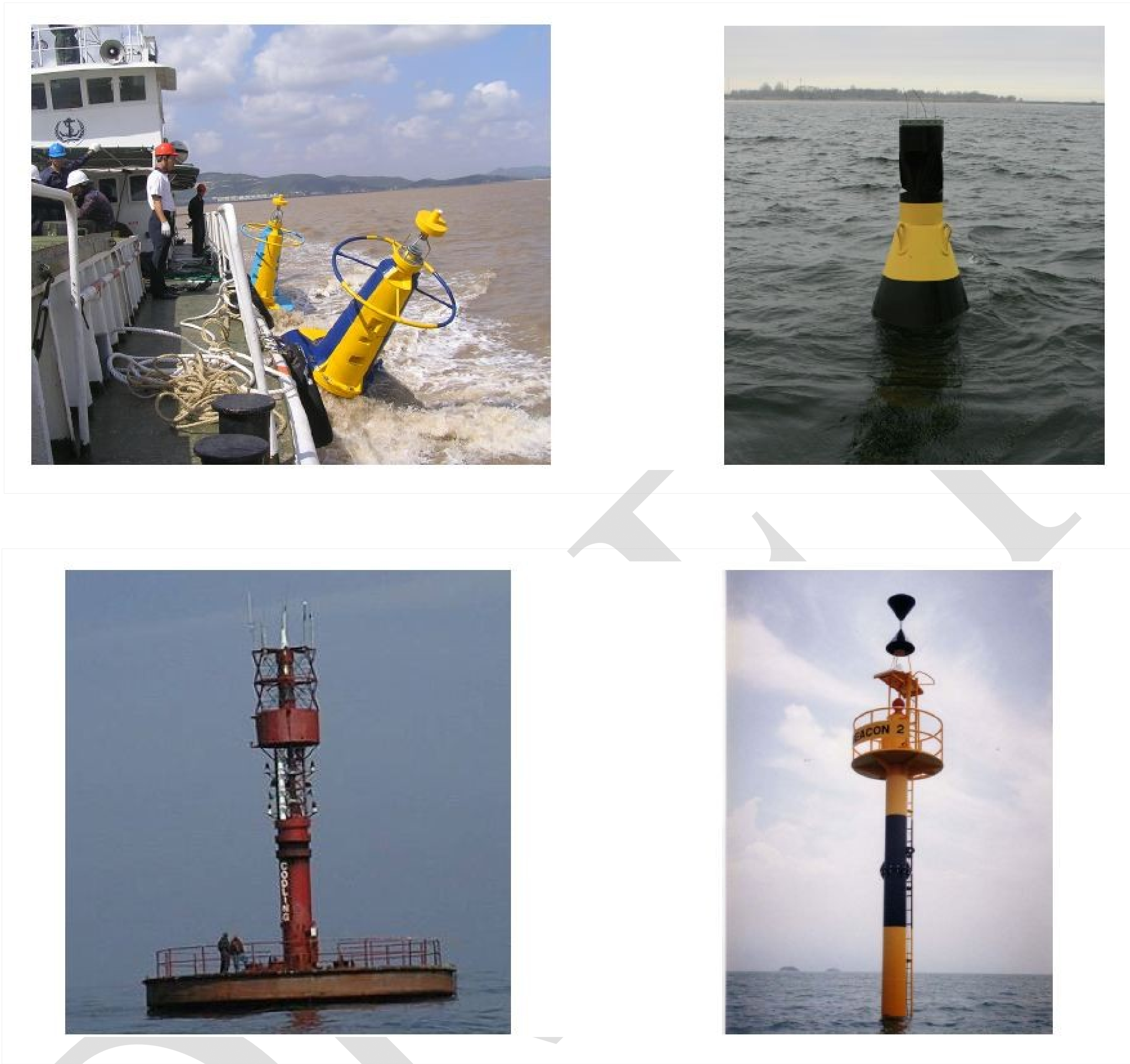

Figure 17 – Examples of Floating Aids

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[10].

The availability of a floating aid is the principal measure of performance determined by IALA. The recommended availability targets are indicated in Table 20. The availability objective assigned to floating aids to navigation conforming to the IALA Maritime Buoyage System should also apply to the topmark.

Description of Aid	Availability Target	
Floating aids to navigation that are considered to be of vital navigational significance	Category 1	99.8%
Floating aids to navigation that are considered to be of important navigational significance	Category 2	99.0%
Floating aids to navigation that are considered to be of necessary navigational significance	Category 3	97.0%

Table 20 - Availability Targets

Refer to IALA publications:

- Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation;
- Guideline 1035 on Availability and Reliability of Aids to Navigation.

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.

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 an 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 on Cost Comparison Methodology of Buoy Technologies.

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);
- optimising the design.

Refer to IALA publications:

- Maritime Buoyage System (and supporting guidelines);
- Guideline 1006 on Plastic Buoys;
- Guideline 1011 on a Standard Method for Defining and Calculating the Load Profile of Aids to Navigation;
- Guideline 1036 on Environmental Considerations in Aids to Navigation Engineering;

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- Guideline 1037 on Data Collection for Aids to Navigation Performance Calculation;
- Guideline 1040 on the Maintenance of Buoys and Small Aids to Navigation Structures;
- Guideline 1042 on Power Sources and Energy Storage for Aids to Navigation;
- Guideline 1043 on Light Sources Used in Visual Aids to Navigation;
- Guideline 1094 on Daymarks for Aids to Navigation;
- Guideline 1099 on the Hydrostatic Design of Buoys;
- Recommendation E-106 on the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System.

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;
- 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.
  L = Length of mooring line (m)
  H = Depth[11] of water (m)

All moorings should be designed as per Guideline 1066 on Design of Floating Aids to Navigation Moorings.

Refer to IALA publications:

- Guideline 1066 on the Design of Floating Aids to Navigation Moorings.

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 DGNSS position fixing is increasingly seen as the preferred method. The benefits of DGNSS position fixing are: convenience, accuracy and repeatability. A buoy tender using DGNSS 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.

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, extracts of which are shown in Annex D. Topmarks should conform to Guideline 1094 on Daymarks for Aids to Navigation.

Refer to IALA publications:

- Guideline 1094 on Daymarks for Aids to Navigation.

Notes

[1] CIE website address: www.cie.co.at/cie

[2] Blue surface colours may be used in inland waterways. estuaries and harbours where the colour may be seen at close range. see IALA recommendation E108. in addition, blue lights are being tested for use on emergency wreck marking buoys - IALA Recommendation O-133 refers

[3] CIE website address: www.cie.co.at/cie

[4] 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.

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

[6] Lateral marks differ between buoyage regions A and B.

[7] For example, in waterways where the aid may be drifting or destroyed due to ice conditions.

[8] Also known by the trade name of PEL light.

[9] In these situations the beacon will generally show a colour scheme and topmarks in accordance with the IALA Maritime Buoyage System.

[10] As adapted from the IALA Guidelines on Availability and Reliability of Aids to Navigation, Theory and Examples (Edition 2, December 2004).

[11] This is defined as the maximum depth of water and includes the highest tide level and half the maximum wave height at the particular site.

Navguide: Chapter 4 - e-Navigation

4.1 Introduction

The IMO-led initiave termed e-Navigation is an area which covers many disciplines.

Stated simply, the goal of e-Navigation is to provide harmonised information in electronic formats, in a seamless, customised and efficient manner, to better-designed navigational systems on board. Ashore, e-Navigation aims to streamline the way maritime authorities, agencies and other stakeholders gather and exchange information.

This chapter describes areas of e-Navigation development that IALA has been involved in.

4.2 Background

4.2.1 Origins

In 2006, the International Maritime Organization (IMO) approved a proposal from seven of its Member States, which requested IMO develop an e-Navigation strategy.

The aim of the proposal was to "...develop a strategic vision for the utilization of existing and new navigational tools, in particular electronic tools, in a holistic and systematic manner." (MSC 81/23/10). The sponsors of the submission were concerned that if the introduction of new technology remained uncoordinated, it would result in a lack of standardization on board and an increased level of complexity. The proposed e-Navigation vision was to create an overarching system that would provide a greater level of safety and incident prevention, resulting in reduced navigation-related accidents.

IMO led other international organisations, notably IALA and the International Hydrographic Organization (IHO) and developed a stratgey for the implementation of e-navigation in 2008 (MSC85/26/Add.1 Annex 20). A plan to implement the strategy, termed the Strategy Implementation Plan (SIP), was completed in 2014 (NCSR1/28 Annex 7).

4.3 IMO's strategy for the development and implementation of e-Navigation

4.3.1 The case for 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 watchkeeping officers make critical decisions for navigation and collision avoidance in isolation. This is partly due to a general reduction in manning.

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 onboard 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.

4.3.2 Vision

A vision for e-Navigation includes the following general expectations for onboard, ashore and communications elements:

Onboard

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;

Ashore

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; and

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.

4.3.3 Definition

The IMO stratgey defines e-Navigation as the *"harmonised collection, integration, exchange, presentation and analysis of maritime information onboard 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.
- Harmonized 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.
- Improved design of navigational and communication equipment.

4.3.4 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 can 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.

4.3.5 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 standardization
- Scaleability

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.

4.3.6 e-Navigation solutions

The centrepice of the current SIP is the following five prioritized e-Navigation solutions:

- S1: improved, harmonized 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
- S9: 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. 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).

4.4 IALA's Role

4.4.1 IALA's Strategic Vision 2014-2026

The aim of IALA is to foster the safe and efficient movement of vessels through the improvement and harmonisation of marine aids to navigation worldwide. This purpose is given effect by two key goals for 2026.

Goal 1 (G1)

Ensure that aids to navigation systems and related services, including e-Navigation, Vessel Traffic Services and emerging technologies, are harmonised through international cooperation and the provision of standards.

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The strategy for e-Navigation is to improve and harmonise VTS, information structures, Martime Service Portfolios and communications, so as to achieve worldwide interoperability of shore and ship systems.

Goal 2 (G2)

All coastal states have contributed to an efficient global network of aids to navigation and services for the safety of navigation, through capacity building and the sharing of expertise.

Here, the strategy is to coordinate the further development of VTS, e-Navigation and short range aids to navigation, taking into account new technologies and sustainability. Additionally, to continue to develop capacity building activities to improve the global operations and management of aids to navigation systems and related services.

4.4.2 The e-Navigation Committee

Since 2006, the e-Navigation Committee (ENAV) has led the development of IALA's substantial contribution to the formulation of the IMO's e-Navigation strategy and the SIP.

There remains a vast amount of work to be done to translate the e-Navigation concept into an operational reality. The working groups of the ENAV Committee are engaged in the following technical domains:

- Technical Domain 1: Data modelling and message systems (AtoN data information structure, exchange, presentation, S-100 Registry and Product Specifications)
- Technical Domain 2: e-Navigation communications (VDES, satellite, MRCP and AIS technology)
- Technical Domain 3: Shore technical infrastructure (resilient PNT shore services - DGPS, eLoran and virtual AtoN technology)
- Technical Domain 4: e-Navigation test beds (gathering and sharing of testbed results)
- Technical Domain 5: Maritime Services Portfolios(design, content and implementation)

Several multi-million dollar projects (completed and underway) have made noteworthy inroads in developing aspects of e-navigation. The IALA e-Navigation portal (http:/ / www. iala-aism. org/ products-projects/ e-navigation) provides detail on known testbeds and their results.

4.4.3 Answers to Frequently Asked Questions on e-Navigation

IALA has developed answers to some Frequently Asked Questions (FAQs) on certain aspects of e-Navigation. These can be found on the IALA website.

4.5 Maritime Service Portfolios

The e-Navigation SIP states that *"As part of the improved provision of services to vessels through e-Navigation, MSPs have been identified as the means of providing electronic information in a harmonized way, which is part of Solution 9."*

4.5.1 What are MSPs?

A Maritime Service Portfolio (MSP) defines and describes the set of operational and technical services (and the level of service) provided by a stakeholder in a given sea area, waterway, or port, as appropriate. (NCSR 1/ 28 Annex 7 refers).

As identified by the IMO, there is a need for a harmonised framework for the electronic provision of information related to maritime services between shore and ships. The list of maritime services available at a port, in a region or sea area is structured into services, based on responsible bodies. Such a service is termed a Maritime Service Portfolio or MSP. For instance, "Maritime Safety Information" is one such MSP, with the "National Competent Authority" being the responsible body for the area in question.

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Services in a portfolio will vary, depending on the port's or region's facilities. For example, a small port may offer only a few services, whereas a large port may offer a greater number of services.

The objective of the MSP concept is to align maritime services globally with the need for information and communication services in a defined operational area. To achieve this, the first step should be to identify the need for information services and communication infrastructure in different areas.

4.5.2 The sixteen initial MSPs

MSPs are being developed to achieve harmonisation and based on use of the IHO's S-100 Geospatial Information (GI) Registry.

IALA is developing guidance on the 16 initial services identified by the IMO. These are listed in Table 21 below. It aims to harmonise the format, structure and communication networks that will be used to exchange MSP information. Although the IMO identified the preliminary list of 16 MSPs below (MSC 94/21 Annex 17), these may evolve with time.

MSP Number	Services	Responsible Service Provider
1	VTS Information Service (IS)	VTS Authority
2	Navigational Assistance Service (NAS)	National Competent VTS Authority/Coastal or Port Authority
3	Traffic Organization Service (TOS)	National Competent VTS Authority/Coastal or Port Authority
4	Local port Service (LPS)	Local Port/Harbour Operator
5	Maritime Safety Information Service (MSI)	National Competent Authority
6	Pilotage Service	Pilot Authority/ Pilot Organization
7	Tug Service	Tug Authority
8	Vessel Shore Reporting	National Competent Authority Shipowner Operator/Master
9	Telemedical Assistance Service (TMAS)	National health organization/dedicated health organization
10	Maritime Assistance Service (MAS)	Coastal/Port Authority/Organization
11	Nautical Chart Service	National Hydrographic Authority/Organization
12	Nautical Publications Service	National Hydrographic Authority/Organization
13	Ice Navigation Service	National Competent Authority/Organization
14	Meteorological information service	National Meteorological Authority/WMO/ Public Institutions
15	Real time hydrographic and environmental information Service	National Hydrographic and Meteorological Authorities
16	Search and Rescue (SAR) Service	SAR Authorities

Table 21: Initial Maritime Service Portfolios (MSPs)

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4.5.3 Technical Services

Based on the concepts of service-oriented architectures, a technical service refers to a set of related software functionalities that can be reused for different purposes, together with policies that govern and control its use. A technical service is a service offered by one electronic device to another electronic device. Often operational services are implemented by electronic devices that rely on one or more technical services.

A technical e-Navigation service should be formally specified and documented, as described by an IALA guideline. At the time of writing, this draft guideline aims at improving the visibility and accessibility of available e-Navigation technical services and information provided by them. This will enable service providers, consumers and regulatory authorities to have a common understanding of a technical service and its implementation.

4.6 Maritime Digital Infrastructure

Like other industries, the maritime industry has also adopted the use of modern information and communication technologies on board ships and ashore. For example, ships have, for centuries, used paper charts to navigate. These have recently partially given way to the use of Electronic Chart Display and Information Systems (ECDIS). In the early 2000s, the IMO introduced the Automatic Identification Systems (AIS), as one of the first fully digital data exchange systems in the maritime domain, to improve maritime safety. These are but two examples. However, the introduction of new regulations is characteristically slow - major changes take time to be agreed upon and introduced at international level.

This modernisation of navigation and communication systems, incrementally and over time, has led to ship and shore facilities being fitted with heterogeneous systems. Different technologies and increased information flows can contribute to information overload on ship bridges and shore-based facilities. On the other hand, the integration (and harmonisation of) different systems can offer new opportunities to improve maritime safety and efficiency.

The IMO, by developing the e-Navigation strategy (and a plan to implement the strategy) aims to address the above issues by introducing harmonisation and establishing a digital information exchange framework.

From an IALA perspective, harmonisation and digitalisation will have an impact on shore services. For example, a VTS centre will be able to use IALA-defined Inter VTS Exchange Format (IVEF) to exchange information with other VTS centres.

4.6.1 Architectures

The maritime domain is a complex eco-socio-technical system, with many different actors and stakeholders. The international maritime industry is witnessing more and increasingly larger ships being built. Growing ship numbers result in an increase of marine traffic. Therefore, a safe, reliable and environmentally sustainable shipping industry is needed to ensure international trade.

The introduction of new information technologies and their associated system architectures, with increased ability to receive, analyse and present information to optimise a vessel's passage, is changing international shipping. These systems do more than enhance safety and security in the shipping domain. For example: traffic management and port call optimisation technologies are interwoven into other domains such as transport logistics.

The evolution of technology and its data requirements leads to an increased need for maritime systems with bandwidth demands, such as broadband connections on the high seas. Additionally, the growing number of new developments in the shipping industry results in a large and diverse number of maritime systems.

These complex Information and Communications Technology (ICT) systems need an architecture to address organisational and technical aspects and to ensure alignment with regulations, governance and operational processes.

The Maritime Architecture Framework (MAF) is introduced below, to provide a common platform for the design of maritime architectures. The Common Shore-based System Architecture (CSSA) is introduced as a blueprint for a specific architecture.

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4.6.1.1 Maritime Architecture Framework (MAF)

The Maritime Architecture Framework is an architecture framework for maritime eco-socio-technical system-of-systems (SoS). It provides a methodology to structure the specification of architectures in a common way, and furthermore provides an architecture model to enable the representation of the architecture in a maritime SoS context. The MAF orients towards the e-Navigation and other related approaches such as e-maritime.

Current technology innovations in the maritime domain allow for a holistic approach to guide common engineering processes among (new) maritime systems, and their field of activities in the operational context – state more simply. Therefore, it is essential to establish a standardised methodology to analyse, design, compare and discuss different maritime IT-architectures and socio-technical systems, including related regulations within their (envisioned) maritime context, in a consistent and harmonised way.

Therefore, the MAF take IMO's e-Navigation approach into account to provide a methodology and architecture model to compare maritime systems with each other, and to identify overlaps or gaps on different interoperability levels in order to support the implementation process of new e-Navigation approaches. Furthermore, it contributes to the necessity of setting new e-Navigation approaches in a broader context within the current state of the maritime domain and the e-navigation strategy (and relatives) (see Figure 18 below).

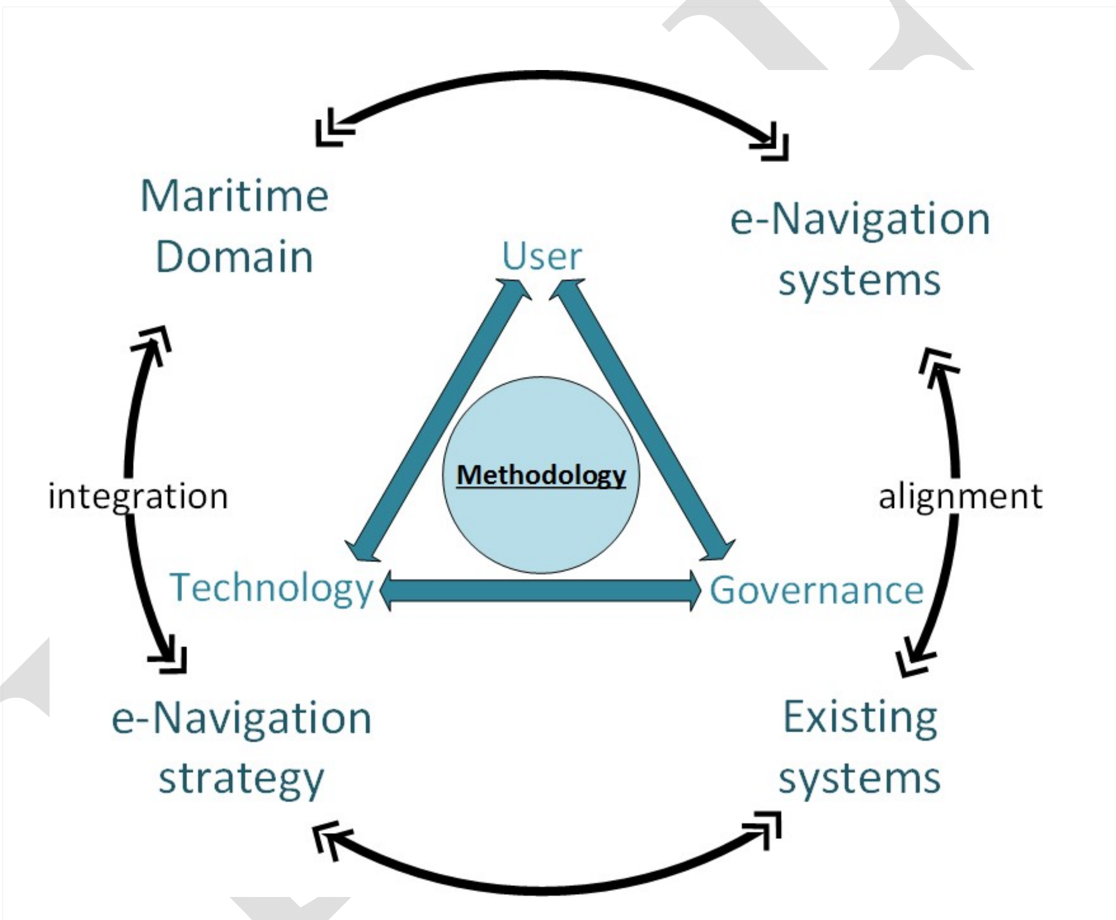

Figure 18 - Contextualisation of e-Navigation in the maritime domain

The Maritime Architecture Framework faces the challenge of bringing the maritime domain, with its manifold and divergent aspects, into an order. It also encapsulates different views on architectures, with the goal of ensuring a comprehensive architecture description of a system. It is based on enterprise architecture-engineering methods and supports the harmonisation of systems from relevant perspectives: Conceptual, Organisational and Technical.

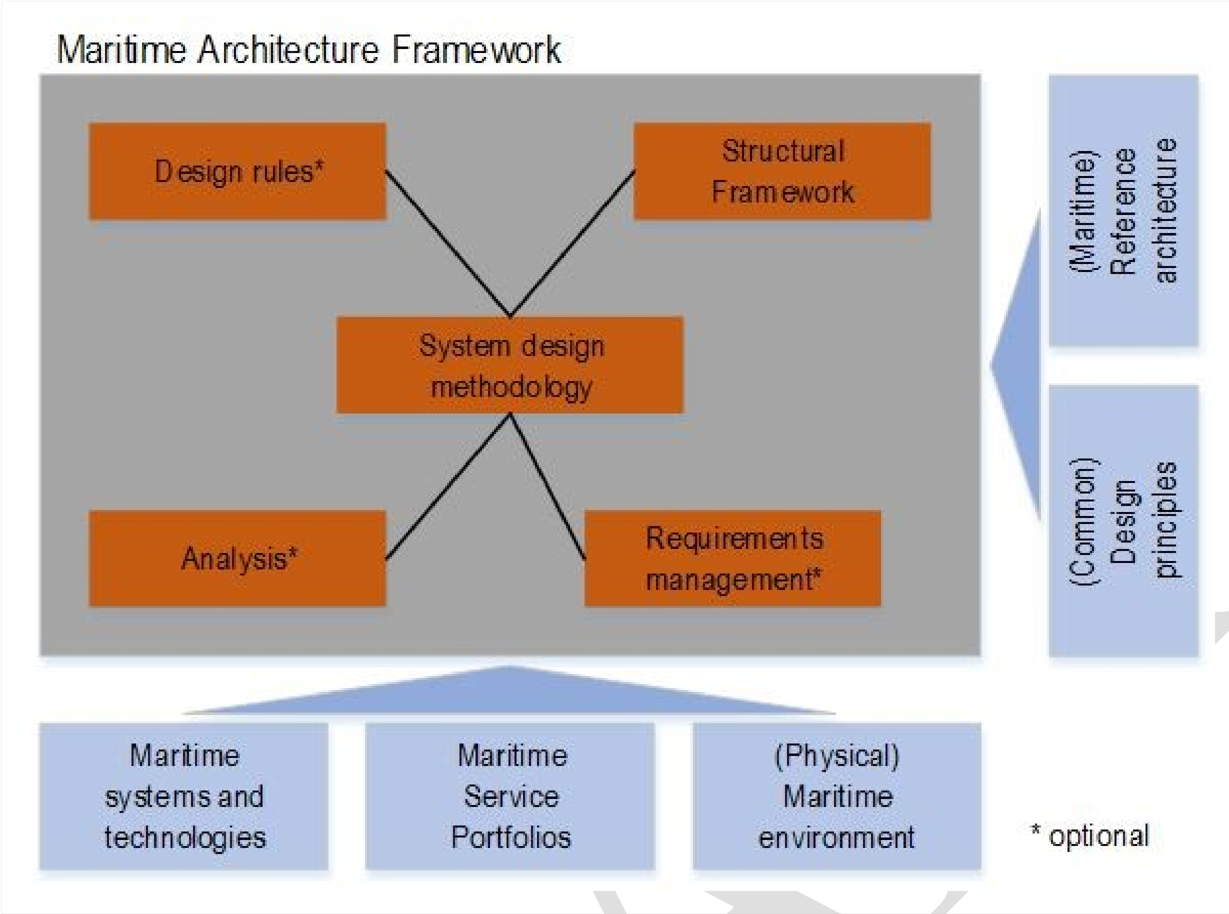

Figure 19: The structure of the Maritime Architecture Framework

As seen in Figure 19, the framework exists of a set of elements arranged around, and integrated into, a system design methodology. This methodology is for the specification of socio-technical system architectures and its maritime SoS environment and follows an iterative approach. The Structural Framework element is a multidimensional architecture model for the allocation and representation of system architectures in the maritime and interoperability context.

The Requirements Management and Analysis elements provide methods and processes for continuous requirements management during the specification, as well as for multiple kinds of analyses on reflected system architectures. The optional (*) design rules element, is intended for the definition of a set of rules concerning the inherent structure of a defining system architecture, with the goal to establish a template for how the system elements need to be arranged.

All elements of the MAF contribute to the real maritime environment, its systems and technologies and towards design and reference architecture that stem from engineering principles.

Therefore, during the application of the MAF, a common terminology shall be considered by its users and existing maritime systems and technologies. Furthermore, if used for the definition of new system architectures and their integration into the maritime environment, the IMO's Maritime Service Portfolios and the maritime environment is relevant. There are design principles from a broad field of system engineering which affect the building of systems. Finally, non-governmental organizations, such as IALA, should recommend reference architectures such as the CSSA (Common Shore-based System Architecture, as described below), which must be reflected within the design of system architectures.

The multidimensional model of the MAF (The Structural Framework)

The MAF integrates within its methodology a multidimensional model approach. This enables the visualisation of those architecture aspects in a "cube" for an easy identification of interoperability issues, gaps and overlaps between the mapped system components. This establishes clear relationships between:

- existing business objectives,
- governmental aspects, which regulates the maritime domain,
- technical functions, that are required to realise the business objectives,
- information exchange between those technical functions, including the related information types and/or data models,
- communication protocols to allow the aspired information exchange, and
- components required to implement the technical hardware.

The benefits of having these are various: Firstly, it supports optimal alignment of technical systems with organisational concepts. This integrated view is required to ensure technical and organisational interoperability. Secondly, it supports the potential integration of systems into a system environment by providing a model for the combined mapping of multiple Systems components. A component can be for instance a constituent system itself (System of Systems, SoS).

The model consists of a three-dimensional structure of architectural aspects assembled in a meaningful way. It is structured in layers to "cut" the cube at each category along each dimension. Therefore, the terminology "axis" is used for the name of the dimension, and "layer" for the surface with all aspects which belong to a category. All aspects on a layer can be sub-structured by the categories of other dimensions.

With regards to the IMO's e-navigation architecture and its definition, the cube covers interoperability aspects to support different views on the interaction of maritime systems. Furthermore, it features the distinction between ship-side and shore-side and breaks down the structure of management and control systems in the maritime domain into a hierarchical order.

The model represents characteristics of the maritime domain using the three dimensions, Interoperability axis, Topological axis and Hierarchical axis (see Figure 20 below). The different axes of the multidimensional model are further described below.

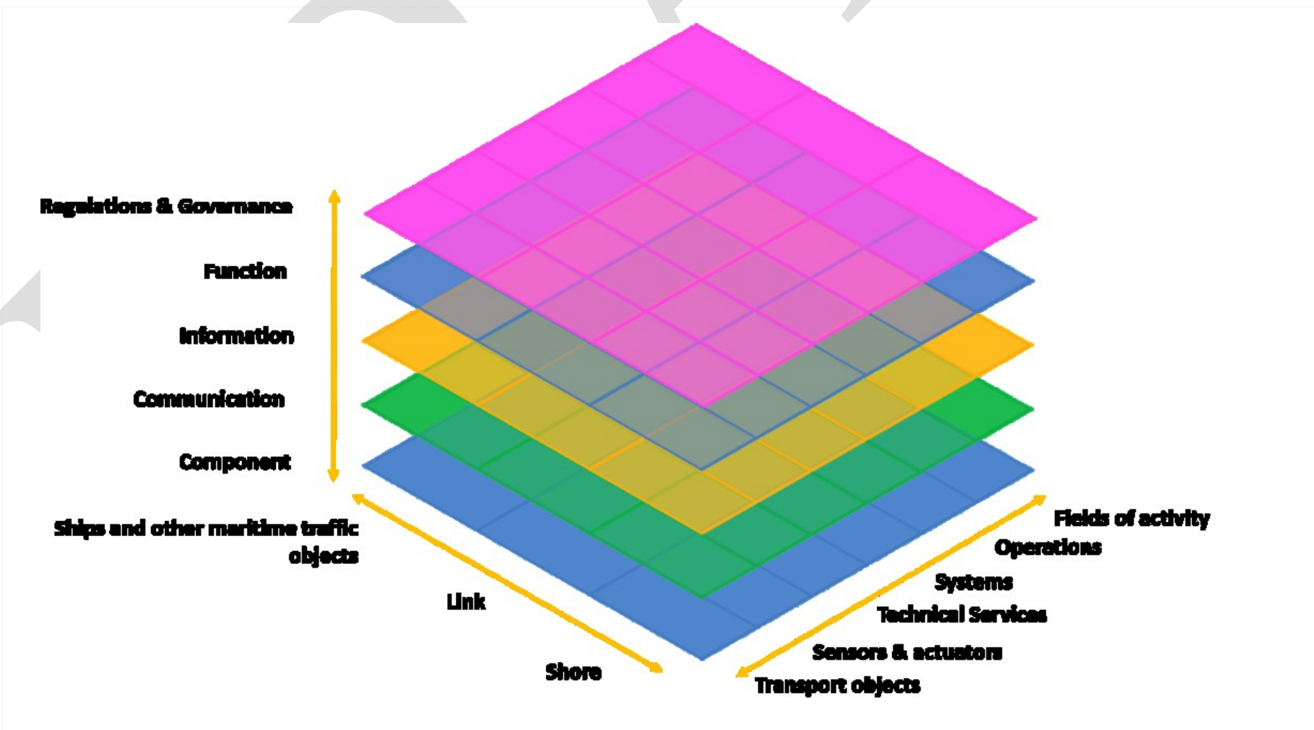

Figure 20: The multidimensional model of the MAF

Hierarchical axis

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The Hierarchical axis brings the maritime domain into an order. The layers of this hierarchy reflect the structure and aggregation of the organisational aspects (management) and control systems in the maritime domain. The dimension categories cover economic and governmental aspects (fields of activity), operation control parts of maritime systems (Operations), the technical (Systems, Technical Services, Sensors and actuators) as well as physical components (Transport objects). Each layer addresses both technical and human aspects.

- Fields of activity: Systems which support or manage different markets or eco systems along the maritime domain.
- Operations: Global, regional, national and local operational perspectives used by companies or authorities (e.g. a traffic flow management).
- Systems: Technical systems which integrate or use technical services for gaining a virtual representation and control of the transport processes.
- Technical Services: Single technical and logical services.
- Sensors & actuators: Local infrastructure for detecting objects with physical means, and receiving and processing the results with physical systems and hardware.
- Transport objects: Entities of maritime transport processes such as vessels, floating objects and aircrafts operating in the maritime domain.

These layers help to understand the definition and role of operational services, as for instance described in the Maritime Service Portfolio (MSP). This includes their provision by technical systems providing technical services.

Topological axis

The Structural Framework covers the elements and its interrelationship of the maritime domain. It reflects the maritime structure from a topological perspective as defined in IMO's e-navigation architecture. This axis is sub-structured into the following categories:

- Ships and other maritime traffic objects: Representing entities in the maritime domain (e.g., vessels). It covers the ship-side entities of the e-navigation architecture.
- Link: Representing entities dedicated to physically interact between maritime traffic objects and shore, such as telecommunication methods and protocols. Represents the three levels of Operational links, Functional links and Physical Links between ship-side and shore-side.
- Shore: Representing entities of the shore side infrastructure, activities and systems on shore including interfaces to logistical movements in/out of the maritime domain.

Interoperability axis

The interoperability layers cover organisational, informational and technical aspects and include the different levels of interaction (operational, functional, technical and physical) as stated in the IMO's e-Navigation vision. This axis is sub-divided into the following categories:

- Regulation & governance: Role and legal basis of international, regional or national (shipping) authorities.
- Function: Functions and (elemental) services including their relationships.
- Information: Data and information that is being used and exchanged between functions, services and components. It describes data and information objects including its semantic and data models.
- Communication: Protocols and mechanisms for the interoperable exchange of data between components.
- Component: Required components in engineering terms. This includes, amongst others: systems, actors, applications, services and network infrastructure.

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4.6.1.2 IMO Architecture

As mentioned previously, the IMO has identified a generic architecture for e-Navigation. One way of understanding the concept of e-Navigation is to consider it from a user's perspective. In Figure 21 below, the architecture can be divided into three parts; ship-side, shore side and the interaction between ship and shore.

The ship-side represents the users on-board a ship, whilst the shore side typically represents users from communities like VTS, allied services and users from the logistics domain.

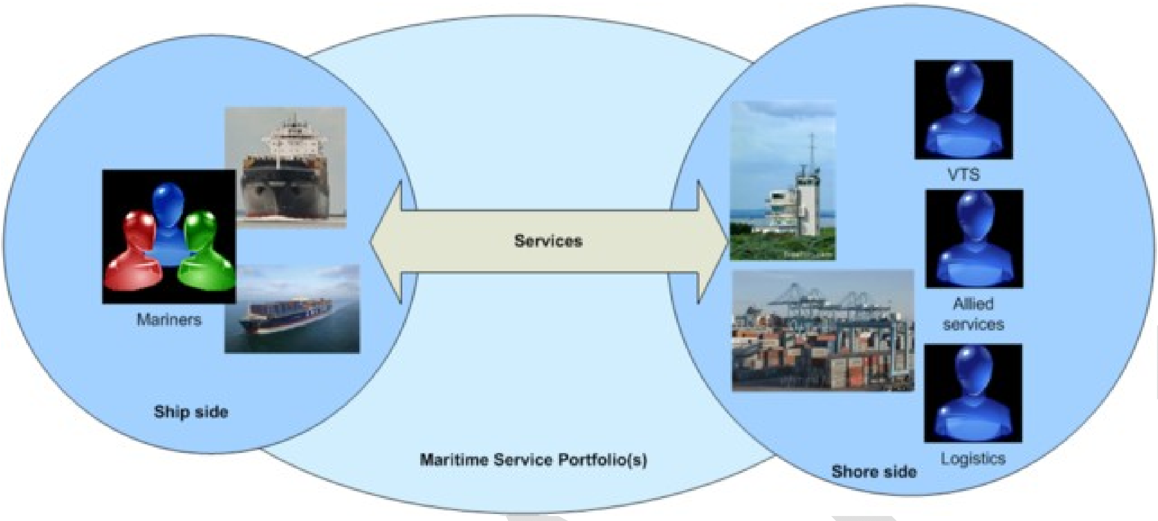

Figure 21: e-Navigation users' perspective at a given moment and place

To enable both sides to communicate and exchange information, e-Navigation uses the generic term "service". From a user's perspective, the important services will be the "operational services". These services are referred to within a Maritime Service Portfolio (MSP). The MSP concept was conceived to achieve harmonisation. However, there also needs to be "technical services" to be able to support and provide these operational services (see Figure 22 below).

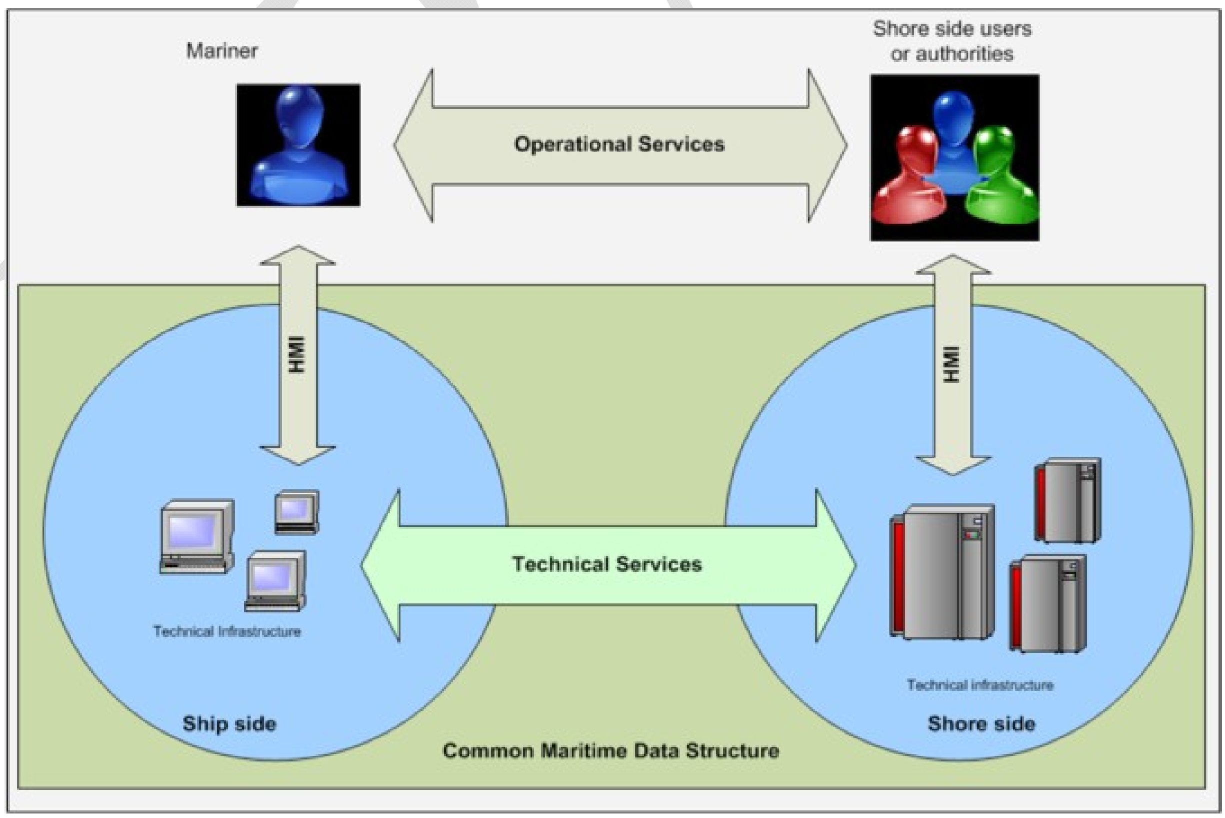

Figure 22: The e-Navigation services concept

These base concepts are detailed in the overarching e-navigation architecture, which is defined in the IMO e-Navigation Strategic Implementation Plan (SIP).

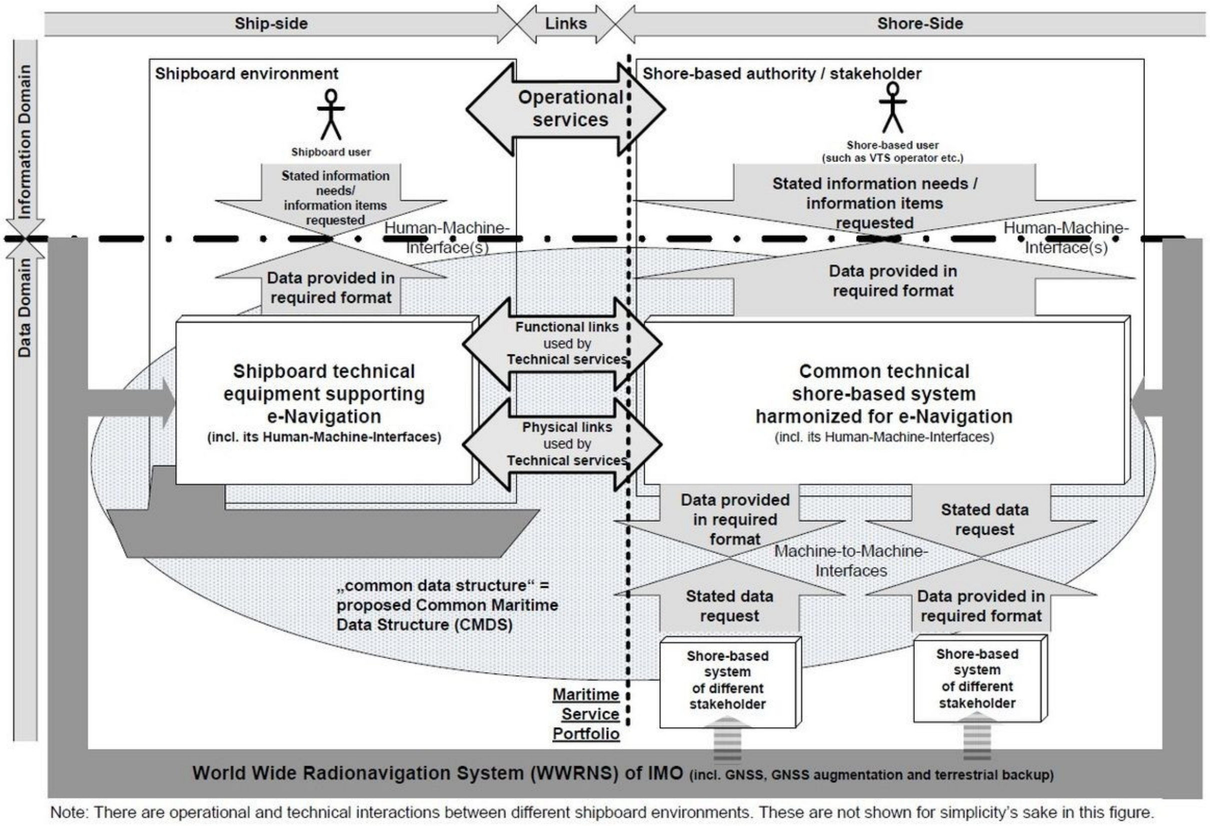

Figure 23: IMO e-Navigation architecture

Figure 23 shows the most important features and elements. These are:

1. the distinction between the ship and shore-sides;
2. the distinction between the information and data domains;
3. the notion of request/fulfilment relationships throughout;
4. the technical Human Machine Interfaces (HMIs);
5. the notion of operational and technical services provided to shipping, as defined by Maritime Service Portfolio(s);
6. the ‘shipboard technical equipment supporting e-Navigation’;
7. the ‘common shore-based technical system harmonised for e-Navigation’;
8. the overarching role of the Common Maritime Data Structure (CMDS) within the data domain;
9. the shore-to-shore data exchange facilities, and the required Machine-to-Machine (M2M) interfaces, and
10. the dependency on the World Wide Radio Navigation System (WWRNS).

4.6.1.3 Common Shore-based System Architecture (CSSA)

IALA Guidelines 1113 (Design and Implementation Principles for Harmonised System Architectures of Shore-based Infrastructure) and 1114 (A Technical Specification for the Common Shore-based System Architecture (CSSA)) identify the principles of a shore-based system architecture and propose its technical specification. As stated earlier, there are three major components of the e-navigation architecture that interact with each other. They are:

1. Shipboard systems that process information/data;
2. Application-to-application data exchange via physical links;
3. Shore-based systems that integrate a variety of shore based technologies and data processing devices.

The CSSA describes the technical set-up of the shore-based system of a shore authority. The main building block of the CSSA is the technical service, which encapsulates all primary functions dealing with a specific technology or

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user, depending on the kind of technical service. To reap the maximum benefit, all technical services of the CSSA should adhere to the same object-oriented engineering model. All technical services are self-contained and provide all capabilities needed for their tasks, including their own service management.

The CSSA is modelled in a client-server-fashion. The individual technical services can regularly assume either role, i.e. clients or server, depending on their present role in a given interaction chain, in support of a given application-to-application data exchange within the overarching architecture.

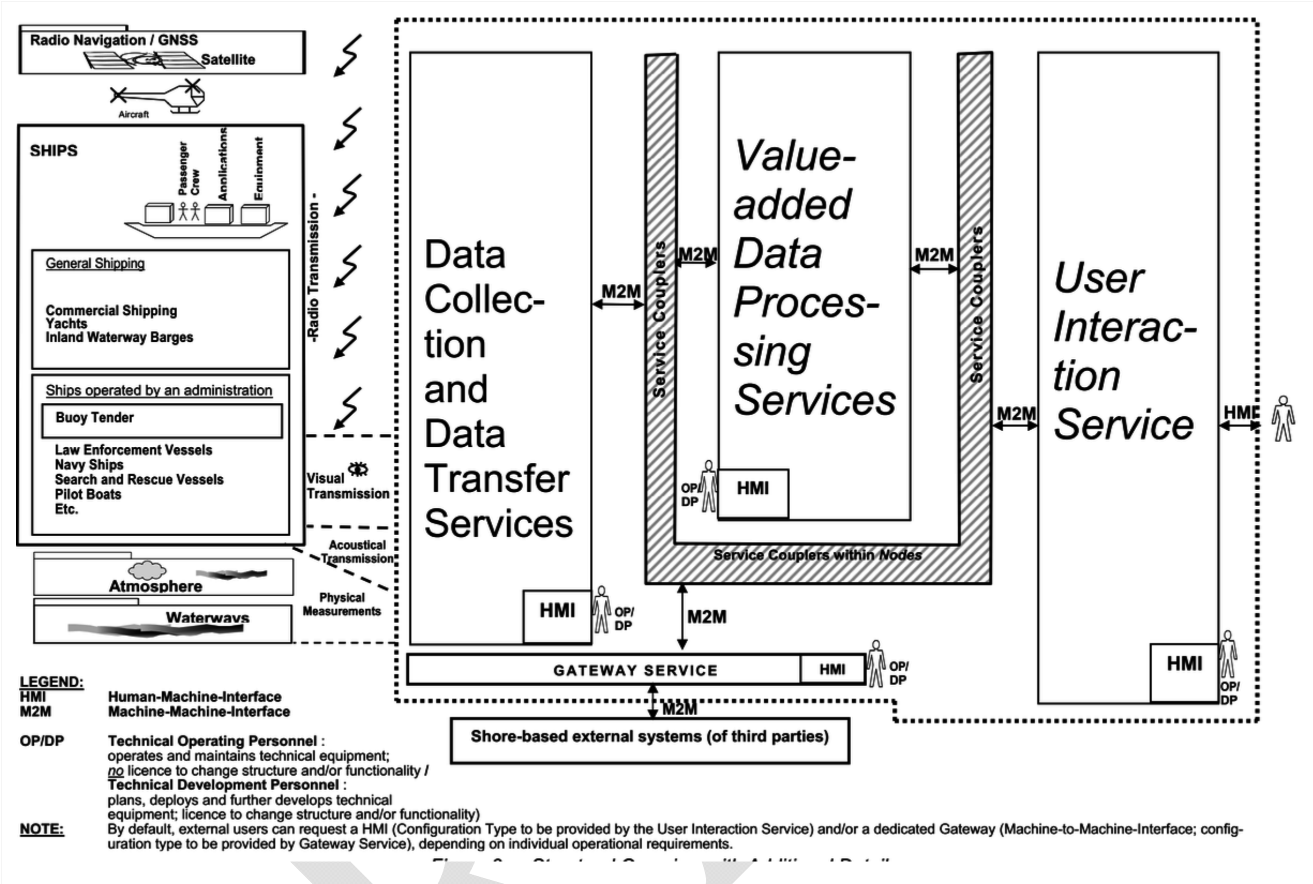

Figure 24: The Common Shore-based System Architecture concept

Figure 24 provides the main concepts of the CSSA:

- Data collection and transfer services are a group of technical services interfacing the shore system, via physical links to the electronic systems of traffic objects', to the waterways and to the natural environment.
- Value added data processing services are also a group of individual technical services. Their main task is to add value to (raw) data by processing, combining, comparison etc., store data and information and to provide it upon request to other technical services.
- The user interaction service – an individual technical service – is specialised to provide the Human-Machine-Interface (HMI) to the primary users of the CSSA, i.e. such users as are supported directly by the system via dedicated displays, keyboards and other human interaction devices.
- The gateway service – another individual technical service – specialises in shore-to-shore data exchange. It interfaces mainly to the external systems of third parties. Upon authorised request, external systems provide data to and/or receive access to relevant data from own system. The Gateway Service can also interface different shore-based systems locally, regionally, and globally.

Examples of data collection and data transfer services are AIS, radar services, direction-finding services and DGNSS augmentation services. Some value added data processing services are position determination services, ship data consistence algorithms and data mining services.

4.6.2 Common Maritime Data Structure

The purpose of the IMO-defined Common Maritime Data Structure or CMDS (see Figure 25) is to harmonise data exchange in the maritime domain, by providing a common, authoritative reference. The CMDS is an abstract representation of entities within the maritime domain. It should be accessible by any stakeholder and should be the reference for the development of maritime services, applications and databases.

Considering the extent of the maritime domain with all of its stakeholders, the responsibility for the CMDS is subdivided into smaller units, each of which is governed by a recognised authority. However, these authorities need to cooperate to harmonise the CMDS as a whole (e.g. to avoid duplication of entries). This is one of the main tasks of the IMO established IMO/IHO Harmonisation Group on Data Modelling (HGDM).

IHO developed the IHO GI Registry[1], S-100 provides the data framework for the development of the next generation of ENC products, as well as other related digital products required by the hydrographic, maritime and GIS communities. The GI Registry is generic in setup and has been adopted by IMO to support development of the CMDS.

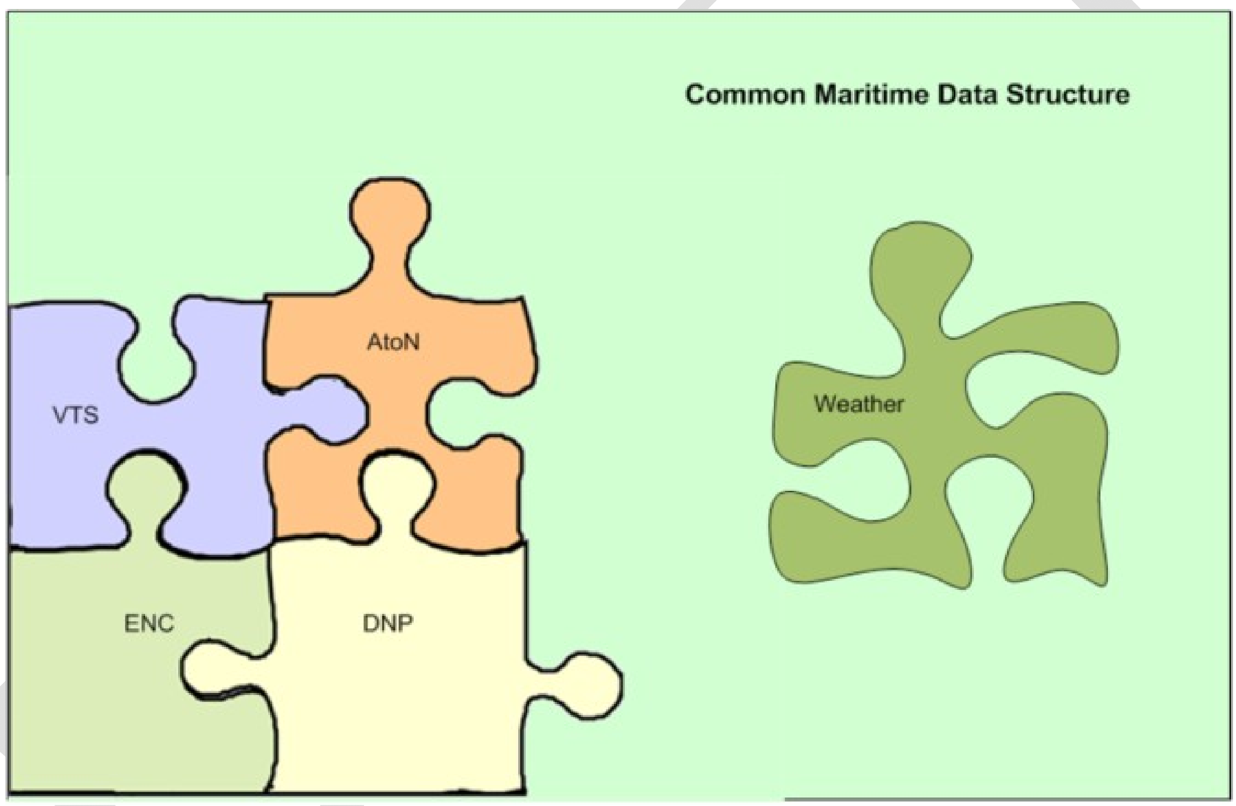

Figure 25: The Harmonised Common Maritime Data Structure

Figure 25 describes the simplified generic structure of the GI Registry. The major features of the registry include registers for:

- Product Specifications – includes everything needed to fully describe and specify a 'product', such as data exchange protocols and references to HMI and CMDS entities from the GI Registry.
- Human-Machine Interface (HMI) – HMI definitions/specifications can also include references to CMDS entities from the GI Registry. (This register is named Portrayal by IHO).

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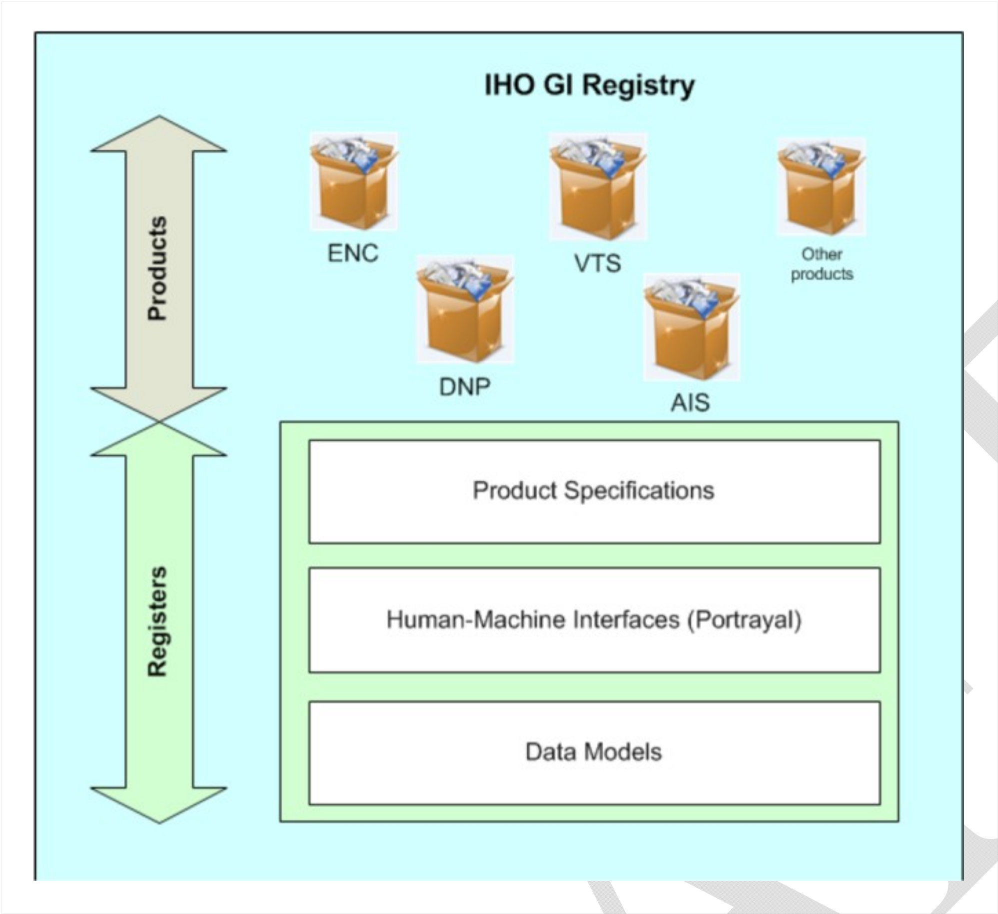

Figure 26: Simplified View of the IHO GI Registry

4.6.3 Common Maritime Infrastructure

In order to facilitate the integration of e-Navigation into the maritime domain, shared and broadly available infrastructure is needed. GMDSS and its services are good examples for such a critical infrastructure. New technological developments and their deployment, like better satellite bandwidth and terrestrial mobile data services, will foster Internet based technologies in this global system.

In order to provide such infrastructures and interoperability between used technologies, the introduction of common approaches for identity management or Maritime Resource Name (MRN) are necessary.

4.6.3.1 Identity Management

The notion of identity is vital for all information exchange and communication technologies. Just as human-to-human communication on a global scale would be impossible without unique telephone numbers/email addresses, so too is a globally agreed digital maritime identity required for the various participating 'actors'.

In the maritime sector, there are already many identity systems in place (e.g. IMO number, MMSI). These are managed by different organisations. The challenge in creating a single maritime identity regime is to create a solution that satisfies the most common identification needs of the entire maritime industry, on a global scale, while also being compatible with already established identity systems. A key task is to establish authentication between maritime users.

The way in which a human user or machine may be authenticated typically falls into three different categories, based on what is commonly known as the factors of authentication: something the user knows, something the user has and something the user is. Each authentication factor covers a range of elements used to authenticate or verify a person's identity prior to being granted access, approving a transaction request, signing a document or other work product,

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granting authority to others and establishing a chain of authority.

- Knowledge factors: passwords, pass phrases, pins, challenge / response
- Ownership factors: ID card, cell phone, certificates
- Inheritance factors: Fingerprint, retinal patterns, facial and voice recognition

Emerging approaches, such as the Maritime Communication Platform, address the identity issues.

4.6.3.2 Maritime Resource Name (MRN)

In order to assist with the implementation of the Common Maritime Data Structure (CMDS), IALA has proposed the concept of Maritime Resource Name (MRN).

IALA has developed a draft guideline on Unique Identifiers for Maritime Resources, introducing the concept of a MRN as a means for the creation of globally unique identifiers. The MRN is a Universal Resource Name (URN) scheme that makes national AtoN numbers globally unique by applying a (national) prefix. In addition to AtoN numbers, the larger scale use of unique identifiers is necessary for e-Navigation, for harmonisation across domains and services. Navigationally unique objects such as AtoN, VTS products and services and other maritime resources require identification to avoid duplication and misalignment.

As of 2017, IALA is working with authorities such as the Internet Assigned Numbers Authority (IANA) to pursue the registration of MRNs.

4.6.3.3 Maritime Connectivity Platform

The Maritime Connectivity Platform (MCP) (formerly known as the Maritime Cloud) is an emerging concept for a proposed communication framework that will enable efficient, secure and reliable electronic information exchange between authorised stakeholders. Basically, it defines the standards, protocols, infrastructure and governance for information exchange based on the Service Oriented Architecture concept. It is not a storage cloud – nor is it cloud computing. Neither does it provide a communications infrastructure. The MCP will make use of new communication platforms and provide a standardised use concept.

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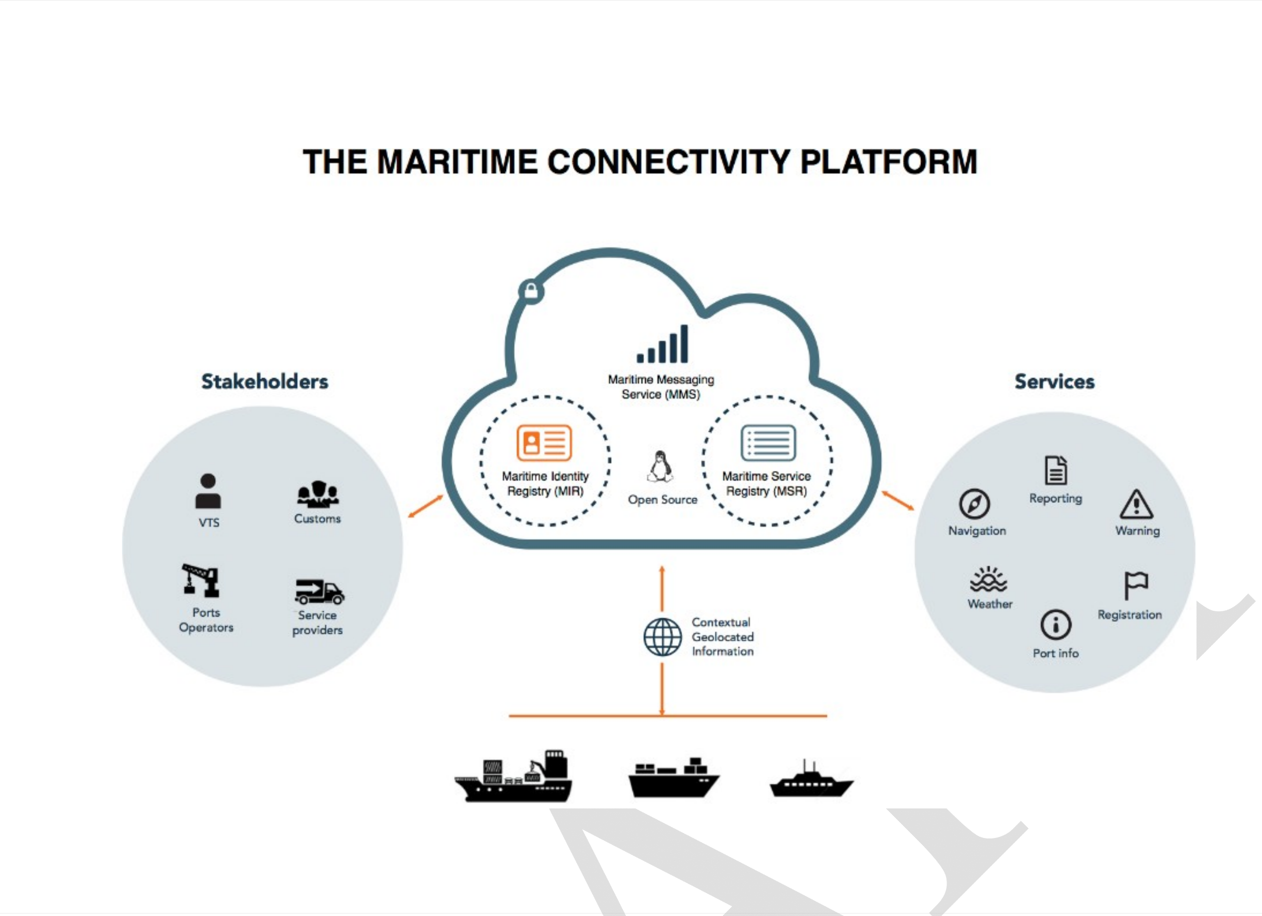

Figure 27: The Maritime Connectivity Platform concept (Image credit: EfficienSea2 Project)

The MCP is structured such that:

- Communications is based on the client-server concept;
- Services can be easily registered, discovered and used;
- Identities can be verified and used to digitally sign communication; and
- Messages can be exchanged between components connected to the MCP. These can be either clients operated by humans or services.

Geographic and organisational contexts (e.g. a vessel's location) are used as key parameters for service discovery, identity verification and message exchange.

The MCP offers a Service Registry. Connected components "ask" the service registry how to access and use a service. Additionally, the MCP provides a Maritime Messaging Service (MMS). This component can be thought of as an automated switchboard. It uses the communication channel available for communication to a service while the access point stays the same. Depending on the request (name, type, location etc.), the end user is provided with possible service providers, and can then choose which service to use. The MCP offers means to digitally assure the identity of the communicating partners (thereby doing away with the need for signed documents to prove authenticity).

The MCP does not include data storage or application hosting. This remains the responsibility of service providers and organisations. The MCP is focused on improving communication and digital interactions based on open standards, while reusing existing components and infrastructure within the current organisations to enable a cost-effective and smooth transition to adoption.

4.6.4 Cyber Security

Digitalisation in the maritime industry presents new threats such as systems failures and cyber security. AIS, GNSS and GMDSS provide no protection against cyber-attacks. They can be attacked very easily, with little financial or technical effort. The only resilience against cyber-attacks is the redundancy of systems. AIS is an unencrypted system operating in the VHF maritime mobile band; positioning technologies use resilient systems to overcome vulnerability. However, the risk of concentrated actions, which can lead to system failures, is ever-present.

As technology continues to evolve, information technology and operational technology onboard ships are increasingly being connected – to each other and to the world wide web. This gives rise to greater risk of unauthorised access or malicious attacks to ships' systems and networks. Risks may also occur from personnel having access to the systems onboard, for example, by introducing malware via removable media.

Responding to the increased cyber threats, BIMCO undertook a comprehensive analysis of cyber security related threats and risks and produced Guidelines on Cyber Security onboard Ships in 2017. These guidelines are designed to assist companies develop resilient approaches to cyber security onboard ships.

Relevant personnel should be trained to identify typical modus operandi of cyber-attacks. The safety, environmental and commercial consequences of not being prepared for a cyber incident may be significant.

Approaches to cyber security will be company, ship and service provider specific, but should be guided by appropriate standards and the requirements of relevant national regulations.

4.7 Communications

4.7.1 Introduction

The e-Navigation concept aims to enhance the efficiency, safety and security of navigation and communications in the maritime sector. e-Navigation relies on applications which provide mariners with the information they need in a more secure and efficient manner. These applications require communication technologies that can provide the necessary capability for ship-ship and ship-shore (including ship-satellite) communication.

The role of communications as a cornerstone in safety at sea was highlighted by the sinking of Titanic in 1912. The two radio operators, Jack Philips and Harold Bride, transmitted the first SOS message, which resulted in the rescue of some 700 persons. Effective and efficient radiocommunications at sea are vital for the safety of life, protection of the environment, efficiency of ship movements and maritime Search and Rescue (SAR).

The nine GMDSS functional requirements cover not only distress alerts and SAR communications, but Maritime Safety Information (MSI), general radiocommunications and bridge-to-bridge communications as well. The four levels of priority in radiocommunications are described in the ITU Radio Regulations. They are distress, urgency, safety and other communications.

4.7.2 Digital Communications

Digital communications are now an integral part of our daily lives – be it for work, social interaction or recreation. The introduction (and expectation) of 'anytime, anywhere' access to up-to-date information via the internet, text and image-rich communications, geospatial locating and more, are driving demand for faster, more robust, and more integrated communication solutions.

Almost every e-Navigation solution currently being developed (and foreseen) depends upon efficient and robust ship-ship, ship-shore or shore-ship electronic data transfer. Existing communications systems may in many places be adequate to serve these needs. However, it is necessary to develop new methods to realise the full potential of e-navigation. The performance requirements, in particular data capacity, for communications systems to support e-Navigation are, in many cases, unknown and are likely to change over time. However, studies and user requirement workshops have been conducted to better determine the data transfer requirements, to address e-Navigation elements and facilitate development of digital communications solutions for the maritime environment.

Development of robust and reliable communications infrastructure is not only related to the implementation strategy for e-Navigation, but is also a core element of the modernisation of GMDSS.

Work on maritime communications not only looks at more effective use of existing systems, but also developments in digital communications. Some of the technologies for future digital maritime communications include:

- VHF Data Exchange System: VDES is being developed to meet the increasing need for data communication between maritime users, and was driven by the increasing use of AIS resulting in a significant rise in load on the VHF Data Link. VDES will provide faster data transfer rates with greater integrity than current VHF data link systems.
- Digital Selective Calling: DSC transmits packets of data over existing maritime radio spectrum, on VHF, MF and HF. The system uses Maritime Mobile Service Identity (MMSI) and enables direct transmission or group/area transmissions of basic data. DSC is included in the Global Maritime Distress and Safety System (GMDSS) as a distress sand calling mechanism.
- NAVDAT: This system is an enhancement of the current NAVTEX system. The service will support the same major functions as NAVTEX, namely navigational warnings, weather forecasts and emergency information for shipping, but will provide a much greater capacity and data rate.
- Digital VHF: Digital VHF is the evolution of analogue-based mobile radio systems currently used by mariners for voice communication, transmission/reception of distress and safety information and reception of urgent marine information broadcasts. As well as digitally encoding voice transmissions, digital VHF will enable the exchange of data messages. This may be a longer term development.
- Digital HF: Digital HF is the evolution of analogue-based mobile radio systems currently used by mariners for voice communication, transmission/reception of distress and safety information, and reception of urgent marine information broadcasts. As well as digitally encoding voice transmissions, digital HF will enable the exchange of data messages. Digital HF, including standards for digital HF, exist, but are not commonly used.
- Wi-Fi: provides local area wireless data transfer using the 2.4 GHz to 5 GHz radio wave band. However, the coverage of this system is limited to small areas within a port or harbour environment.
- 4G: a mobile telecommunications standard supporting mobile internet broadband, succeeding 3G. Provides mobile broadband with data rates of 100 Mbps for mobile users. Systems that perform to the 4G standard include WiMAX and LTE. LTE developments include LTE-Advanced, which will provide greater range.
- 5G: The Long Term Evolution (LTE) planned for 4G, with data rates expected to be 1 Gbps and intended for availability in the year 2020.
- Satellite communication systems and services including, but not limited to:

i. Inmarsat Global Xpress - GEO satellite constellation. The latest set of services to be offered by Inmarsat, including shared channel IP packet-switched internet broadband service with fast data rates provided by satellites in the Ka band with global coverage.

ii. Inmarsat C - GEO satellite constellation. Existing short burst data, store and forward system, providing low data rates for small message size transfers and also supporting the Global Maritime Distress and Safety System (GMDSS).

iii. Iridium - LEO satellite constellation. Existing low-earth orbiting communications system, providing voice and limited internet access.

In 2009, IALA developed a Maritime Radio Communications Plan (MRCP) for the communications required to support e-navigation. The MRCP has been updated in 2017. It can be found at http:/ / www. iala-aism. org/ product-category/publications/other-publications/

The MRCP is intended to meet the key e-Navigation strategy element of identifying communications technology and information systems to meet user needs. This can involve the enhancement of existing systems and the development of new systems. The IALA plan identifies existing and future systems, then draws on identified user requirements to assess the information flows and the data channels needed.

4.7.3 VHF Data Exchange System

4.7.3.1 Overview

The Automatic Identification System (AIS) provides an effective means to transfer digital data. In addition to the originally-intended purpose of providing vessel position and related information to aid in collision avoidance, support VTS operations and contribute to the safety of navigation, AIS is being used for a number of other applications. This has seen an overloading of the VHF data link in some areas.

At the World Radio Conference 2015, the International Telecommunications Union identified an additional 6 duplex channels in the VHF maritime mobile band for the use of digital data transfer. The frequencies form part of the developing VHF Data Exchange System (VDES). With the ability to group these frequencies together to provide more bandwidth for data transfer, the VDES will enhance digital data functionality in the future.

VDES provides a solution to ensure that the existing AIS VHF data link does not become overloaded. VDES is made possible by the development of software definable radios (SDRs) and the frequency allocation in addition to the existing AIS within the system. VDES includes VHF Data Exchange (VDE) and Application Specific Messages (ASM). The VDE includes an agreed Terrestrial element (VDE-T) as well as a developing Satellite element (VDE-S). The satellite component of VDES will ensure global communication capability including the polar-regions. VDE-S is under development, with studies to be provided to the World Radio Conference in 2019. VDES is seen as an effective and efficient use of radio spectrum, building on the capabilities of AIS and addressing the increasing requirements for data through the system. VDES will include AIS as it currently exists. It will also include new techniques that provide higher throughput using multiple channels which can:

- be merged to provide higher data rates; and
- provide simultaneous message diversity from multiple sources.

Furthermore, the VDES network protocol is optimized for data communication. The objective is that each VDES message is transmitted with a high degree of confidence of reception.

The VDES should improve the safety of life at sea, the safety and efficiency of navigation, the protection of the marine environment and enhance maritime safety and security. These goals will be achieved through efficient and effective use of maritime radiocommunications, incorporating the following functional requirements:

1. As a means of AIS.
2. As a means of radiocommunications equipment through exchange of digital data between ship and ship, ship and shore including satellite via AIS, Application Specific Messages (ASM) and VHF Data Exchange (VDE).
3. As a means of applications external to the VDES equipment itself. These applications use AIS, ASM or VDE separately or combined.

Implementation of VDES has commenced, building on the allocation of spectrum at WRC-15 where the ITU approved a standard for VDES (Recommendation ITU-R M.2092-0). A remaining issue is the approval of the satellite component for the VDE channels which is targeted for approval at WRC-19.

The system concept including VDES functions and frequency usage are illustrated pictorially in Figure 28 (entire system, including satellite allocations).

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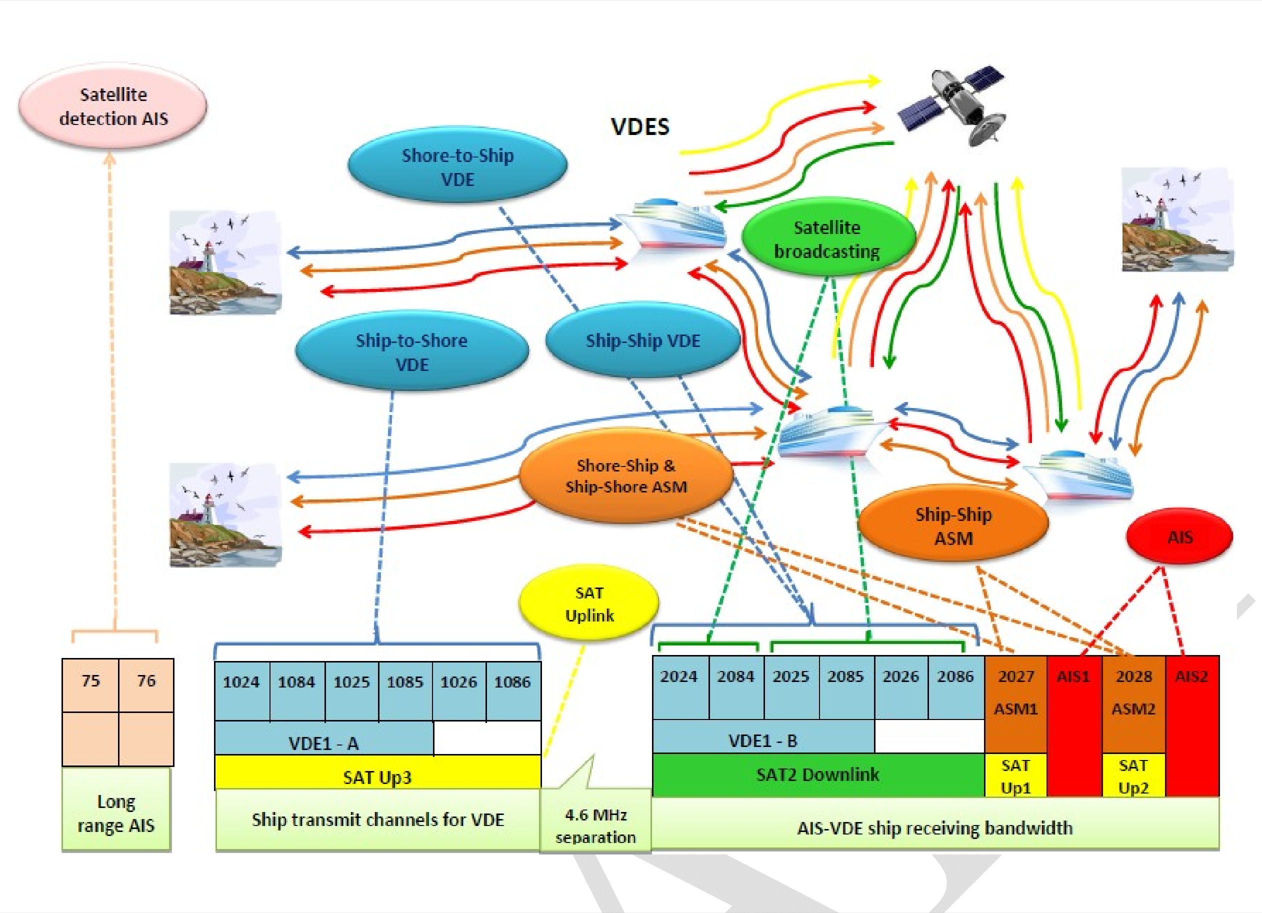

Figure 28: VDES functions and frequency use – a view of the entire system

	Transmitting frequencies (MHz) for ship and coast stations	
Channel number in RR Appendix 18	**Ship stations (ship-to-shore) (long range AIS) Ship stations (ship-to-satellite)**	**Coast stations Ship stations (ship-to-ship) Satellite-to-ship**
AIS 1 (was 87B)	161.975	161.975
AIS 2 (was 88B)	162.025	162.025
75 (long range AIS)	156.775 (ships are Tx only)	N/A
76 (long range AIS)	156.825 (ships are Tx only)	N/A
2027 (ASM 1)	161.950 (2027) (SAT Up1)	161.950 (2027) (SAT Up1)
2028 (ASM 2)	162.000 (2028) (SAT Up2)	162.000 (2028) (SAT Up2)
24/84/25/85 (VDE 1)	**100 kHz channel (24/84/25/85 lower legs merged) Ship-to-shore Ship-to-satellite (SAT Up 3)**	**100 kHz channel (24/84/25/85 upper legs merged) Ship-to-ship, Shore-to-ship Satellite-to-ship under certain conditions (SAT2 possible extension)**
24	157.200 (1024)	161.800 (2024)
84	157.225 (1084)	161.825 (2084)
25	157.250 (1025)	161.850 (2025)
85	157.275 (1085)	161.875 (2085)

26/86	**50 kHz channel** **(26/86 lower legs merged) VDE2** **Ship-to-satellite (SAT Up3)**	**50 kHz channel** **(26/86 upper legs merged)** **Satellite-to-ship (SAT 1)**
26	157.300 (1026) VDE 2, SAT Up3	161.900 (2026) (SAT 1)
86	157.325 (1086) VDE 2, SAT Up3	161.925 (2086) (SAT 1)
80/21/81/22	**100 kHz channel** **(80/21/81/22 lower legs merged)** **Ship-to-shore (VDE-T)**	**100 kHz channel** **(80/21/81/22 upper legs merged)** **Shore-to-ship (VDE-T)**
80	157.025	161.625
21	157.050	161.650
81	157.075	161.675
22	157.100	161.700
82	157.125 Ship-to-shore (VDE-T)	161.725 Shor-to-ship (VDE-T)
23/83	50 kHz channel (23/83 lower legs merged) Ship-to-shore (VDE-T)	50 kHz channel (23/83 upper legs merged) Shore-to-ship (VDE-T)
23	157.150 (VDE-T)	161.750 (VDE-T)
83	157.175 (VDE-T)	161.775 (VDE-T)

Table 22: VDES Channel allocation

IALA has published a guideline that provides an overview of VDES, including the road map to develop and implement this system.

4.7.3.2 AIS

The issue of correlating a ship's identity and its position in coastal waters and port approaches had been frustrating shore authorities for some time. It was long realised that an automatic reporting device fitted to vessels would mitigate this problem. It would contribute greatly to the safety of navigation and traffic management by exchanging information such as identity, position, time, course and speed between ship and shore regularly, automatically and autonomously. Vessel Traffic Services (VTS) and ports have a requirement for clear and unambiguous identification of vessels within their area, while the ability to provide such information ship-ship was identified as a benefit for safety of navigation and collision avoidance. Separately, the maritime community was developing the technology and rules for a VHF radio system which would enable ships to automatically communicate data with each other for the purpose of safe and efficient navigation. This was the Universal Automatic Identification System, now known as just AIS. It quickly became clear to shore authorities that AIS also had the potential to support a wide range of maritime regulatory and traffic monitoring activities and assist with maritime security. These include:

- ship operations;
- vessel tracking;
- investigations and prosecutions;
- search and rescue;
- environment protection;
- port State control;
- casualty management;
- compliance with pilotage requirements;
- vessel traffic services;
- planning of navigational services (e.g. ships' routeing measures);

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- monitoring of (and use as) aids to navigation; and
- strategic planning.

AIS is a critical element of VDES as a system. Overview information on AIS can be found in IALA Guideline 1082 (An overview of AIS). This and numerous other IALA guidance documents are available at the Publications area of the IALA website (http:/ / www. iala-aism. org/ product-category/ publications/). There are also a number of AIS reference documents published by the IMO, ITU and IEC.

Satellite AIS Terrestrial AIS systems have the benefit of continuous coverage and detection rates that approach 100% close to shore. Terrestrial AIS includes both receive and transmit capabilities, although many shore stations (AIS base stations) may be capable of only receiving AIS information. Terrestrial AIS, however, has the disadvantage of limited range and relatively high cost per square mile covered.

Satellite AIS (S-AIS) is a receive-only system, but has the advantage of providing complete global coverage with comparable average detection performance, as well as low cost per square mile covered. It has the disadvantages of lower detection rates close to shore stations and only periodic vessel refresh.

Satellites carrying AIS units are placed in Low Earth Orbit (LEO) where they travel at about 27,400 km/h at a distance of 650 to 800km above the surface of the earth. A single revolution around the earth takes approximately 90 minutes. As these are LEO satellites, a constellation of satellites is required to provide coverage in a timely method.

Satellite and terrestrial AIS systems provide capabilities offering unique and complementary benefits to national administrations, which mean that both are needed for complete maritime domain awareness. Refer to IALA Recommendation A-124 Appendix 19 (Satellite AIS).

ASM and VDE channels

VHF data exchange refers to the exchange of data in a digital manner on specified frequencies within VDES. The ITU identified six duplex channels for VDE-T and two channels for each AIS and ASM use (detailed in Table 22.)

The two ASM frequencies were identified specifically to provide increased capability for the transmission of application specific messages. In a terrestrial environment, ASM can be both transmitted and received. ASM can also be received by satellite, similar to the reception of AIS by satellite.

The VDE frequencies were agreed to address the ongoing requirement for digital data exchange as identified in e-navigation. The ability to group frequencies together within VDES will provide for increased bandwidth within the VDE aspect of VDES. The frequencies allocated to VDE can be used individually (as 25 kHz channels) or grouped together to provide 50 kHz or 100 kHz. The increased bandwidth, coupled with revised approaches to access the bandwidth, will support increases in data transfer when compared with existing AIS. Following ITU-WRC 2015, the VDE frequencies were agreed for transmit and receive at the terrestrial level, while work is continuing to enable satellite use of the frequencies to enable a truly global digital data exchange capability.

4.7.4 Digital VHF, MF and HF

VHF is commonly used worldwide in the maritime industry for general voice communication, transmission/reception of distress and safety information and reception of urgent marine information broadcasts, nominally for ‘line of sight’ distances. VHF has been traditionally based on analogue technologies. Changing user requirements and a demand for more sophisticated services have led to the development of digital mobile radio standards and systems.

Digital VHF should enable full communications – duplex and simplex – with higher data rates and more efficient use of spectrum.

4.7.4.1 Digital Selective Calling (DSC) (VHF, MF and HF)

DSC is a tone signalling system, which sends packets of digital data over radio spectrum. The MF/HF DSC distress and safety channels are 2187.5, 4207.5, 6312.0, 8414.5, 12577.0, and 16804.5 (kHz); the VHF DSC distress and safety channel is channel 70.

DSC is similar to the tone dialling on a telephone, but with the ability to include data such as the vessel's identification number, the purpose of the call, the vessel's position, and the channel for further voice communications. With DSC there is the ability to call individual vessels directly by use of their MMSIs (similar to a telephone number), or send a signal to vessels in the area – for example when sending a Distress/Urgency call. Table 23 presents the key characteristics of DSC.

System	Frequency	Bandwidth	Data Rate
DSC	22187.5, 4207.5, 6312.0, 8414.5, 12577.0, and 16804.5 (kHz) 156.525 MHz	VHF – 25 kHz HF - bandwidth constrained by SSB modulation scheme	VHF – 1,200 bps HF – 100 bps

Table 23: DSC characteristics

4.7.4.2 Digital VHF, MF and HF Radio (other than DSC)

MF/HF is commonly used worldwide in maritime for general voice communication, transmission/reception of distress and safety information, and reception of urgent marine information broadcasts. Long-range HF communications rely on refraction of signals by the ionosphere. MF can have a range of between 50 - 300 kms, with long-range HF reaching to 4,000 kms. The greater range depends on antenna configuration, power levels and atmospheric conditions.

Other than DSC (previous section refers), MF/HF is based on analogue technologies. Changing user requirements and a demand for more sophisticated services have led to the development of digital mobile radio standards and systems, in the land mobile environment. Digital techniques for HF, including digital voice, have been developed to address the inherent weaknesses of HF such as susceptibility to interference, fading and dropouts due to ionospheric effects and frequent poor voice quality.

Digital HF systems should enable full duplex communications, higher data rates and more efficient use of spectrum.

Table 24 provides the technical characteristics for digital VHF/UHF.

System	Frequency	Bandwidth for a simplex channel	9.6-19.2 kbps/4.8 kbps
Digital VHF/UHF	156-162 MHz/450-470 MHz	25 kHz/6.25 kHz	9.6-19.2 kbps/4.8 kbps

Table 24: Digital VHF/UHF system characteristics

4.7.5 Wi-Fi

The Wi-Fi communication system is one that runs across local networks, and is defined by the Institute of Electrical and Electronic Engineers (IEEE) . Wi-Fi networks consist of routers and adapters which translate a wired ethernet connection into a local wireless network for devices to connect. Wi-Fi can provide internet access to users. Wi-Fi hot spots may be set up in public places, such as ports, airports and restaurants to enable users to access the internet whilst on the move. Wi-Fi networks may be set up on board a vessel to enable data transfer within the ship, but access to internet is reliant on access through a service provider.

Table 25 presents the key characteristics of Wi-Fi.

System	Frequency	Bandwidth	Data Rate
Wi-Fi 802.11ai	2.4 and 5 GHz	40 MHz	Up to 1.3 Gbps

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Table 25: Wi-Fi system characteristics

The IEEE 802.11ai standard is a recent standard introduced which is solely based on the 5 GHz band and is able to theoretically transfer data at rates up to 1.3 Gbps. The higher frequency 5 MHz channels have a lower range than the lower frequency 2.4 MHz channels, however 2.4 MHz is a very congested band and may experience interference.

4.7.6 4G and 5G networks

4G is the 4th generation of mobile telecommunications, succeeding the 3rd generation system, 3G. 4G is defined as a set of standards to provide a given level service for a communication system. Within these standards, various technologies are built, which can then be identified as 4G, if they met the required standards.

Two systems that are considered to meet this standard are WiMax and LTE. WiMax was initially invested in heavily, with the technology offering high speed internet connection within a large coverage areas. However, the uptake of WiMax has been limited and some providers are decommissioning networks. In contrast, LTE (long term evolution) is widely used, with the more recent development, LTE-Advanced (LTE-A) regarded as a fully compliant 4G network.

4G is defined by the set of IEEE standards and LTE-A is a technology that complies with these standards. The LTE-A network uses Orthogonal Frequency-Division Multiplexing (OFDM), by encoding data on multiple frequencies. Table 26 presents the key characteristics of LTE-A.

System	Frequency	Bandwidth	Data Rate
4G – LTE Advanced	700 MHz, 1.7 to 2.1 GHz and 2.5 to 2.7 GHz	20 MHz	600 Mbps (download)

Table 26: 4G -LTE Advanced system characteristics

5G is a development from the 4G network and is advertised to be delivered from 2020. This latest development includes faster mobile data rates. The updated standards that will define the 5G network are still under consideration, but network trials have been successfully implemented. In bench trials speeds with a peak bitrate of 1 Tbps have been achieved. It is anticipated that realistic rates for 5G will achieve 1.2 Gbps. In addition, it is envisoned that 5G will have a satellite component.

5G developments will ensure a much faster connection than 4G. Not only will the data rate be increased, but the capacity is also intended to increase allowing for more users to access the higher speeds simultaneously. Table 27 provides the technical characteristics for 5G.

System	Frequency	Bandwidth	Data Rate
5G	SHF – above 6 GHz	Greater than 4G	1.2 Gbps (download)

Table 27: 5G system characteristics

4.7.7 Satellite communication systems and services

There is a wide range of satellite services that are currently provided, with plans for new services to be introduced in the near future. Satellite in itself is not a communications technology; rather the satellite carries a payload for communications and uses spectrum that is allocated by altitude. Satellite services are provided from geostationary (GEO) satellites, medium earth orbit (MEO) and low earth orbiting (LEO) satellites.

GEO satellites operate at an altitude of about 36,000 km in orbit over the Equator (0 degrees latitude), at various longitudes. These satellites have an orbital period equal to the rotation of the Earth and appear stationary above a fixed point on the Earth's Equator. They provide continuous coverage for the majority of the earth's surface, but do not provide coverage in the polar-regions (e.g. at latitudes typically greater than 70°).

MEO satellites operate at altitudes between 2,000 - 35,786 km. The most common MEO orbits are at just over 20,000 km with an orbital period of 12 hours. These satellites are commonly used for navigation services. MEO have recently been introduced into the Cospas/Sarsat system to support search and rescue (MEOSAR).

LEO satellites operate at altitudes between 80 - 2,000 km. The majority of LEO satellites make a complete revolution of the Earth in approximately 90 minutes. For persistent coverage of any one area of the Earth, there is a need to have a grouping of multiple satellites, known as a 'constellation'. The footprint of a LEO satellite would be in the realm of 3,281 km or 1,770 nautical miles. These satellites use different orbiting planes and can provide full global coverage, but coverage is reliant on the orbit of the satellite and no one spot on the Earth's surface can be served continuously by a single satellite.

Inmarsat is an example of a GEO satellite constellation. Inmarsat was originally established on the initiative of the International Maritime Organization (IMO) to operate a satellite communications network for the maritime community, including public safety services. Current data services include support for GMDSS, high data rate internet broadband/data streaming, low data rate, low latency, high availability data reporting, short burst data and store and forward capabilities.

Galileo is an example of an MEO constellation. There are 18 satellites available within the Galileo satellite service. The complete constellation will comprise of 30 satellites, 6 of which are spares.

Iridium is an example of a LEO satellite constellation. Iridium uses a constellation of over 60 cross-linked LEO satellites to provide high-quality voice and data connections, including coverage over polar regions with the use of polar orbiting satellites.

Some sample GEO and LEO satellite options are presented. As satellite technology is developing rapidly, this is not an exhaustive representation but provides a general overview of the existing, and expected, capabilities to address maritime requirements.

4.7.7.1 Geostationary satellites (GEO)

Noting that the satellite itself is the means to deploy a specific payload for communications, there are a number of existing or developing technologies that can be deployed on GEO satellites.

Inmarsat C

Inmarsat C is a store and forward satellite service used to transmit data from shore-ship, ship-ship and ship-shore. It provides global coverage (excluding the polar regions) and is designed to send low data packages such as position reports, meteorological reports and navigational warnings. The benefits of this technology include the restriction to maritime services, reducing the load on the system.

Inmarsat C is used for low data transmissions. The data rate provided by the Inmarsat C service is 600 bps and works in the L band.

Table 28 provides the technical characteristics for Inmarsat C.

System	Frequency	Bandwidth	Data Rate
Inmarsat C	1626.5-1645.5 MHz (transmit) 1530.0- 1545.0 MHz (receive)	15-20 MHz	600 bps

Table 28: Inmarsat C technical characteristics

Inmarsat Global Express (GX) is the latest satellite service offering from Inmarsat providing higher bandwidth than the existing Inmarsat SwiftBroadband and FleetBroadband services. As a global service, it provides broadband access to vessels outside the reach of normal terrestrial broadband, such as 4G and 5G. With the Ku band becoming increasingly saturated, the Inmarsat GX system has migrated the broadband services to the Ka band. Although the Ka band is more susceptible to rain attenuation, it provides the capacity that is required for delivering a high bandwidth internet connection. The service uses a number of spot beams, giving a high data rate to a wider area, with further steerable beams also available to provide additional capacity where it's needed. However, this service is not reserved solely for maritime meaning there is a higher risk of system overload.

The Inmarsat GX system functions in the SHF-EHF frequency bands (26.5 - 40 GHz) and provides higher bandwidth for internet connection. The service is expected to facilitate a data rate of 50 Mbps.

Table 29 provides the technical characteristics of Inmarsat GX.

System	Frequency	Bandwidth	Data Rate
Inmarsat GX	26.5-40 GHz	64 MHz per spot beam 200 MHz for high capacity overlay	50 Mbps

Table 29: Inmarsat Global Express system characteristics

4.7.7.2 Low Earth Orbiting satellites (LEO)

Noting that the satellite itself is the means to deploy a specific payload for communications, there are a number of existing or developing technologies that can be deployed on LEO satellites.

Iridium

Iridium has been effectively providing satellite communication services since 2001. While the initial service was seen as effective for rescue services and missions to remote areas of the globe, the demand for services has led to the development of Iridium Next. The revised basic functions include additional bandwidth, end-to-end IP technology and the incorporation of earth imaging and other secondary payloads.

The Iridium satellite system uses L band transponders to communicate with users, using frequencies in the band 1616 - 1626.5 MHz. It provides up to 134 kbps bidirectional (OpenPort broadband service).

Table 30 provides the technical characteristics of Iridium (Pilot).

System	Frequency	Bandwidth	Data Rate
Iridium (Pilot)	Ground users - 1616–1626.5 MHz (L-band) Terrestrial gateway 29.1 – 29.3 GHz	31.5 kHz	Up to 134 kbps

Table 30: Iridium (Pilot) system characteristics

The differences in the technologies are not only related to area of coverage and data rate, but also to the transmission process - for example, some are addressed (point to point only), while others can be addressed, broadcast to a group of ships or broadcast to a geographic area.

4.7.8 Overview of Digital Communications Systems

Table 31 provides a summary matrix outlining the communication technologies.

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Communication Technology	Data rate	Infrastructure	Coverage	Transmission	Maritime / public
NAVDAT	12-18 kbps	Based on NAVTEX	250/300NM	Broadcast	Maritime
VDES VDE	307 kbps	VHF Data link, RR Appendix 18 channels	Line of sight, approx 15NM-65NM Satellite component provides further coverage	Addressed / broadcast	Maritime
VDES ASM	19.2 kbps	VHF Data link, RR Appendix 18 channels	Line of sight, approx 15NM-65NM	Addressed / broadcast	Maritime
Wi-Fi (IEEE 802.11ac)	1,300 kbps	Routers/Access points	50m	Addressed	Public
Digital VHF	9.6-19.2 kbps	Base station/mobile radios	Line of sight, approx 15NM-65NM	Addressed	Maritime
Digital HF	19.2 kbps	Base station/mobile radios	Global	Addressed	Maritime
4G (including LTE)	600 Mbps	4G Base stations	5-30km (3-6 NM)	Addressed	Public
5G	1,200 Mbps	5G base stations	5-30km (3-6 NM)	Addressed	Public
GEO Satellite					
Inmarsat C	600 bps	Satellite service	Global, spot beams	Addressed / broadcast	Maritime
Inmarsat GX	50 Mbps	Satellite functioning on Ka band	Global, spot beams	Addressed / broadcast	Cross Industry
LEO Satellite					
Iridium	Up to 134 kbps	Satellite functioning on L band	Global, dependent on constellation size	Addressed / broadcast	Cross Industry (Iridium Pilot Maritime)

Table 31: Summary of communication technologies

4.8 Positioning, Navigation and Timing

4.8.1 Introduction

Positioning, Navigation and Timing (PNT) information is used widely in the maritime sector, both to navigate ships and in Aids to Navigation (timing and positioning). There are a number of systems available that deliver PNT.

More details of these systems can be found in the IALA World Wide Radio Navigation Plan (WWRNP).

4.8.2 Electronic Position Fixing Systems

4.8.2.1 Global Navigation Satellite Systems

Global Navigation Satellite System (GNSS) is the generic term for a satellite system that provides a world-wide position determination, with time and velocity capability, for multi-modal use.

GNSS is based on a constellation of active satellites which continuously transmit coded signals in one or more frequency bands. These signals can be received by users anywhere on the earth's surface to determine the user's position and velocity in real time, based on ranging measurements.

If a GNSS is recognised by the IMO as a component of the World Wide Radio Navigation System (WWRNS), as set out in IMO Resolution A.1046 (27), the receivers of that GNSS will satisfy the IMO carriage requirements for position fixing equipment referred to in Chapter V of the SOLAS Convention.

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GNSS receivers in combination with other equipment are able to provide PNT information such as:

- 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).

Several Global Navigation Satellite Systems (GNSS) have been deployed, fully or partially, or are under development. GPS, GLONASS, BeiDou and Galileo have been recognised as components of the WWRNS. It is planned that regional GNSS components like QZSS and NAVIC will become operational in the next few years and may be submitted for recognition in WWRNS in due course. GPS, Galileo, BeiDou, QZSS and NAVIC operate interoperable services under the framework of the International Telecommunication Union (ITU).

Global Positioning System

The Global Positioning System (GPS) is a three-dimensional positioning, velocity and time system that became fully operational in 1995. The system is operated by the United States Air Force on behalf of the United States Government.

The U.S. Government provides two levels of GPS service. The Precise Positioning Service (PPS) provides full system accuracy to designated users. The Standard Positioning Service (SPS) provides accurate positioning to all users.

GPS has three major segments: space, control and user. The GPS Space Segment consists of a nominal constellation of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) 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) [2]

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.

Global Navigation Satellite System

The GLObal NAvigation Satellite System (GLONASS) is a three-dimensional positioning, velocity and time system managed by the Russian Space Agency for 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 24 satellites, the service satisfies the requirements for general navigation and gives a horizontal position accuracy in the region of 12.4m (95%) over any 24-hour interval, given a position dilution of precision (PDOP) of 2. [3]

Recent launches have included the improved GLONASS M satellites with a second civil signal. Since 2011, the constellation is being replenished with GLONASS-K satellites that provide a third civil signal on L3.

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. Further information on GLONASS and future developments can be found on the Russian Space Agency, Information Analytical Centre website (www.glonass-ianc.rsa.ru).

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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. BeiDou can provide all-time, all-weather PNT services with high accuracy and high reliability for all kinds of users. A joint office established by related governmental departments, China Satellite Navigation Office (CSNO) is in charge of management on the construction, application promotion and industrialisation of BDS.

BDS consists of three major components: the space constellation, the ground control segment and the user segment. The space constellation consists of 5 GEO satellites and 30 non-GEO satellites. Upon completion of the full system, BDS will provide positioning, velocity measurement and timing services to users worldwide. It can also provide wide area differential services with the accuracy of better than 1m.

It is expected that when fully operational, the BeiDou constellation will consist of approximately 40 satellites and be capable of providing global coverage. For further details on BDS, including the number of satellites currently in orbit, please refer to the CSNO website [4]

Further information on BDS can be found on the CSNO website (http://en.beidou.gov.cn/index.html)

Galileo

Galileo is the European GNSS designed to be interoperable with other GNSS, managed and operated under civil control. The Galileo programme is currently in its deployment phase and is due for completion in 2020. Initial services were declared in 2016. Galileo will offer the following services:

1. An Open Service (OS): With positioning accurate to around 1 metre using up to three different frequencies (E5a, E5b and L1), free of user charges and providing positioning and synchronisation information intended mainly for high-volume satellite navigation applications.
1. A Public Regulated Service (PRS): Restricted to European Union government-authorised users, for sensitive applications which require a high level of service continuity. It will use strong, encrypted signals. It may be accessed by non-EU states and international organisations subject to bilateral agreements.
1. A contribution to the Search and Rescue Service (SAR) of the COSPAS-SARSAT system: Galileo's worldwide search-and-rescue service will forward distress signals to a rescue coordination centre by detecting emergency signals from beacons and relaying messages to them in near real time.
1. A Commercial Service (CS): Encrypted for authentication purposes and offering very high accuracy to the sub-decimetre level, it will target applications for professional or commercial use. It will offer improved performance and data with greater added value than that obtained through the open service.

Galileo will use 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).[5]

4.8.2.2 Regional systems

Quasi-Zenith Satellite System

Japan is developing a Quasi-Zenith Satellite System (QZSS). QZSS is based on three satellites in highly 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 L-band: 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.jps/.

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.

Three NAVIC services are anticipated:

- 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.

4.8.2.3 Differential Global Navigational Satellite Systems

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.

DGNSS service provides correction in terms of ranging errors per satellite in view. This principle is applied by IALA Beacon DGNSS providing range and range rate corrections, derived at a reference station site from differences between surveyed and known distances to satellites in view. Satellite Based Augmentation Systems (SBAS) provide an area correction parameter, whose application enables the determination of range and range correction for users in large-scale regions such as continental Europe. In this case, a network of ranging and integrity monitoring stations (RIMS) is used to measure and model the spatial varying error behaviour.

Centimetre-level accuracies can be achieved by DGNSS services employing the application of real time kinematic techniques (RTK) for positioning. The gain of accuracy is achieved by the common processing of range and phase measurements collected at reference station and user site, to apply single and double difference methods during position determination.

In safety-critical applications, DGNSS services should be enriched with integrity functions, realising the monitoring of data and system integrity in real time. The monitoring can be realised by plausibility and consistency tests as well as methods estimating error behaviour and budgets. Results of the integrity monitoring informs the user about the current usability of applied components and provided output data.

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

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terrestrial radio transmitters (i.e. IALA beacon transmissions or AIS) or via satellite transponders (SBAS).

Terrestrial augmentation systems

The following sections consider the different correction methods which used ground-based infrastructure. IALA Beacon DGNSS

The aim of IALA beacon DGNSS is the provision of non-encrypted differential corrections, as well as integrity information, to 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 1990s, is internationally accepted and supported in most coastal waters, especially in areas of high traffic density. The differential corrections are determined at known positions of reference stations or a network of stations. For this purpose, the difference between expected and measured ranges is used to derive actual range and range rate corrections.

Additionally, integrity monitoring functionalities are implemented to assess the usability of GNSS signals and provided DGNSS service.

The radio link used for the provision of DGNSS correction and integrity data is internationally defined at ITU (Recommendation ITU-R M.823-3). At present, the DGNSS signal transmission is realized in the maritime radionavigational band (283.5 to 325 kHz)[6] . 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 recapitalisation of DGNSS infrastructure is an ongoing process. Of the options available, some service providers have opted to replace existing hardware with similar dedicated Reference Stations and Integrity Monitors (RSIM); some have invested in software RSIM; while others have adopted a network of reference stations to create virtual RSIMs. Other solutions, such as integration with SBAS may evolve within the enhancement of the maritime PNT system.

The full list of about 400 maritime radiobeacon based DGNSS stations (as notified to IALA by aids to navigation authorities) is at the IALA website (www.iala-aism.org).

Refer to IALA publication:

- Recommendation R-1115 (Provision of maritime radionavigation services in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Region 2 and 3);
- Recommendation R-121 (Performance And Monitoring of DGNSS Services In The Frequency Band 283.5-325khz); and
- Guideline 1112: (Performance and Monitoring of DGNSS Services in the Frequency Band 283.5-325kHz).

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 Section 7.

AIS has the capability of providing DGNSS corrections to onboard equipment using standardised transmissions (Message No 17) as described in IALA Recommendation A-124.

Maritime Phase-Based GBAS (MGBAS)

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.

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.

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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 - 70 kms from the coast line).

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.

Satellite Based Augmentation Systems

Satellite Based Augmentation Systems (SBAS) support wide-area or regional augmentation through the use of additional satellite-broadcast messages. The basic arrangement is to use a set of monitoring stations (at precisely known positions) to receive GNSS signals. These will be processed in order to obtain estimations of these 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.

'Wide Area Augmentation System'

The Wide Area Augmentation System (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 was recently extended to cover parts of Mexico and Canada. At present, the WAAS architecture includes 38 reference stations, 3 master stations, 4 up-link stations, 2 geostationary satellite links and 2 operational control centres. Further information on WAAS can be found on the USCG Navigation Centre website (www.navcen.uscg.gov).

'European Geo-stationary Navigation Overlay Service'

The European Geostationary Navigation Overlay Service (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. (https://egnos-user-support.essp-as.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_os_sdd_v2_2.pdf);
- Safety of Life (SoL) Service, provides the most stringent level of signal-in-space performance developed primarily to support aviation. Its use in the maritime sector is being explored with a view to supporting maritime SoL users in the future.

(https:/ / egnos-user-support. essp- sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_sol_sdd_in_force.pdf);

- 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) (https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_edas_sdd_v2_1.pdf).

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 via website http:/ / www. egnos-portal. eu/ and https:/ / egnos-user-support.essp-sas.eu/).

Multi-Satellite Augmentation System 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 on L5 in the future[7]. Further information on MSAS can be found via the website: (www.kasc.go.jp/_english/msas_01.htm).

GPS-Aided Geo Augmented Navigation System

India is developing a GPS-Aided Geo Augmented Navigation system (GAGAN), which is a SBAS similar to WAAS and EGNOS. GAGAN includes 8 reference stations, 1 mission control centre, 1 up-link station and 1 GEO-link through the L1/L5 transponder on the INMARSAT 4-F1 satellite. At the time of writing, further information on GAGAN may be found at www.isro.org.

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. Two satellites have been launched and are in operation.

Korea Augmentation Satellite System

Republic of Korea is developing a Korea Augmentation Satellite System (KASS), which is an SBAS similar to WAAS and EGNOS. KASS includes 7 reference stations, 2 master stations, 2 up-link stations, and 2 operational control centres. Upon completion of system development and establishment, scheduled in 2019, KASS will begin to provide its open service in 2020. It will then undergo a series of system certification processes in the next several years before its provision of safety of life (SoL) service in the aviation sector in October 2022. Further information on KASS can be found via website (www.kass-eng.re.kr).

4.8.2.3 Terrestrial systems

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. There are currently about 19 Loran - C and CHAYKA chains operating around the world. The principal coverage areas include Saudi Arabia, China Sea, Korea, North West Pacific, Russian Federation and North West Europe.

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.

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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. Although offering reduced accuracy, it will allow GNSS users to retain the safety, security and economic benefits of GNSS, even when their satellite services are disrupted. 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 also synchronised with, but independently of, GNSS time. Synchronising to a common time source allows receivers to employ a mixture of eLoran and GNSS signals. 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 are 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 back 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.

For more information, the reader is encouraged to seek advice from the Radio Technical Commission for Maritime Services Special Committee 127 (SC-127) on eLoran Systems.

Compatibility Between eLoran and Loran-C

Legacy receivers are able to use both eLoran and Loran-C signals as eLoran stations form part of the presently organised chains. However, legacy Loran-C receivers will likely not provide the user with the best accuracy performance.

Users should ensure their receivers are able to decode the Loran Data Channel to receive integrity alerts, UTC time and differential-Loran correction data. They should also ensure their receiver is capable of storing and applying up-to-date ASF data.

Receiver Autonomous Integrity Monitoring

Receiver Autonomous Integrity Monitoring (RAIM) is a technology developed to assess the integrity of GNSS signals, and therefore the 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.

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.

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 and 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

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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 (www.navipediA.net/index.php/araim).

Ranging mode

Studies are being conducted on the benefit of expanding the functionality of existing systems by providing a timing signal from which the user may then calculate their position independently from GNSS. This is known as Ranging Mode (R-mode).

At present, the IALA MF beacon system and AIS services are being considered as candidates for modification to add R-mode functionality. By providing timing information over their normal MF or VHF transmissions, a shipboard receiver may then calculate a distance (range) to the transmitter. By calculating the range to several stations, the user is able to calculate the ship's position. Coverage, geometry and interference issues would need to be investigated.

The provision of R-Mode services would require the availability of an accurate non-GNSS timing source at the transmitter. High stability 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.

4.8.3 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, 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 radars, often referred to 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.

4.8.3.1 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 1m2 reflecting area.

The range at which a radar reflector target can be detected is dependent on the heights of the radar antenna, the reflector and the output power of the radar. There are analogies to the geographical range of visual marks. The radar

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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.

4.8.3.2 Radar Target Enhancers

A Radar Target Enhancer (RTE) is a 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 100 m2, compared with an RCS of 20 to 30 m2 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.

4.8.3.3 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. Please note that IMO MSC.192 (79) has done away with the requirement for 3GHz 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 29) 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.

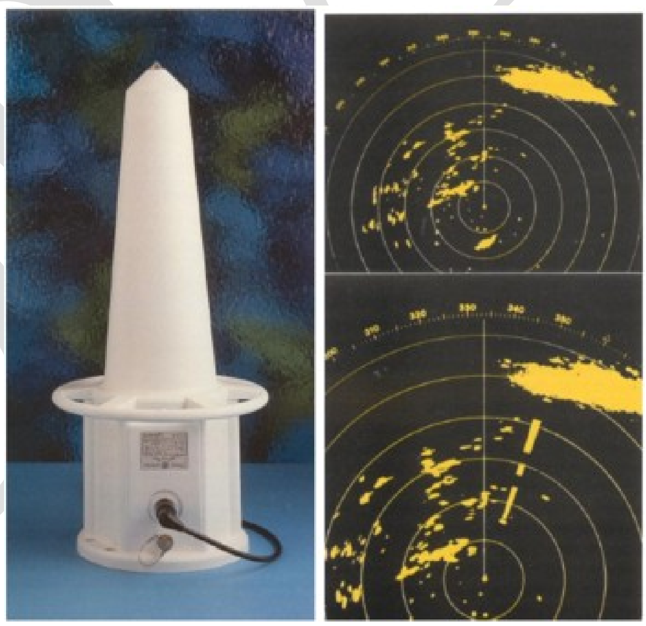

Figure 29: A Racon (left) and a Radar Display (right) with and without the Racon character

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:

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- 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.

4.8.3.4 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.

Signal Characteristics

Racons operate in the 9 GHz band with horizontal polarisation, and/or in the 3 GHz band, with horizontal and optional vertical polarisation.

Preferred Terminology	Alternatives		
9 GHZ	9300 9500 MHZ	X-BAND	3 CM
3 GHZ	2900 3100 MHZ	S-BAND	10 CM

Table 32: Preferred terminology for the description of Racon Operating Frequencies

4.8.3.5 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%.

For more information on racons, refer to the following IALA publications:

Refer to IALA publication:

- Guideline 1010 on Racon Range Performance
- Recommendation R-101 on Maritime Radar Beacons (Racons)
- Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability
- Recommendation O-113 for the Marking of Fixed Bridges over Navigable Waters

4.8.3.6 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.

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4.8.3.7 Use with New Technology Radars

All currently available and installed racons are designed for use with high power pulse radars. In comparison, New Technology (NT) radars 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 NT radars and may not transmit a response usable by NT radars. Studies have shown that pulsed NT radars are able to reliably trigger racons at shorter ranges than would have been achieved with a conventional magnetron pulsed radar. The IMO regulations regarding X band radars and racons remain unchanged and although detection and triggering range might be reduced, it is the responsibility of manufacturers of X band NT radars to retain racon functionality.

Despite changes to the IMO regulations relating to S band racons, existing racons with 3 GHz capability will continue to be useful to 3 GHz pulse radars of both Magnetron and pulsed New Technology variants. Advanced clutter reduction techniques of NT radars do not automatically mean that racons are no longer useable. Some manufacturers are continuing to provide racon compatibility in their NT 3 GHZ radars.

Please refer to Recommendation eNAV-146 Strategy for Maintaining Racon Service Capability for more information on NT radars.

4.8.3.8 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.

4.8.4 Non-radio Positioning Systems

4.8.4.1 Inertial systems

Many studies have been carried out on the integration of GNSS with Inertial Measurement Units (IMU) for marine 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.

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 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.

4.8.4.2 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.

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4.9 Testbeds

The term testbed is used across many disciplines to describe a platform that is used for research, development or testing. Testbeds generally involve rigorous, transparent and replicable testing of scientific theories, innovative solutions, computational tools and new technologies.

IALA Guideline 1107 (on Planning and Reporting Of e-Navigation Testbeds) states that e-Navigation testbeds allow for early identification and assessment of new system functionality, operational usability, areas of enhancements, identification of weaknesses and socio-technical impact. Such testbeds should not be limited or restricted by current architecture, data structures or procedures.

Note that not all testbeds may lead to commercial implementation of solutions.

4.9.1 Testbed information

As e-Navigation evolves from concept to operational reality, the importance of testbeds continues to grow.

In order for e-navigation solutions to have global application, IALA facilitates the collation and sharing of the outcomes of testbeds. A list of testbeds that are known to IALA can be found at:

http://www.iala-aism.org/products-projects/e-navigation/test-bedsprojects/

Testbed managers are encouraged to share results (including interim and final reports) of testbeds with the maritime community, through IALA. IALA can post testbed findings, including an executive summary and description, as provided by the testbed manager, at the testbeds page of the IALA website. It is then available to everyone involved with e-navigation and testbeds.

It is important that outcomes or lessons learnt from test-bed projects be considered in the context of the main elements of the IMO Strategy Implementation Plan (i.e. user needs, architecture, gap analysis and solutions that are the subject of cost-benefit and risk analyses).

Notes

[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 Nation Office of Outer Space Affairs

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Navguide: Chapter 5 - Vessel Traffic Services (VTS)

5.1 Introduction

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.

5.2 Purpose

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 (IMO Resolution A857(20), Guidelines for Vessel Traffic Services (VTS)).

5.3 Definition

A VTS, as defined by IMO Resolution A857(20), Guidelines for Vessel Traffic Services, is:

"A service implemented by a competent authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and respond to traffic situations developing in the VTS area."

5.4 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 contents are 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.

5.5 Objectives

The purpose of vessel traffic services is to improve the safety and efficiency of navigation, safety of life at sea and the protection of the marine environment and/or the adjacent shore area, worksites and offshore installations from possible adverse effects of maritime traffic.

A clear distinction may need to be made between a Port or Harbour VTS and a Coastal VTS. A Port VTS is mainly concerned with vessel traffic to and from a port or harbour or harbours, while a Coastal VTS is mainly concerned with vessel traffic passing through the area. A VTS could also be a combination of both types. The type and level of service or services rendered could differ between both types of VTS; in a Port or Harbour VTS a navigational assistance service and/or a traffic organization service is usually provided for, while in a Coastal VTS usually only an information service is rendered.

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

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pollution and co-ordination of pollution response.

The efficiency of a VTS will depend on the reliability and continuity of communications and on the ability to provide good and unambiguous information. The quality of accident prevention measures will depend on the system's capability of detecting a developing dangerous situation and on the ability to give timely warning of such dangers.

The precise objective of any vessel traffic service will depend upon the particular circumstances in the VTS area and the volume and character of maritime traffic

5.6 Functions

VTS functions can be subdivided into internal and external functions. Internal functions are the preparatory activities that have to be performed to enable a VTS to operate. These include data collection, data evaluation and decision making. External functions are activities executed with the purpose of influencing the traffic characteristics by means of active traffic management strategies including the provision of information, advice, warnings and instruction.

Amongst the most important functions that a VTS may carry out are those related to, contributing to and thereby enhancing:

- Safety of life at sea;
- Safety of navigation;
- Efficiency of vessel traffic movement;
- Protection of the marine environment;
- Supporting maritime security;
- Supporting law enforcement;
- Supporting allied and other services;
- Protection of adjacent communities and infrastructure.

5.7 Types of Service in VTS

IMO Resolution A.857(20) states that a VTS should comprise of at least an Information Service and may also include others, such as a Navigational Assistance Service or a Traffic Organisation Service, or both.

5.7.1 Information Service

An Information Service (INS) provides essential and timely information to assist the on-board decision-making process. An Information Service involves maintaining a traffic image and allows interaction with traffic and response to developing traffic situations. An Information Service should provide essential and timely information to assist the on board decision-making process.

5.7.2 Traffic Organization Service

A Traffic Organization Service (TOS) is a service to prevent the development of dangerous maritime traffic situations and to provide for the safe and efficient movement of vessel traffic within the VTS area. A Traffic Organization Service provides essential and timely information to assist the on-board decision-making process and may advise, instruct or exercise authority to direct movements. It concerns the operational management of traffic and the planning of vessel movements and is particularly relevant in times of high traffic density or when vessel movements may affect the traffic flow. A Traffic Organization Service should be responsible for separating traffic in the interest of safety. This separation could be defined in space, time and/or distance.

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5.7.3 Navigational Assistance Service

A Navigational Assistance Service (NAS) may be provided in addition to an Information Service and/or Traffic Organization Service. It is a service to assist in the on-board navigational decisionmaking process and is provided at the request of a vessel, or when deemed necessary by the VTS. It is a service that provides essential and timely navigational information to assist in the on-board navigational decision-making process and to monitor its effects. It may also involve the provision of information, warning, navigational advice and/or instruction.

The Navigational Assistance Service is especially important in difficult navigational or meteorological circumstances or in case of defects or deficiencies. A Navigational Assistance Service is an important supplement to the provision of other navigational services, such as pilotage. Navigational Assistance Service may be provided at the request of a vessel, irrespective of whether a pilot is on board, or when a navigational situation is observed and intervention by the VTS is deemed necessary.

5.8 Surveillance Requirements

The extent of the VTS area, amongst other factors, should be taken into account with regard to determining the operational requirements for surveillance equipment. The operational requirements for surveillance should be determined by a needs analysis as described in IALA Recommendation V-119. This analysis should take into account variations in weather and general local conditions and any impact they might have on the performance of surveillance equipment. Most VTS use VHF for communication, and obtain a traffic image through use of a combination of Radar, AIS and CCTV in some areas.

5.9 Equipment Requirements

IALA Recommendation V-128 and IALA Guideline 1111 provide guidance on the preparation of operational and technical performance for VTS systems.

VTS Equipment may be defined as the individual items of hardware and software which make up the VTS System. The VTS System is considered to be the hardware, software and their behaviour as a coherent entity. This excludes personnel and procedures.

Traffic density and structure, navigation hazards, local climate, topography, environmental requirements, commercial aspects and the extent of a VTS area sets the requirements for VTS equipment and these factors will have substantial impact on life cycle costs of a VTS and the acquisition of VTS equipment. Equipment examples include:

- Communications (VHF; Telephone; Satellite telephone; Mobile telephone; E-mail; AIS messaging);
- Radar System;
- Automatic Identification System (AIS);
- Electro Optical Systems (EOS);
- Radio Direction Finders (RDF);
- Hydrometeo Equipment;
- VTS Data System;
- Recording and replay systems;
- Data Processing;
- Decision Support;
- External Information Exchange.

5.10 Personnel

VTS personnel, masters, bridge watchkeeping personnel, pilots and all other stakeholders share a responsibility for good communications, effective co-ordination and understanding of each other's role for the safe conduct of vessels in VTS areas. They are all part of a team and share the same objective with respect to the safe movement of vessel traffic.

Depending on the size and complexity of the VTS area, service type provided, as well as traffic volumes and densities, a VTS centre may include VTS Operators, VTS Supervisors, VTS On-the-Job Training Instructors and a VTS Manager. It is for the Competent/VTS Authority to determine the appropriate types of service, operational procedures and equipment in order to meet its obligations and to ensure that appropriately trained and qualified personnel are available.

IALA Recommendation R0103 provides guidance on the standards for the recruitment, training and certification of VTS personnel. There are currently five model courses related to VTS:

- V-103/1 VTS Operator;
- V-103/2 VTS Supervisor;
- V-103/3 VTS On-the-Job Training;
- V-103/4 VTS On-the-Job Training Instructor;
- V-103/5 VTS The revalidation process for VTS qualification and certification.

5.11 Promulgation of information

Information on VTS areas and procedures can be found in internationally recognised marine publications and individual websites.

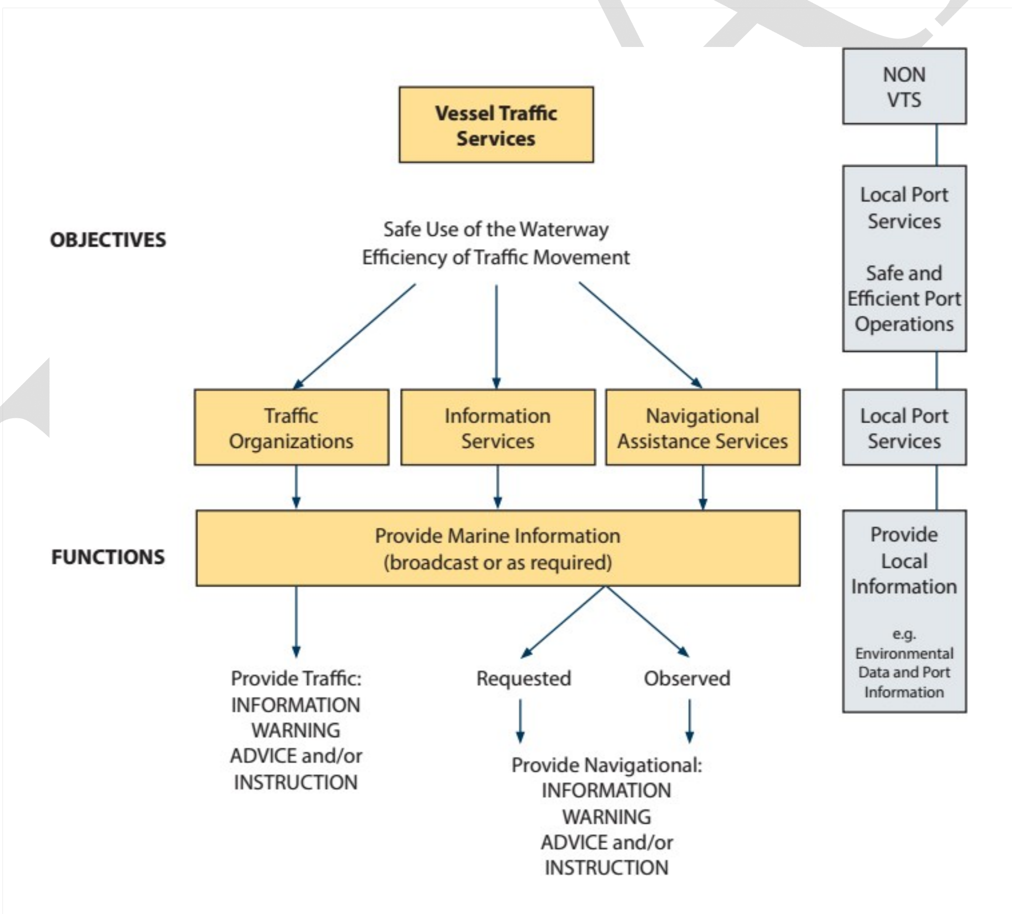

Figure 30 - Overview of Types of VTS Services and Functions

5.12 Summary

Readers are encouraged to refer to the:

- IALA VTS Manual

Refer to IALA publications:

- Recommendation V-102 on the Application of "User pays" principle to Vessel Traffic Services;
- Recommendation R0103 (V-103) on the Standards for Training and Certification of VTS personnel;
- Recommendation V-119 on the Implementation of Vessel Traffic Services;
- Recommendation V-120 on Vessel Traffic Services in Inland Waters;
- Recommendation V-125 on the use and presentation of symbology at a VTS Centre;
- Recommendation V-127 on the Operational Procedures for Vessel Traffic Services;
- Recommendation V-128 on the Operational and Technical Performance Requirements for VTS Equipment;
- Recommendation V-145 on the Inter-VTS Exchange Format (IVEF) Service;
- Recommendation A-123 on the Provision of Shore Based AIS;
- Recommendation A-124 on the AIS Service;
- Recommendation A-126 on the Use of AIS in Marine Aids to Navigation;
- Guideline 1014 on the Accreditation and Approval process for VTS Training;
- Guideline 1017 on the Assessment of training requirements for existing VTS Personnel, Candidate Operators and the Revalidation of VTS Operator Certificates;
- Guideline 1018 on Risk Management;
- Guideline 1026 on AIS as a VTS Tool;
- Guideline 1027 on Designing and Implementing Simulation in VTS Training;
- Guideline 1045 on Staffing Levels at VTS Centres;
- Guideline 1071 on establishment of a Vessel Traffic Service beyond territorial seas;
- Guideline 1082 an overview of AIS;
- Guideline 1089 on Provision of VTS types of service;
- Guideline 1101 on Auditing and Assessing VTS;
- Guideline 1105 on shoreside portrayal ensuring harmonisation with e-Navigation related information;
- Guideline 1111 on Preparation of Operational and Technical Performance Requirements for VTS Systems;
- Guideline 1115 on Preparing for an IMO Member State Audit Scheme (IMSAS) on VTS;
- Guideline 1118 on Marine casualty / incident reporting and recording including near-miss situations as it relates to VTS;
- Model Course V-103/1 VTS Operator;
- Model Course V-103/2 VTS Supervisor;
- Model Course V-103/3 VTS On-the-Job Training;
- Model Course V-103/4 VTS On-the-Job Training;
- Model Course V-103/5 The Revalidation Process for VTS Qualification and Certification.

Navguide: Chapter 6 - Other services and facilities

6.1 Pilotage

6.1.1 Introduction

Pilotage is a specialised (and usually licensed) service to navigation, specifically in restricted and/or navigationally challenging waters. The skill of the pilot draws on local knowledge related to geographic and hydrographic points of interest, aids to navigation, submerged features, hazards to navigation, the navigable depth of water and any limitations associated with the waterway in which pilotage is being conducted. Pilots must also possess a high degree of ship handing skills, be cognisant of the local tides, currents, and climatic conditions, as well as the handling characteristics for the specific ship receiving the pilotage service.

Pilotage may be required in coastal waters, estuarial waters, rivers, channels, ports, harbours, lakes, canals, enclosed dock systems or any combination of these areas. In addition, deep sea pilotage services are provided in some international waters, such as the North Sea, English Channel, Entrances to the Baltic Sea and the Baltic Sea.

When a pilot boards a vessel, he / she is given "conduct of the vessel", but not "command". The role of the pilot often includes:

- giving necessary instructions to ship's personnel who operate equipment essential to the safe navigation and manoeuvring of the vessel;
- assisting local communication with a VTS centre, port control and other vessels;
- communicating instructions to tugs and linesmen if berthing or sailing;
- providing current and specialist knowledge of:
  - local conditions and traffic;
  - operational status of aids to navigation;
  - sailing directions;
  - restrictions applicable to the piloted vessel.
- being able to quickly adapt to:
  - operational culture aboard the vessel;
  - the vessel's handling characteristics;
  - the state of the navigation equipment aboard.

6.1.2 Portable Pilot Units (PPUs)

A Portable Pilot Unit (PPU) can be generally described as a portable, computer-based system that a pilot may bring onboard a vessel to use as a decision-support tool for navigating in confined waters. Interfaced to a positioning sensor such as GNSS/DGNSS and using some form of electronic chart display, it shows the vessel's position/movement in real-time. In addition, PPUs provide information about the location/movement of other vessels via an AIS interface. Increasingly, PPUs are being used to display other types of navigation-related information such as soundings/depth contours from recent hydro surveys, dynamic water levels, current flow, ice coverage and security zones.

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6.1.3 Types of Pilotage

Pilotage services exist within declared ports but may also exist in some coastal areas, lakes and inland waterways. These areas would normally fall within the definition of restricted waters.

Where pilotage services are licensed, it is usual for the applicable pilotage area to be stated on the licence. The individual pilot may then be described as a port pilot or a coastal pilot etc. Various levels of enforcement can be applied to a pilotage area:

- **Compulsory (Mandatory) Pilotage:** Applicable vessels must take a pilot when entering a declared area.

Some Competent Authorities require compulsory (mandatory) pilotage for vessels of certain characteristics and/or carrying specific types of cargo when entering a declared area.

In Particularly Sensitive Sea Areas (PSSA) approved by IMO, Additional Protective Measures may be applied to shipping, which could include compulsory pilotage arrangements. In some instances, individual countries may establish a system of pilotage or domestic laws which give effect to the compulsory pilotage arrangements established in association with and IMO-approved PSSA.

- **Recommended Pilotage:** An authority can promulgate notices recommending that masters of applicable vessels, who are unfamiliar with a particular area, should engage a licensed pilot.

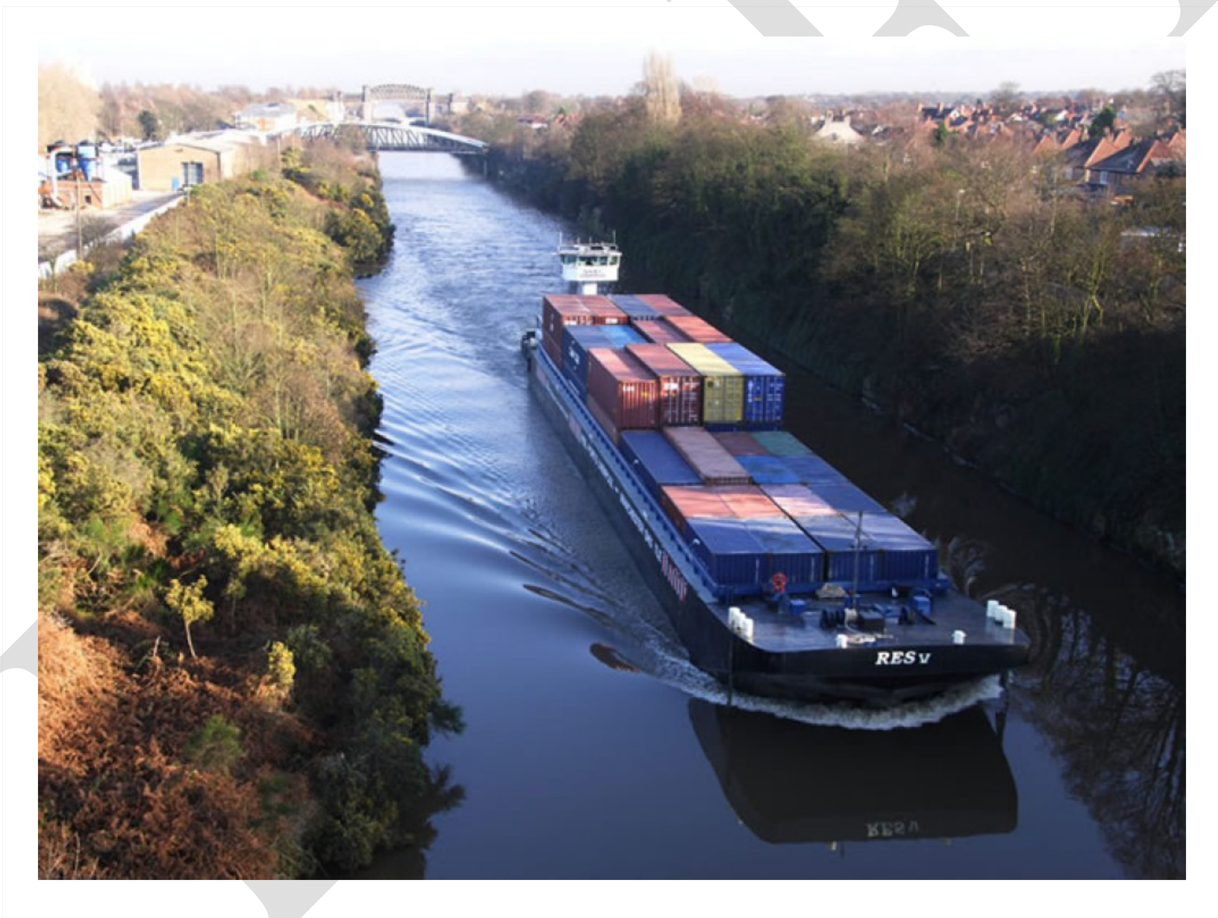

Photo Couresy of Instituto Hidrografico (Portugal)

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6.1.4 Other Pilotage Considerations

Pilotage services can be provided by public or private operators, however the pilot licensing authority should generally be government-regulated to maintain the highest standards of service.

The IMO has set the minimum standards for pilots and includes recommendations on the qualification and training of pilots other than deep sea pilots[1]. Individual countries may however, impose more stringent standards.

Photo Courtesy of Swedish Maritime Administration

When developing proposals for marking restricted waterways, the requirement for pilotage services should be considered concurrently with the selection of the aids to navigation.

6.1.5 Simulation Pilot Training and Certification

The IMO Assembly in 2003 adopted Resolution A.960(23) Recommendations on training and certification and operational procedures for maritime pilots other than deep-sea pilots. IMO Resolutions encouraging the use of pilots on board ships in certain areas are described further below:

- Resolution A.480(XII) (adopted in 1981) recommends the use of qualified deep-sea pilots in the Baltic;
- Resolution A.620(15) (adopted 1987) recommends that ships with a draught of 13 metres or more should use the pilotage services established by Coastal States in the entrances to the Baltic Sea;
- Resolution A.486(XII) (adopted 1981) recommends the use of deep-sea pilots in the North Sea, English Channel and Skagerrak;
- Resolution A.579(14) (adopted 1985) recommends that certain oil tankers, all chemical carriers and gas carriers and ships carrying radioactive material using the Sound (which separates Sweden and Denmark) should use pilotage services;
- Resolution A.668(16) (adopted 1989) recommends the use of pilotage services in the Euro-Channel and IJ-Channel (in the Netherlands);
- Resolution MEPC.133(53) recommends that Governments recognize the need for effective protection of the Torres Strait and inform ships flying their flag that they should act in accordance with Australia's system of pilotage for merchant ships 70m in length and over or oil tankers, chemical tankers, and liquefied gas carriers, irrespective of size, when navigating the Torres Strait and the Great North East Channel;
- Resolution A.827(19) (adopted 1995) on Ships' Routeing includes in Annex 2 Rules and Recommendations on Navigation through the Strait of Istanbul, the Strait of Canakkale and the Marmara Sea the recommendation that "Masters of vessels passing through the Straits are strongly recommended to avail themselves of the services of a qualified pilot in order to comply with the requirements of safe navigation.";
- Resolution A.960(23) gives recommendations on training and certification and operational procedures for Maritime Pilots other than Deep Sea pilots;

- Resolution A.1045(27) on Pilot Transfer Arrangements gives recommendations on the construction of pilot ladders.

6.2 Ships Routeing

The General Provisions on Ships' Routeing are established by SOLAS Chapter V, Regulation 10.[2]

6.2.1 Objectives

The purpose of ships' routeing is to improve the safety of navigation in converging areas and in areas where the density of traffic is great or where freedom of movement of shipping is inhibited by restricted sea-room, the existence of obstructions to navigation, limited depths or unfavourable meteorological conditions. Ships' routeing may also be used for the purpose of preventing or reducing the risk of pollution or other damage to the marine environment caused by ships colliding or grounding in or near environmentally sensitive areas.

The precise objectives of any routeing system will depend upon the particular hazardous circumstances which it is intended to alleviate, but may include some or all of the following:

- separation of opposing streams of traffic so as to reduce the incidence of head-on encounters;
- reduction of dangers of collision between crossing traffic and shipping in established traffic lanes;
- simplification of the patterns of traffic flow in converging areas;
- organization of safe traffic flow in areas of concentrated offshore exploration or exploitation;
- organization of traffic flow in or around areas where navigation by all ships or by certain classes of ship is dangerous or undesirable;
- organization of safe traffic flow in or around or at a safe distance from environmentally sensitive areas;
- reduction of risk of grounding by providing special guidance to vessels in areas where water depths are uncertain or critical; and
- guidance of traffic clear of fishing grounds or the organization of traffic through fishing grounds.

6.2.2 Definitions

The following terms are used in connection with matters related to ships' routeing:

Approach Channel: Any stretch of waterway linking the berths of a port and the open sea. There are two main segments; the seaway or outer channel, and the main approach or inner channel which lies in relatively sheltered waters.

Area to be Avoided: An area within defined limits in which either navigation is particularly hazardous or it is exceptionally important to avoid casualties that should be avoided by all ships, or just certain classes of ship.

Deep-water Route: An accurately surveyed route within defined limits that is clear of obstructions to a specified depth as indicated on the applicable navigation chart.

Established Direction of Traffic Flow: A traffic flow pattern indicating the directional movement of traffic as established within a traffic separation scheme.

Inshore Traffic Zone: (Note 3) A routeing measure comprising a designated area between the landward boundary of a traffic separation scheme and the adjacent coast, to be used in accordance with the provisions of rule 10(d), as amended, of the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs).

Mandatory Routeing System: A routeing system adopted by the International Maritime Organization, in accordance with the requirements of SOLAS Regulation V/10, for mandatory use by all ships, certain categories of ships or ship carrying certain cargoes.

No Anchoring Area: A routeing measure comprising an area within defined limits where anchoring is hazardous or could result in unacceptable damage to the marine environment. Anchoring in a no anchoring area should be avoided

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by all ships or certain classes of ships, except in case of immediate danger to the ship or the persons on board.

Precautionary Area: A routeing measure comprising an area within defined limits where ships must navigate with particular caution and within which the direction of traffic flow may be recommended.

Recommended Direction of Traffic Flow: A traffic flow pattern indicating a recommended directional movement of traffic where it is impractical or unnecessary to adopt an established direction of traffic flow.

Recommended Route: A route of undefined width, for the convenience of ships in transit, which is often marked by centreline buoys.

Recommended Track: A route which has been specially examined to ensure, so far as possible, that it is free of dangers and along which, ships are advised to navigate.

Roundabout:[3] A routeing measure comprising a separation point or circular separation zone and a circular traffic lane within defined limits. Traffic within the roundabout is separated by moving in a counter clockwise direction around the separation point or zone.

Routeing System: Any system of one or more routes or routeing measures aimed at reducing the risk of casualties, it includes traffic separation schemes, two-way routes, recommended tracks, areas to be avoided, inshore traffic zones, roundabouts, precautionary areas and deep water routes.

Separation Zone or Line: (Note 3) A zone or line separating the traffic lanes in which ships are proceeding in opposite or nearly opposite direction or separating a traffic lane from the adjacent sea area; or separating traffic lanes designated for particular classes of ship proceeding in the same direction.

Traffic Lane: (Note 3) An area within defined limits in which one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary.

Traffic Separation Scheme: (Note 3) A routeing measure aimed at the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes.

Two-way Route: A route within defined limits inside which two way traffic is established, aimed at providing safe passage of ships through waters where navigation is difficult or dangerous.

6.2.3 Vessel Manoeuvering

If a waterway is defined as a series of straight and turn sections, the passage of a vessel along the waterway can be described by a number of navigational phases that are illustrated in Figure 31. These comprise:

- turning;
- recovery;
- track keeping.

The type of manoeuvre within a section determines the information that the navigator requires from the aids to navigation.

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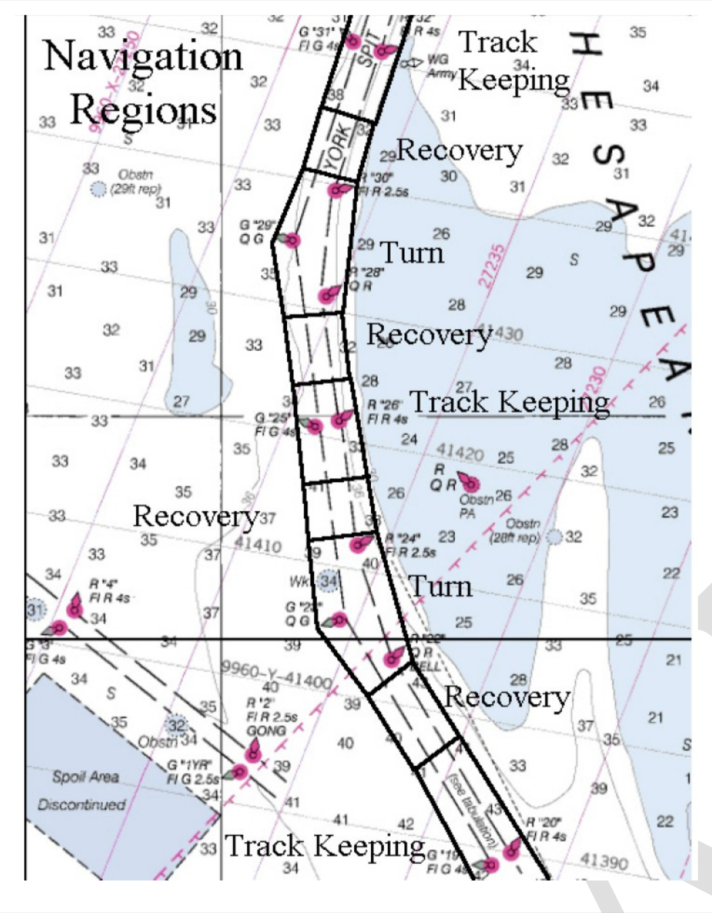

Figure 31 - Vessel Manoeuvring Phases

6.3 Minimum Comprehensive Mix of AtoN for Channels and Waterways

The primary goal of the design of AtoN systems for a waterway is to facilitate safe and efficient movement of vessels while playing a prevention role in the protection of the marine environment. The responsible provision of AtoN systems requires that systems be designed to meet the minimum requirements for safe and expeditious navigation through specific waters in accordance with the type and volume of traffic and the degree of risk.

AtoN are normally intended to function as part of a system(s) and therefore mariners should make use of all information provided by the system of AtoN.

Whether designing a new waterway system or evaluating an existing one, there are many factors that must be considered. The identification of these factors allows Competent Authorities to develop a greater understanding of the risks and threats that are present within a particular waterway.

Waterways will vary in their characteristics. Site analysis, needs analysis, simulation, and operational analysis provide the necessary framework to evaluate the overall risks that may be present and identify measures that reduce the risk to safe transit to an acceptable level.

Once the evaluation has been completed, Competent Authorities should use this information to design the AtoN system. In completing the design it is important to note that the entire waterway must be viewed using a systematic approach, recognizing that each individual element of the waterway design by itself will not reduce transit risk. While individual areas of the waterway must be considered, the overall aids to navigation system must support a smooth transit of the entire waterway. The tools used for waterway design consists of the IALA MBS (Annex A of this document) and the technical tools referred to in section 3.1 (AtoN) and Chapter 4 (e-Navigation), which are also described in IALA Recommendations and Guidelines.

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

- Be available at the time it is needed;
- Provide timely warnings of channel limits and fixed obstructions to navigation;
- Enable mariners to determine quickly their location within the channel, relative to fixed obstructions to navigation, and relative to other vessels;
- Enable a safe course for the vessel.

AtoN systems may be provided for the safety of navigation in various areas such as:

- Fairways, dredged channels and canals;
- Waters adjacent to the coast;
- Archipelagic waters, in pristine and/or improved condition;
- Estuarine rivers;
- River systems;
- Straits;
- Isthmuses;
- Open sea.

Once the system has been established, maintaining the availability of this system is critical to controlling overall risks.

It is useful to analyse the functional requirements of the design in a number of parts. For example, the open water component or outer channel, and the inner channel component which may lie in relatively sheltered waters.

The design process requires inputs from a number of disciplines, including:

- ship dynamics;
- vessel size and behaviour;
- human factors;
- maritime engineering;
- aids to navigation;
- the physical environment (including bathymetry and hydrometeorology).

The joint PIANC-IAPH Working Group II-30 in cooperation with IMPA published a document "Approach Channels - A Guide for Design".

6.3.1 Design Considerations

During design, different design parameters should be considered.

In this phase the functional requirements have to be translated into physical systems. However, it is often a question of utilising practical experience with AtoN, if the performance parameters are to be met.

Accuracy

The required accuracy depends on the difference between the manoeuvring lane of the ship and the width of that part of the fairway, which is used by a ship of a particular draft. The available under keel clearance has to be taken into account. The ship's manoeuvring lane depends on the ship's beam, length and manoeuvring ability and on environmental conditions (wind, currents, etc.).

Availability

In those areas in which the level of risk has been determined to be high, the use of certain types of aids to navigation may prove to provide greater risk mitigation. However, the planner must also consider higher availability criteria that may be required. Competent Authorities should refer to IALA Recommendation O-130 on Categorisation and

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Availability Objectives for Short Range Aids to Navigation for additional information in relation to the categorization of individual aids to navigation, the calculation of availability targets, and recommended availability criteria.

AtoN systems should be designed to assist mariners regardless of weather, sea and ice conditions.

Short Range AtoN, especially buoys, should be designed with regard to their visual information, radar information (active or passive) and other modes of information (for example AIS). System design must take into account the visibility and radar availability implications. Designing for worst case visibility is not usually practical; however, reduced visibility due to haze and fog must be considered.

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

Additionally, integrity and continuity can be used to define requirements, if appropriate.

Refer to IALA publication:

- Recommendation O-130 on Categorisation and Availability Objectives for short range AtoN.

6.3.2 Dredging Considerations

Competent authorities should consider the contribution that proper use of aids to navigation make in improving positioning accuracy and navigational accuracy and hence to the efficiency of major dredging projects and waterways maintenance. In some instances, the required channel width could be reduced as can the costs for major and maintenance dredging. The PIANC Guide “Approach Channels,” contains further information on this matter.

6.3.3 Hydrographic Considerations

Usually, the uncertainty of positioning an AtoN should not be greater than the uncertainty in hydrographic surveys and charts.

Horizontal uncertainty is the uncertainty of a position defined as the uncertainty of the sounding or feature within the geodetic reference frame. Positions should be referenced to a geocentric reference frame based on the International Terrestrial Reference System (ITRS) e.g. WGS84.

The position uncertainty, at the 95% confidence level, should be recorded together with the survey datA. The position of the following items should be determined such that the horizontal uncertainty meets the requirements specified:

- Soundings;
- Dangers;
- Other significant submerged features;
- AtoN features significant to navigation;
- Coastline and topographical features.

This includes all uncertainty sources not just those associated with positioning equipment.

6.3.4 Design Validation and Visualisation and the Use of Related Tools

Prior to implementing a new AtoN system or changing an existing one, Competent Authorities should consider using simulation techniques to assess the overall safety and effectiveness of these changes. The use of Geographic Information System (GIS) technology can improve the efficiency of AtoN deployment and waterway layout. GIS enables the volume of traffic to be overlaid (e.g. taken from AIS data), and planning the position and type of AtoN to mitigate the identified risks for all users. Having designed a potential AtoN configuration in this manner, the Competent Authority can use simulation tools to model a ship passages using combinations of various types of vessels, in order to validate the design. Simulation is best done in consultation with appropriate stakeholders eg. local pilots. To achieve a high level of realism in the simulations, GIS data can be integrated to the waterway models used in the simulator.

In addition, simulation could be useful for ensuring sufficient channel width, channel depth, and optimal orientation and design of breakwaters as well as ensuring that the lay-out of a channel and port is suitable from a manoeuvring perspective.

Sophisticated computer simulation techniques are becoming increasingly available, and they provide an important tool to assist in decision making.

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

Refer to IALA publications:

- Recommendation O-138 on the Use of GIS and Simulation by Aids to Navigation Authorities;
- Guideline 1069 on Synchronisation of Lights.

6.3.5 Economic Considerations

A comparative analysis of cost effective combinations of aids (cost-effectiveness analysis) is required to select from viable alternatives. The effectiveness of different alternatives can be assessed using IALA risk assessment tools, especially the Port And Waterway Safety Assessment (PAWSA) tool as a qualitative risk assessment procedure and the IALA Waterway Risk Assessment Program (IWRAP) as an analytical risk assessment program.

It is necessary to establish comparative direct costs - including maintenance costs - of each proposed AtoN, to assist in determining the most cost-effective system of aids to navigation. Simulation offers a method to help ensure that AtoN are appropriate.

6.3.6 Simulation

Simulation tools are capable of providing very realistic and accurate results and input to investigation and evaluation of channel and port design including the placement of AtoN. The purpose of simulation for design evaluation is to evaluate the risks of a given design ship operating in a specific fairway and port area. It also includes evaluation of channel layout, placement of AtoN and manoeuvring aspects.

Simulations offer a relatively low cost method to help ensure that the AtoN solution provided meets the users' requirements in an effective and efficient manner.

By providing a simulation tool to the user an overall improvement in safe and efficient operation can be realised by assisting in demonstrating the operation of the waterway, channel design and associated AtoN before the reality of navigating a vessel in the area.

User consultation is an integral part of all AtoN planning and simulation processes. Accurate simulation tools will potentially improve the usefulness of the feedback obtained from users. It is important that the providers of the simulation services include the key stakeholders in the simulation studies including experienced mariners and engineers, local pilots and competent authorities who can ensure that applicable regulations and recommendations are followed.

The use of simulators can be of real benefit in confirming the effectiveness of marking proposals that will have a high cost or that are intended to meet the needs of a complex navigational situation. When defining simulation tools for design evaluation (as opposed to training in, for example generic ship handling or watch keeping) it is important that the ship, tug and area models used are very realistic and accurate and that the simulation provider can document

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the realism and accuracy such that it does not become a “black-box” study with non-transparent processes.

The requirement for realism and accuracy is increasingly important as the industry is constantly striving for improved safety levels and increased efficiency.

It is important to note that accurate simulation of AtoN is a complicated process due to the challenges of visual simulation. Providing visual images for observation and detection of AtoN during night and day time, at sufficient resolution, light intensity and contrast pushes the capability of modern projectors and monitors to the edge and even beyond. Understanding the human eye and the physics of light are prerequisites for developing adequate simulation models.

A number of different simulation tools are available for design studies and have different usability and applications.

The following types of simulation tools are the most common:

- Fast Time;
- Desktop;
- Part Task;
- Full Mission;
- Traffic Flow.

Refer to IALA publications:

- Recommendation O-138 on the Use of GIS and Simulation by Aids to Navigation Authorities;
- Guideline 1058 on the Use of Simulation as a Tool for Waterway Design and AtoN Planning.

6.4 The Marking of Man-Made Offshore Structures

There has been an increasing development in man-made structures at sea, which may affect shipping. These structures can be isolated or in groups, small or large, and close to or far from navigation zones.

IALA is monitoring the developments of these structures and will continue to create and update documentation as required to ensure clear and unambiguous marking of waterways for safe navigation, protection of the environment and protection of the structures themselves.

Effective and consistent marking of these diverse structures, during their construction or decommissioning phase and when established, are an significant challenge for Aids to Navigation Authorities. IALA Recommendation O-139 for the Marking of Offshore Structures provides comprehensive information on the required marking. The marking of the various structures are set out in five groups:

- Offshore Structures (in general);
- Oil and Gas Platforms;
- Offshore Wind Farms;
- Wave and Tidal Energy Devices;
- Aquaculture Farms.

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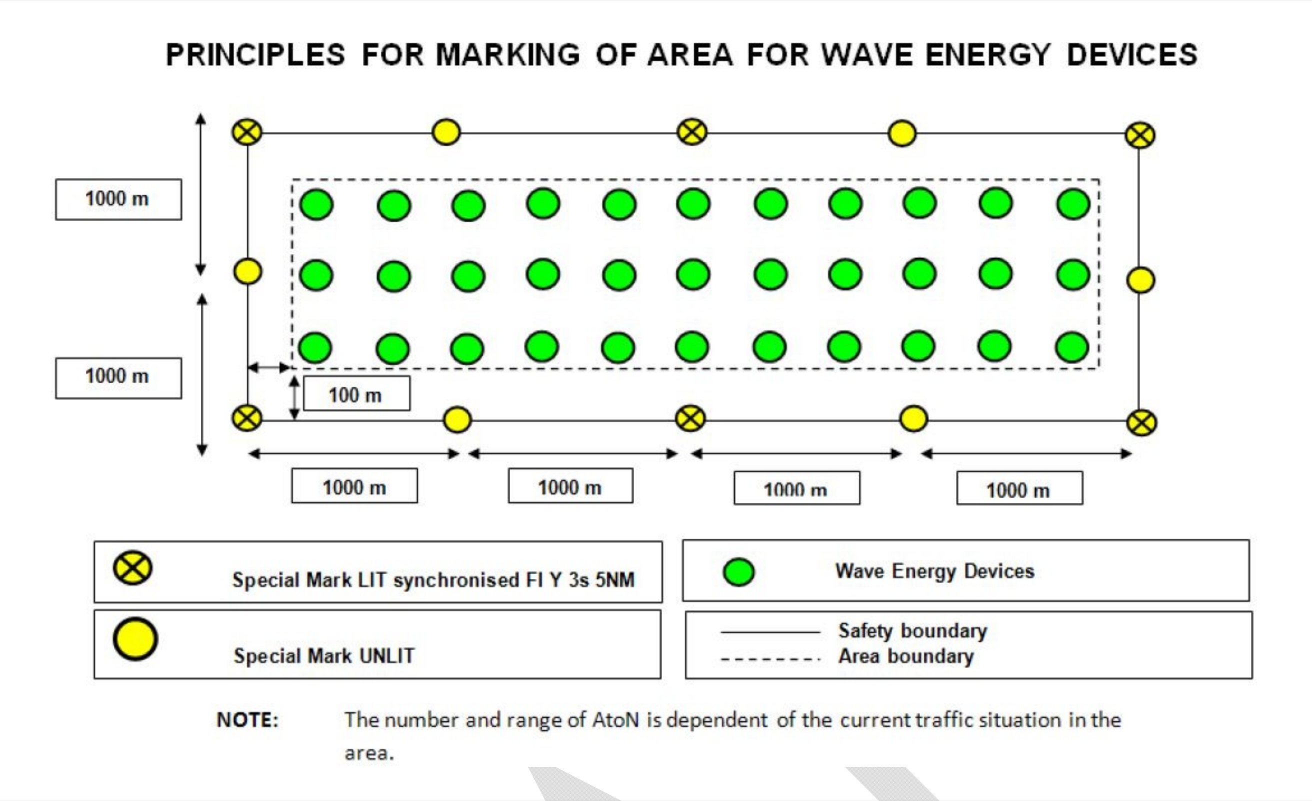

Figure 32 - Sample for Marking Wave Energy Devices

Refer to IALA publications:

- Recommendation O-113 for the Marking of Fixed Bridges over Navigable Waters;
- Recommendation O-139 for the Marking of Offshore Structures;

6.5 Audible Signals

This section has been moved to Chapter 3 - refer 3.2.4.1

6.6 Nautical Publications

6.6.1 Navigational Warnings

SOLAS Chapter V Regulation 13 requires for contracting governments to provide navigational information to mariners.

Regulation 13 states that *Contracting Governments undertake to arrange for information relating to aids to navigation to be made available to all concerned users. 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 in effect after timely and adequate notice has been promulgated.*

This information falls into three basic categories:

- information about **planned changes**, such as:
  - dredging, surveying, platform installation, pipe and cable laying;
  - changes to an existing aid or the establishment of new aids to navigation;
  - changes to traffic arrangements;
  - commercial maritime activities;
  - short term events (naval exercises, yacht races, etc.).

- information about navigational **unplanned events**, such as:
  - the failure to aids to navigation;
  - marine incidents (groundings, collisions, wrecks etc.);
  - search and rescue activities.
- **new information** arising from survey work or previously undiscovered hazards.

6.6.2 World-Wide Navigational Warning Service

The promulgation of information on navigational safety is coordinated by means of the World-Wide Navigational Warning Service that was established jointly by the IMO and the IHO in 1977.

The World-Wide Navigational Warning Service is administered through 21 NAVAREAS, as is shown in Figure 33. Each NAVAREA has an Area Coordinator who is responsible for collecting information, analysing it, and transmitting NAVAREA Warnings. The delimitation of NAVAREAS is not related to, and shall not prejudice the delimitation of any boundaries between states.

6.6.3 Lists of Aids to Navigation

Lists of aids to navigation (e.g. lights, buoys, radar, audible signals) are produced by (or for) most Competent Authorities as part of the navigational information made available to mariners in support of SOLAS Chapter V Regulation 13.

They provide details of:

- name;
- location;
- the characteristics of the aids;
- operating schedule.

These lists may not include buoys and unlit aids to navigation.

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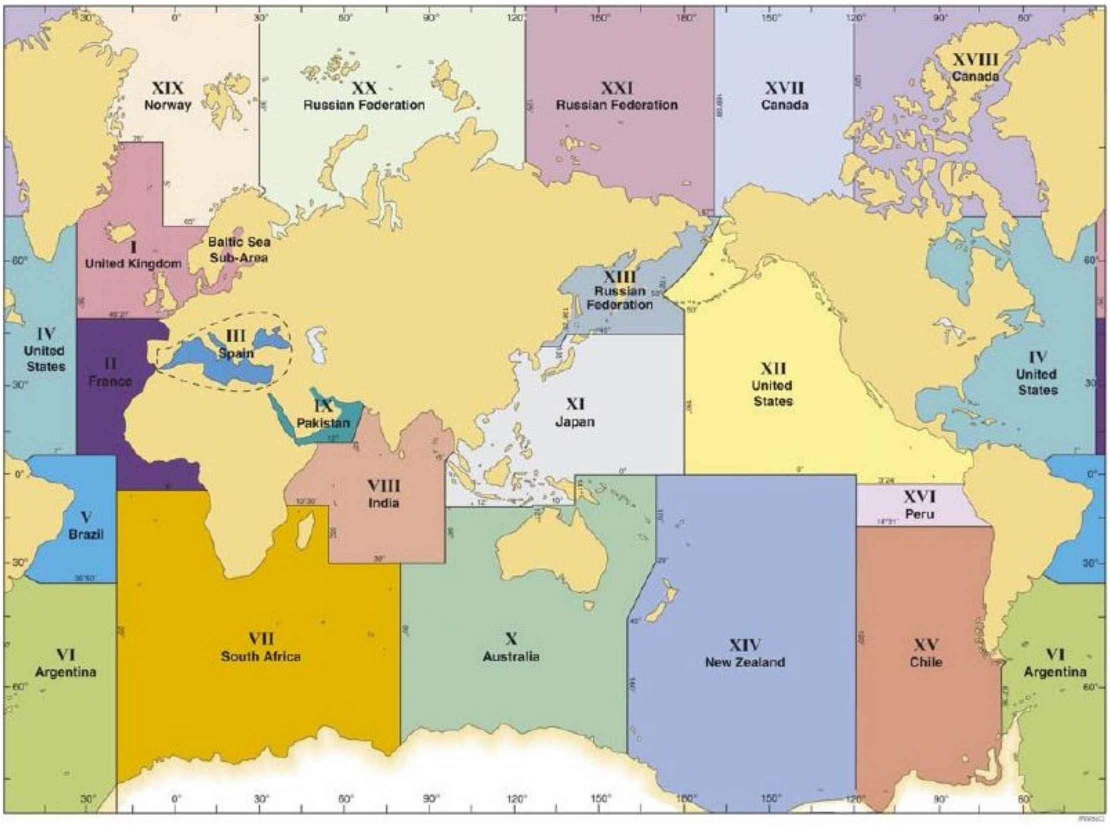

Figure 33 - World-Wide Navigational Warning Service: Limits of NAVAREAS

6.6.4 Standard Descriptions

The Joint IMO/IHO/WMO Manual on Maritime Safety Information (IMO MSC.1/Circ.1310) Edition 3 2009 provides definitions of standard terms to describe particular events that should be used when composing navigational warnings. Some of the terms that are relevant to the condition of aids to navigation have been defined as indicated in Table 33.

Term	Definition
UNLIT	Use UNLIT in place of: Out, Extinguished, Not Burning, Not Working.
LIGHT UNRELIABLE	Use LIGHT UNRELIABLE in place of: Weak, Dim, Low Power, Fixed, Flashing Incorrectly, Out of Character, Incorrect colour of light, Sector limits unreliable.
DAMAGED	Use only for major damage, e.g., loss of significant functionality
DESTROYED	Do not use "Temporarily destroyed".
OFF STATION	Not in charted position, but still in the vicinity of original location. The actual position may be informed, if known.
MISSING	Completely absent from position.
RE-ESTABLISHED	Use for previously charted or listed as DESTROYED or TEMPORARILY REMOVED.

Table 33 - terms that are relevant to the condition of aids to navigation

The above list of terms and definitions do not adequately cover all of the situations that an Authority might want to use when issuing a navigation warning. An expanded set of definitions of terms for use in navigation warnings is provided for Competent Authorities' consideration in Table 34.

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Term	Definition
STATION	The authorised and exact location of an aid to navigation.
ESTABLISHED IN POSITION	Any type of aid placed in operation for the first time at a given station.
RE-ESTABLISHED IN POSITION	Any type of aid placed in operation at a station at which a similar type of aid with identical characteristics had been previously established, but subsequently destroyed, withdrawn or discontinued.
UNLIT	When a light is out because of defective equipment, or any unintentional or deliberate occurrence and it is intended to restore it to normal as soon as practicable.
UNRELIABLE	When an aid of any type is not exhibiting its correct characteristics and it is intended to restore it to normal as soon as practicable.
REDUCED POWER	When an aid of any type is not operating at its correct power, but is exhibiting the correct characteristics and it is intended to restore it to normal replace it as soon as practicable.
OFF STATION	When a floating aid is adrift, missing or out of position and it is intended to replace it as soon as practicable.
ALTERED	When the characteristics or structure of any aid have been altered, without changing the type of aid or its station.
ALTERED IN POSITION	When a change is made to the station of an aid (e.g. its location) without changing the type of aid, character or type of structure.
DESTROYED	Any type of aid that has been damaged to the extent that it is no longer of use as an aid to navigation, but the structure may remain.
RESTORED TO NORMAL	Any type of aid that has been previously described as unlit, unreliable, reduced power or temporarily discontinued and has now been serviced so as to exhibit its correct characteristics and power.
REPLACED IN POSITION	When a floating aid previously described as off station or temporarily discontinued is returned to station or replaced by another with the same characteristics.
TEMPORARILY REPLACED BY	When any aid is discontinued, temporarily withdrawn or off station and another aid of different type or characteristics is immediately established at the same station.
TEMPORARILY WITHDRAWN	When a floating aid has been entirely removed from its station and no similar aid is left in its place, but it is intended to re-establish the aid in the near future.
TEMPORARILY DISCONTINUED	When a sound signal or radionavigation service is silent because of maintenance requirements, or any unintentional or deliberate occurrence, and it is intended to restore it to normal as soon as practicable.
PERMANENTLY WITHDRAWN	When a floating aid has been entirely removed from its station with no similar aid is left in its place and it is not intended to re-establish that aid in the near future.
PERMANENTLY DISCONTINUED	When any aid, other than a floating aid, is removed from a station or the service is terminated or silenced because it is no longer required.

Table 34 - Suggested Expanded List of Standard Terms for Use in Navigation Warnings

6.6.5 Positions

The Joint IMO/IHO/WMO Manual on Maritime Safety Information states that positions should always be given in Degrees, Minutes and decimal minutes in the form:

- DD-MM.mmm N or S;
- DDD-MM.mmm E or W;
- leading zeros should always be included;
- the same level of accuracy should be quoted for both Latitude and Longitude.

Recording of Aids to Navigation Positions

Aids to Navigation positions can be recorded in number of ways:

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- where an Authority has operational DGNSS stations, a program should be implemented to determine the WGS84 positions of each aid to navigation (fixed and floating) within the coverage area, and for this information to be passed to the hydrographic authority for future use. It is anticipated that the information would assist the hydrographic authority in checking the accuracy of charts, planning future survey requirements and for updating List of Lights.
- in the case of lighted fixed aids to navigation, the WGS84 position should be measured close to the focal centre of the light so that the WGS84 elevation is also determined. Alternatively, several positions around the optic or lantern house could be measured and a central position computed.
- in the case of unlighted fixed aids to navigation, the WGS84 position should be the base of the structure.
- in the case of floating aids to navigation, the WGS84 position should be the position of the anchor or sinker.
- each position should be recorded to three decimal places of a minute and include the time, date and details of the measuring equipment.
- where an Authority has to refer to charts of different datum, positions are communicated with the appropriate datum reference. (for example 51° 04.372'N, 100° 26.794'E (WGS 84)).

Refer to IALA publication:

- Recommendation O-118 for the Recording of Aids to Navigation Positions.

Bearings

Bearings, directions of leading lines (ranges) and limits of sectors should always be stated in terms of the bearings that would be seen by the mariner. Observing a practice of communicating bearings with the suffix 'TBS' or True Bearing from Seaward will minimise the risk of confusion.

6.6.6 Maritime Safety Information

Within a NAVAREA, there can be a hierarchy of warnings promulgated by the national co-ordinator.

Collectively referred to as Maritime Safety Information (MSI), the warning hierarchy covers:

- **NAVAREA Warnings** that are concerned with information that ocean-going vessels require for safe navigation:
  - are transmitted in English and, where appropriate, in other languages;
  - are promulgated by:
    - radiotelephony;
    - Digital Selective Calling (DSC);
    - Enhanced Group Calling (EGC);
    - NAVTEX[4] (used for the automatic broadcast of localised Maritime Safety Information (MSI) using radio telex);
  - cover the specific NAVAREA and portions of adjacent areas;
  - have broadcast schedules which are shown in the List of Radio Signals published by Hydrographic Offices and in the publications of the International Telecommunication Union (ITU);
  - are generally promulgated for a sufficient period of time to ensure its safe reception after which it is cancelled or published in a Notice to Mariners;
- **Coastal Warnings** that are concerned with information relating to a regional area covering 100-200 nautical miles from the coast: -- are transmitted from a national network of coastal radio stations; -- are broadcasted at scheduled times; -- use English and the national language;
- **Local Warnings** that cover the area within the limits of a harbour or port authority: -- supplement Coastal Warnings; -- may be limited to the national language.
- **Off-Station Warnings for Major Floating Aids** that pertain to any unmanned Light Vessel / Lightship, or LNB (occasionally referred to as LANBY), is out of position such that it could be misleading to navigation:
  - any light, sound and Racon signal used as aids to navigation should be discontinued;

- it should, to avoid risk of collision, exhibit two all-round red lights in a vertical line where they can best be seen, which should be exhibited in accordance with COLREGS Rule 27 (A) for a vessel not under command;
- if requiring a sound signal to be operated, it should be coded MORSE ‘D’ as prescribed by rule 35 of the COLREGS for a vessel ‘Not under command’;
- if requiring a Racon to be deployed, it should be coded MORSE ‘D’.

Refer to IALA publication:

- Recommendation O-104 on Off Station' Signals for Major Floating Aids.

6.7 Tide Gauges and Current Meters

A number of countries operate tide gauges and current meters to assist the prediction of tidal heights and streams or for the broadcast of real-time information to shipping[5]. The latter is generally used to overcome the sometimes considerable differences between actual tide heights and predicted values due to meteorological and mean sea level fluctuations.

These systems are supplemented in areas of risk by tsunami early warning systems.

Authorities that are procuring or upgrading sea level measurement devices, are encouraged to consider using equipment that can support the requirements of the Global Sea Level Observing System (GLOSS) coordinated by the Intergovernmental Oceanographic Commission. Typically this calls for gauges capable of measuring to centimetre (1 cm.) accuracy in all weather (especially wave) conditions and for the free exchange of hourly sea level data with an International Sea Level Centre. Information on the GLOSS Programme can be found at www.gloss-sealevel.org [6]. Technical recommendations on sea level observations can be found at http://www.psmsl.org/.

6.8 Under Keel Clearance Management Systems

The Under Keel Clearance (UKC) of a vessel should always be such that a safe passage is ensured. The IMO Helsinki Committee has quoted a UKC value of 20% -10% of the ship’s draught, based on many years practical experience, which should be applied depending on whether the passage is exposed or sheltered. As shown in Figure 34, the UKC related to the ship at zero speed and the mean water level must allow for the squat at speed, the ship motions due to waves and swell, heel due to wind and turning and remaining uncertainties in water level and bottom level. Note, however, that the figures advised by IMO address the dynamic UKC, which is the UKC remaining when the vertical motions as well as the squat underway are deducted.

The largest allowance usually has to be made for the wave response. As the wave spectrum is transformed into a motion spectrum of the ship, there is not a specific maximum value to the ship’s vertical motions. What allowance has to be reserved for a safe passage then? The key is to define a maximum probability (per unit of time) that the vessel would contact the bottom. This value should be subject to the bottom type (sandy and flat or with rocks), the type of vessel and cargo, the ecological vulnerability of the area and the possibility that the harbour entrance would be blocked as a result of a contact.

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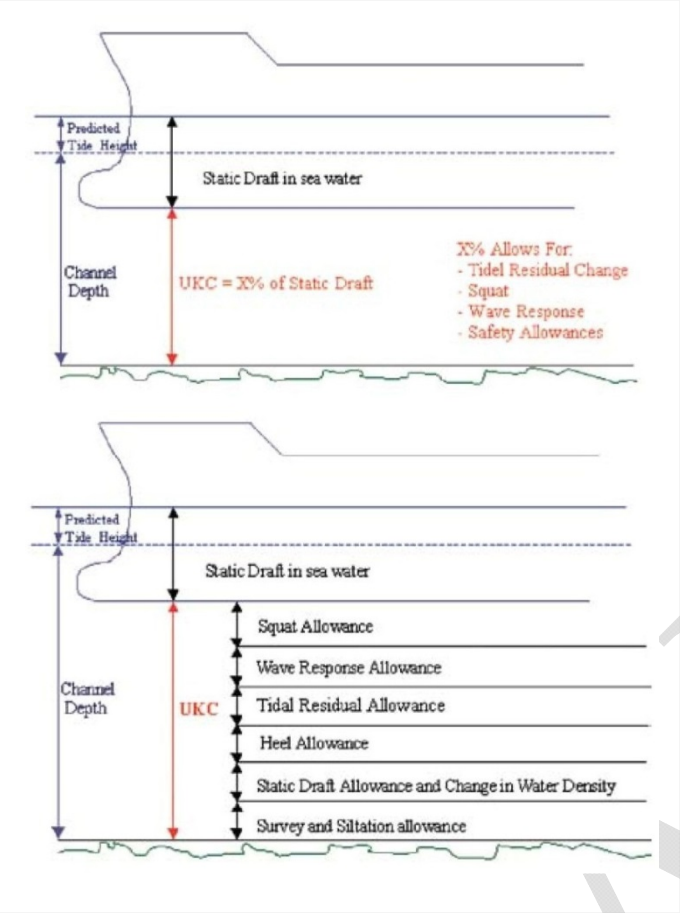

Figure 34 - Vessel Under Keel Clearance (UKC)

For the passage concerned, tidal windows may be calculated on basis of this probability, instead of using a fixed value of UKC. To this end, the expected motion spectrum of the vessel during the passage must be determined. In order to remain maneuverable, a minimum UKC (e.g.1.0 m) has to be maintained at all times disregarding the motions due to waves. Additionally, the motions during the actual passage may be monitored, so that the passage plan might be adapted if conditions differ from the expectations. UKC management may exist as a system to calculate Probabilistic Tidal Windows for a passage or as a real-time monitoring system to be used during a passage. For both, prediction of conditions over the hours ahead is important to make decisions in time.

There is an increasing use of Probabilistic Tidal Window calculation systems in ports. The general rationale for those is that a fixed UKC criterion will under most circumstances be unnecessary large, in order to ensure that all passages under all permitted conditions will be safe. The fixed UKC criterion is then governed by the worst conditions that only occur during a small percentage of the time. Under more favourable conditions the actual UKC may be smaller without compromising safety, which leads to a better accessibility of the port.

Real-time UKC monitoring may be performed for different purposes and in different ways. One purpose is of course to ensure the safety of navigation, providing an early warning if the UKC gets too small. Another important purpose is to evaluate the performance of the prediction systems used, so that these may be improved. The way in which the UKC is monitored depends on the available data sources. To improve a predicted value, the actual value must be deducted from the measured data.

The predicted data comprise:

- Water level;
- Current;
- Wind;
- Wave Height and Direction;

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- Water Density.

Other parameters are known with only limited accuracy or certainty:

- Vessel Characteristics (wave response; draught fore, mid and aft);
- Squat, Trim and Heel;
- Actual Bathymetry.

Metocean models are used for the prediction of wind, water level and current, and wave spectra, often as localised models nested within oceanwide models. Observed data are provided by tide gauges, wave buoys and other devices as available near the passage. The vertical position of the vessel may in some areas be monitored accurately with GPS in RTK mode. This yields the direct measurement of the bottom elevation, but also the squat of the vessel if the actual water level is known or vice versa.

Vessel transits plans or tidal windows are determined using predicted information. The closer to the time of transit, the more accurate the prediction will be as it is corrected using observed values Transits may be executed with the assistance of portable systems that can receive real-time environmental data (tides, waves, current, weather). This enables a pilot to execute a transit having full regard to real-time environmental conditions. If there is time and maneuvering space for it, the pilot may be able to fine-tune a ship's actual UKC by varying speed, which affects squat/ settlement, and rate of turn, which affects angle of heel, to ensure it remains within predefined limits.

Predictive and real time UKC software applications including associated portable pilot software applications require a ground truthing approach for ensuring their operational integrity and Competent Authorities seeking to implement real time UKC management systems may need to provide additional aids to navigation and related infrastructure (e.g.hydrometeo sensors, fully redundant communications links) to support a real time UKC management system.

Competent Authorities considering implementing UKC management systems should undertake a rigorous assessment of the economic benefits that would accrue to the shipping industry through the extension of tidal windows and the increase in maximum draughts that may be accommodated through the use of real time UKC management systems. Using a probabilistic tidal window regime implies that the larger the draught, the larger the probability that the ship may have to wait one or more tides before passage is safe enough.

It is imperative that a robust operational model(s) and governance framework(s) is in place for the introduction of a flexible UKC system. The accuracy of charted depths and predicted tide levels is integral to the management of UKC. Hydrographic surveys have inherent technical limitations due partly to uncertainties in tidal reductions. Therefore, nautical charts cannot always be completely reliable in their representation of depth. Furthermore, in some areas where there are sand waves the shape and hence the depth of the seabed is constantly changing.

Potential components of that framework include:

- Initial validation of the UKC calculation outputs of the system by an independent person or organisation e.g. hydrographers, hydrodynamics experts, using accepted validation techniques such as:
  - Regular calibration of sensors providing hydrometeo data inputs;
  - Accuracy limitations of charted depths and tidal predictions must be factored into any UKC system.

Competent Authorities should ensure an appropriate minimum under keel clearance limit is enforced in conjunction with the operation of the UKC management system.

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Notes

[1] IMO Resolution A.960(23).
[2] Refer to IMO Publication 'Ships; Routeing', IMO, 2015 Edition
[3] These terms are used in the 1972 COLREGs
[4] Also known as Narrow Band Direct Printing (NBDP).
[5] IALA Recommendation V-128 – Operational and Technical Performance Requirements for VTS Equipment Edition 3.0 June 2007.
[6] http://www.gloss-sealevel.org

Navguide: Chapter 7 - Power supplies

7.1 Types

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 35.

Electric Energy Sources	**Non-Electric Energy Sources**
Utility generated electricity	Acetylene
Photovoltaic solar modules	Propane
Diesel and petrol engine driven generators	Butane
Primary battery cells	Kerosene
Wind generators	
Wave activated generators	
Fuel cells using alcohol or hydrogen	

Table 35 - Power Sources for Operating Lighted Aids to Navigation.

There is a general trend away from gas, using utility generated electricity where available and photovoltaic solar power where mains electric power is not available or are unreliable.

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 1067-0 on Selection of Power Systems for Aids to Navigation and Associated Equipment;
- Guideline 1067-1 on the Total Electrical Loads of Aids to Navigation;
- Guideline 1067-2 on Power Sources;
- Guideline 1067-3 on Electrical Energy Storage for Aids to Navigation.

Refer to:

- Applicable national standards for the safe handling of gases.

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7.2 Electric - Renewable Energy Sources

7.2.1 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;
- 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.

Photo Courtesy of the Australian Maritime Safety Authority

Potential difficulties associated with solar power are:

- finding ways to minimise bird fouling;
- ensuring power remains reliable during periods of poor weather;
- solar array footprint can be large at high latitudes;
- protecting solar modules from:
  - wave damage on buoys and exposed lighthouses;
  - vandalism and theft; and,
  - lightning.

Aids to navigation exposed to icing conditions are perhaps the only applications unsuited to the use of solar modules.

Types

The three common technologies employed in the manufacture of silicon based solar modules are listed in Table 36.

Technology	Comments
Monocrystaline 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.
Polycrystaline 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 of silicon directly onto a glass or stainless steel substrate a thin slice cut from a single large crystal of silicon. The cell has a lower efficiency than either of other technologies but can be multi-layered for enhanced performance. Problems have been found with lifetime of these cells.

Table 36 - Silicon Solar Cell Technology

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. For all battery charging applications, a voltage (charge) regulator is considered essential.

Modern developments in electronics have allowed new voltage (charge) regulators to be developed that use maximum power point tracking (MPPT). This ensures that they operate the solar module at a level to obtain the maximum power, for any given level of irradiance. This operating level is independent to the battery charge voltage level. This technology can lead to 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.

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, and 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 trialed, 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.

7.2.2 Wind Energy

Aids to Navigation Applications

Wind generators (or wind turbines) have been used by a number of IALA Members to power their aids to navigation.

The most popular type were 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 susceptibility to storm damage, has limited the wide use of wind generators.

Installations

Wind generator installations at aids to navigation sites pose a number of problems:

- wind generators tend to require a lot of 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.

7.2.3 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 elctricity 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.

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7.3 Rechargeable Batteries

7.3.1 Principal Types

There are two main types of storage battery technologies applied to aids to navigation – lead acid and nickel cadmium. The lead acid type is generally preferred because of its lower cost and higher energy exchange efficiency (95% vs.80%) than the nickel cadmium battery. However, the nickel cadmium battery can operate in lower temperatures and for a greater number of deep discharge cycles.

Recently, new secondary battery technologies have appeared, including nickelmetal-hydride (Ni-MH) batteries, lithium-iron phosphate ($LiFePO_4$) batteries, and lead crystal batteries. These batteries offer lower weight and a greater cycle life for a given capacity but come at a premium cost.

Lead Acid

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. These were originally wet or flooded cells. However in recent years various forms of “sealed” cell batteries have become available and are quite common in aids to navigation applications.

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.

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.

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. This may be a key factor when selecting a suitable battery for an AtoN application.

7.3.2 Primary Battery Cells

Primary battery cells provide electrical energy by a non-reversible chemical process. They were used in large numbers up until the 1980s 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, and occupational health and safety aspects of the frequent replacement of primary cells have worked in favour of converting to renewable energy sources.

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

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primary cells have an open circuit voltage of about 1.2 volts and can supply 1000 to 2000 Ah at a maximum rate of about 1 ampere.

Lithium-Thionyl Chloride Cell

Another type of primary cell in use in buoy applications is the lithium-thionyl chloride cell. This has a higher energy density and a longer shelf life than the zinc-air cell.

Sealed Alkaline Battery

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

7.3.3 Internal Combustion Engine/Generators

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;
- improved efficiency of renewable energy sources.

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;
- the petrol engine generally being regarded as less durable than a diesel.

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.

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7.4 Electrical Loads and Lightning Protection

7.4.1 Electrical Loads

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

Some of the loads that this methodology covers are:

- lights;
- RACONs;
- AIS AtoN;
- audible warning signals;
- visibility detectors;
- monitoring and telemetry systems;
- charge controllers.

Refer to IALA publication:

- Guideline 1067-1 Total Electrical Loads of Aids to Navigation.

7.4.2 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 publication:

- Guideline 1012 on the Protection of Lighthouses and Aids to Navigation Against Damage from Lightning.

7.5 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.

Acetylene

Acetylene (C_2H_2) 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;
- minimizing leaks in pipe work and fittings.

Propane

Propane gas (C_3H_8) 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;
- 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.

Notes

Navguide: Chapter 8 - Provision, design and management

8.1 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 Organisation (IMO). The 1974 Convention (as amended) is divided into twelve chapters and within these are a series of regulations. The contents[1] are outlined in Table 37.

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

Chapter XI-1	Special measures to enhance maritime safety
Chapter XI-2	Special measures to enhance maritime security
Chapter XII	Additional safety measures for bulk carriers
Appendix	Certificates

Table 37 - Contents of SOLAS Convention

SOLAS Chapter V

SOLAS Chapter V, and Regulations 12[2] 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:

1 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.

2 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.

3 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;
- what information services are necessary to adequately inform all concerned - principally mariners.

8.2 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.

8.2.1 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.

8.2.2 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.

8.2.3 Layers of Service

A summary of available aids to navigation systems and obtainable accuracies is provided in Table 4.

The various type of AtoN have advantages and disadvantages for the user as well as for the provider as indicated in Table 38.

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

Table 38 - Comparison of Different Types of Aids to Navigation

Refer to IALA publications:

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- Guideline 1004 on Levels of Service;
- Guideline 1079 on Establishing and Conducting User Consultancy by Aids to Navigation Authorities.

8.3 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 is the probability of an unwanted event occurring, multiplied by the impact or consequence 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 publication:

- Recommendation R1002 Risk Management for Marine Aids to Navigation
- Guideline G1018 Risk Management

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

- service providers (aids to navigation authority, lightkeepers, etc.);
- service users (mariners);
- external groups (politicians, local community, conservation groups, etc.).

8.3.1 IALA Risk Management Tools

IALA continously develops its Risk Management Toolbox which includes tols 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:

- PAWSA Mk II (Port And Waterway Safety Assessment) which is a Qualitative Risk Assessment approach;
- IWRAP Mk II (IALA Waterway Risk Assessment Programme) which is a Quantitative Risk Assessment approach;
- 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 conjuntion 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 publication:

- Guideline G1123 The Use of IALA Waterway Risk Assessment Pprogramme (IWRAP Mk II)
- Guideline G1124 The Use of Ports and Waterways Safety Assessmen (PAWSA Mk II) Tool
- Guideline G1138 The Use of the Simplified IALA Risk Assessment Method (SIRA)

8.3.2 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:

a) Identify hazards;
b) Assess risks;
c) Specify risk control options;
d) Make a decision;
e) Take action.

The diagram in Figure 35 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.

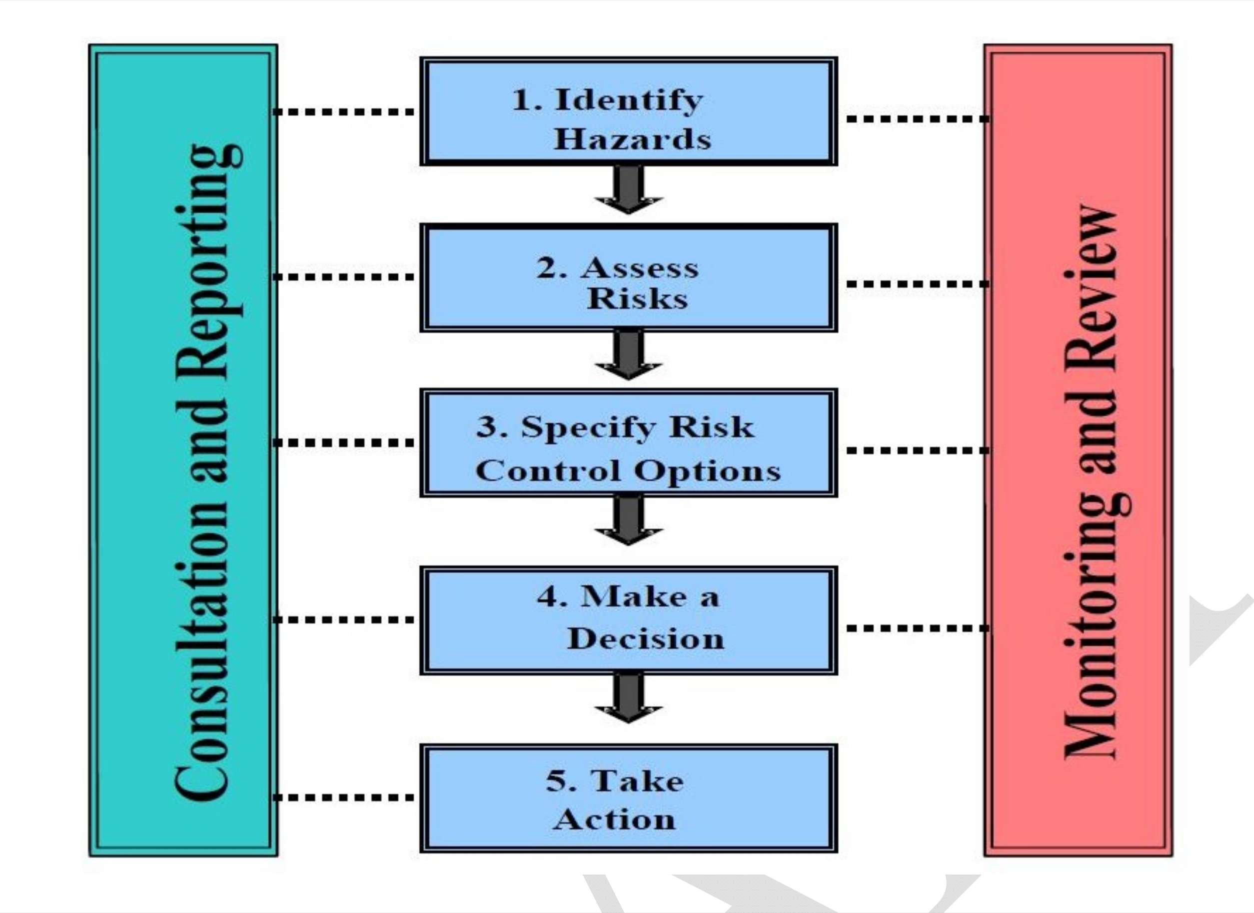

Figure 35 - Risk Assessment and Risk Management Process

The central part of the Figure 35 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 feed back 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.

8.3.3 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 (4)	Very frequent (5)
CONSEQUENCE (IMPACT)	Catastrophic (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 36 - Risk Value Matrix

The SIRA method provides suitable scoring scales for probability (frequency of occurrance) 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 adressed at some stage, the essens being that all risk values should be As Low As Reasonably Practicable (ALARP) considering the cost and effectiveness of the identified risk control options.

8.4 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 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;
- logistics.

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To obtain a true representation of Availability, it is necessary to measure the long-term performance of an aid to navigation. To achieve this it is recommended that the calculations should use a time interval greater than 2 years.

8.4.1 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:

$$Availability = \frac{(MTBF)}{(MTBF + MTTR)} \quad or \quad \frac{Up\ time}{Total\ Time} \quad or \quad \frac{(Total\ time - Down\ Time)}{Total\ Time}$$

MTBF = Mean Time Between Failures

MTTR = Mean Time To Repair

8.4.2 Definition and Comments on Terms

Reliability

This is the probability that an aid to navigation or any nominated system or component, when it is available, performs a specified function without failure under given conditions for a specified time.

Availability

This is the probability that an aid to navigation or system is performing its specified function at any randomly chosen time. 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

This is the probability that an aid to navigation or system will perform its specified function without interruption during a specified time given that it was operational at the beginning of the period.

For example, if a DGNSS station is functioning correctly when a vessel is about to make its approach into a port, the continuity factor is the probability that the DGNSS 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

This is the existence of more than one means, identical or otherwise for accomplishing a task or mission.

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, stares that this time to alarm should be within 10 seconds.

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 DGNSS 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 (ie. =24*365*2/4).

Mean Time to Repair (MTTR)

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This is a measure of an 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, an 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 O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation;
- Guideline 1035 on Availability and Reliability of Aids to Navigation.

8.4.3 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 39. 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.

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

Table 39 - Availability Objectives by Category

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%.

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8.4.4 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 R-121.

Refer to IALA publications:

- Recommendation R-121 on the Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz

Recommendation R-121 retains the original definition of availability, but adds a statement about "nonavailability".

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

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

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

IMO uses a more elaborate definition of Continuity than that given in Section 8.4.2. 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 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:

$$P = exp\ (-t/MTBF)$$

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:

$$C = exp\ (-CTI/MTBF)$$

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

$$C = 1 - (CTI/MTBF)$$

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%.

8.4.5 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 37.

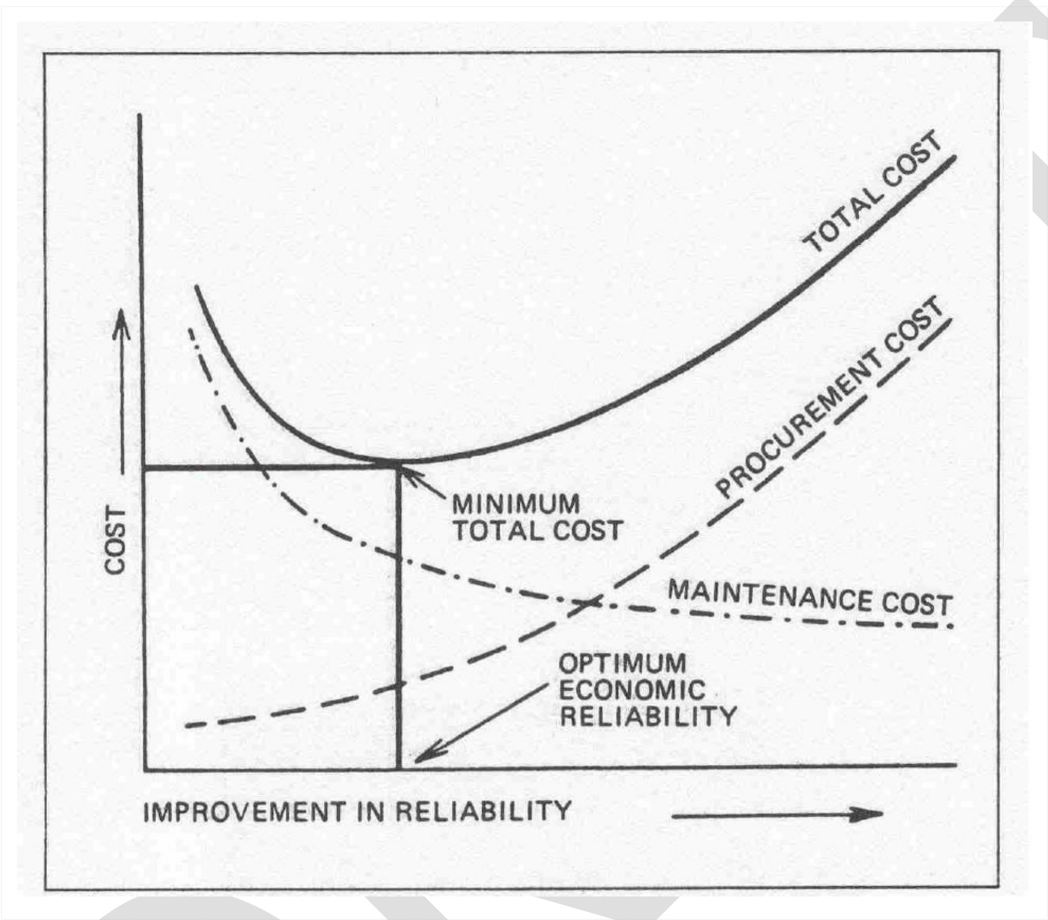

Figure 37 - The Cost of Reliability

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;
- a conservative design approach has its merits.

If the aid 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% (ie. 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 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, it may be of benefit to investigate the reasons for the difference.

If a group of aids 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.

8.5 Reviews and Planning

8.5.1 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.

8.5.2 Strategic Plans

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

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;
- 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.

8.5.3 Operational Plans

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[3]; -- 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 (see section 8.3), or; a level of service process, (see section 3.2), or;

the authority's quality management procedures (see section 8.7) 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.

8.5.4 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.

AtoNs 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 AtoNs 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 O-138 on the use of Geographic Information Systems (GIS) and Simulation by Aids to Navigation Authorities;
- Guideline 1057 on the use of Geographic Information Systems (GIS) by Aids to Navigation Authorities;
- Guideline 1058 on the use of Simulation as a Tool for Waterway Design and AtoN Planning.

8.7 Quality Management

Quality Management Systems have been developed and introduced by numerous businesses, but increasingly are being based on the ISO9000 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:

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- Recommendation O-132 on Quality Management for Aids to Navigation Authorities;
- Guideline 1034 on product certification procedures;
- Guideline 1052 on Quality Management in Aids to Navigation Service Delivery,
- Guideline 1054 on Preparing for a Voluntary IMO Audit on Aids to Navigation Service Delivery

8.7.1 Performance Measurement

Performance measurement is the process of collecting, analyzing and/or reporting information regarding the performance of an individual, group, organization, system or component. It is very important to establish an 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;
- compare the performance of: -- similar systems or equipment in different locations; -- contract and internally provided services[4];
- amend: -- system designs; -- procurement decisions; -- equipment choices; -- maintenance procedures and practices;
- increase or reduce maintenance effort;
- adjust maintenance intervals.

Refer to IALA publications:

- Guideline 1037 on Data Collection for Aids to Navigation Performance Calculation;
- Guideline 1035 to Availability and Reliability of Aids to Navigation Theorie and Examples;

8.7.2 International Standards

ISO 9000 Series

The 1994 quality standard series of ISO 9001, 9002 and 9003 have been jointly revised and amalgamated into ISO 9001-2000.

The new series of standards designated as ISO 9000 comprises:

- 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

ISO 9001 specifies requirements for a quality management system that can be used for internal application by organizations, or for certification, or for contractual purposes. It focuses on the effectiveness of the quality management system in meeting customer requirements. See Figure 38.

ISO 9004 - 2009

ISO 9004 gives guidance on a wider range of objectives of a quality management system than does ISO 9001, particularly for the continual improvement of an organization’s overall performance and efficiency, as well as its effectiveness. ISO 9004 is recommended as a guide for organizations whose top management wishes to move beyond the requirements of ISO 9001, in pursuit of continual improvement of performance. However, it is not intended for certification or for contractual purposes.

ISO 14000 Series

This is a collection of voluntary consensus standards that have been developed to assist organizations to achieve environmental and economic gains through the implementation of effective environmental management systems.

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There are three standards that deal with Environmental Management Systems (EMS). These are ISO 14001, 14002 and 14004. ISO 14001 is the only standard intended for third party accreditation. The other standards are for guidance.

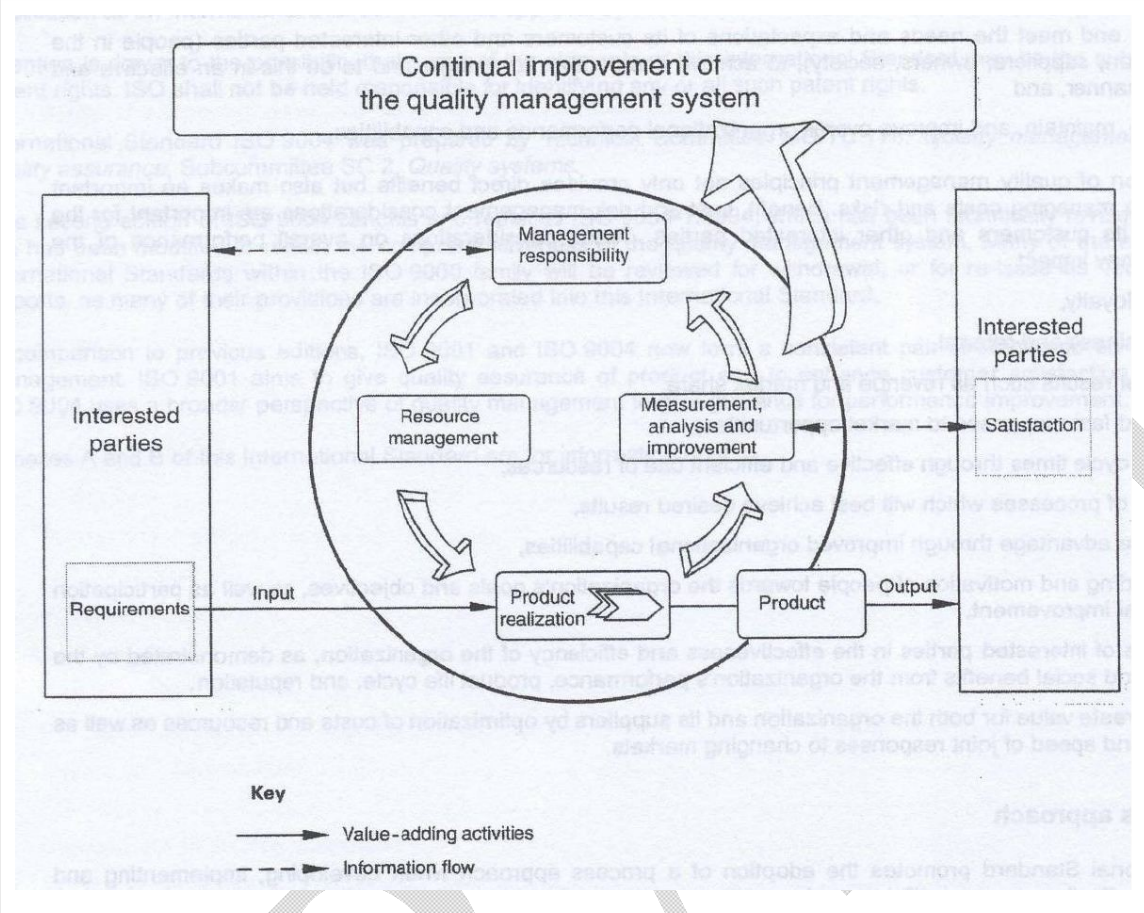

Figure 38 - ISO 9001 Diagram on the Emphasis on Satisfying Customer Requirements

ISO 14001

ISO 14001 specifies the requirements for an environmental management system, to enable 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 organization 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 organization;
- manage and measure a program of continual improvement.

ISO 14001 does not itself state specific environmental performance criteria.

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8.8 Maintenance

8.8.1 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.

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.

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.

8.8.2 Improving Efficiency

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

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.

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);

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- give more flexibility in the choice of basic qualification when recruiting maintenance staff;
- provide more opportunity to understand the inherent deficiencies in particular pieces of equipment and for remedial actions to be implemented.

Power

The conversion of aids to navigation that operate on oil, gas or primary battery to solar power or self-powered LED lanterns, may provide greater flexibility in scheduling maintenance visits because of the renewable energy source and opportunities for extending maintenance intervals.

Fixed vs Floating

Depending on location, it may be possible to replace floating aids with fixed structures in waterways of moderate depth; particularly if it also allows a dedicated buoy tender to be replaced by some other means of transport such as smaller vessel or launch.

A whole-of-life cost benefit analysis should be carried out to assist in any such decisions.

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.

Remote Monitoring

Remote monitoring (and control) 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.

8.8.3 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 and destaffing of major 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;
- 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.

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8.8.4 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 typical maintenance intervals other than what is stated in conference and workshop papers. Some examples include:

- major facilities are being inspected on a monthly basis;
- automated lights are being inspected less frequently (quarterly, annually or bi-annually).

Advances in self-contained beacons, lamps, self-powered LED lanterns, 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 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:

- Guideline 1007 on Lighthouse Maintenance;
- Guideline 1077 on Maintenance of Aids to Navigation;
- Guideline 1076 on Building Conditioning of Lighthouses.

8.9 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;
- local private organisations.

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Photo Courtesy of CETMEF

8.9.1 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 as listed in Section 8.1.

8.9.2 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.

Refer to IALA publication:

- Guideline 1005 on Contracting Out Aids to Navigation Services.

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8.10 Environment

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.

Refer to IALA publication:

- Guideline 1036 on Environmental Management.

8.10.1 Hazardous Materials

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[5]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.

Physical Properties

Mercury is a heavy metal that has the unusual property of remaining liquid at normal temperatures (above − 38 degrees celcius).

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.

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 work-space 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 work-space. 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 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.

Consignment

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.

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;
- clean-up and waste disposal.

Lead

Lead 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.

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).

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8.11 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. Objectives are to:

- promote a greater commitment by members to preserve the historic aspects of their service;
- encourage member countries to see the preservation of their own lighthouses in an international context;
- share information on the subject between both members and non-members, with particular attention being given to the complementary use of lighthouses;
- research and document strategies on the conservation of historic lighthouses, particularly in relation to changes in technology and working practices;
- foster member interaction with related industries in an effort to bring forward common projects in the interest of protecting historic lighthouses.

Examples of work accomplished to date:

- the creation of the format for an IALA database for recording details of historic lighthouses;
- a book, titled "Lighthouses of the World" was published in 1998 with English, French, German and Spanish versions, featuring over 180 historic lighthouses from around the world;
- a Workshop in Kristiansand, Norway on "The Alternative Use of Historic Lighthouses in 2000;
- a Seminar on the "Practical Aspects of Lighthouse Preservation" in 2005 in Gothenburg, Sweden;
- the IALA Conservation Manual was published in 2006 to provide guidance to members on many aspects of Historic Lighthouses Conservation;
- a Seminar on the "Heritage Issues of Introducing New Technologies in Aids to Navigation" in Santander, Spain in 2009. Some key conclusions and recommendations of the seminar were:
    - Change is inevitable. Ideally, changes made during the development of a historical aid to navigation site should be reversible and in all cases properly documented;
    - The preservation and documentation of aids to navigation should focus on whole sites and include historical developments and achievements in technical equipment and related human experiences. Documentation should include the experiences and recollections of those involved in operating aids to navigation, as well as those involved in their conservation.
    - Radionavigation aids were an important part of aids to navigation technology in the 20th century and there is a need to document and disseminate this aspect of aids to navigation heritage.
- a Seminar on the "Preservation of Lighthouse Heritage" in Athens, Greece in 2013 gathered high level professionals from different areas related to the Cultural Heritage.

One of the eighteen recommendations from the 17th IALA Conference held in Capetown, South Africa in March 2010, stated that "IALA should continue to provide guidance on the preservation and maintenance of historic equipment and artefacts"confirms that the work of IALA on guidelines and the exchange of information relating to the Conservation of Historic Lighthouses is still considered important by its members.

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Restoring a Heritage Lighthouse - Photo courtesy of Instituto Hidrografico (Portugal)
Lighthouse Interpretative Display - Photo Courtesy of IALA

Refer to IALA publications:

- Lighthouse Conservation Manual;
- Guideline 1049 on the Use of Modern Light Sources in Traditional Lighthouse Optics;
- Guideline 1063 on Agreements for Complementary Use of Lighthouse Property;
- Guideline 1074 on Branding and Marketing of Historic Lighthouses;
- Guideline 1075 on a Business Plan for Complementary Use of a Historic Lighthouse;
- Guideline 1076 on Building Conditioning of Lighthouses;
- Guideline 1080 on the Selection and Display of Heritage Artefacts;
- Report from the IALA Seminar on Heritage Issues of Introducing New Technologies in Aids to Navigation Santander, Spain in June 2009;
- Report from the IALA Seminar on the Preservation of Lighthouse Heritage, Athens, Greece in June 2013.

8.11.1 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 40.

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		

Table 40 - Terminology for Historical Glass Lens Systems and Associated Quantities of Mercury

8.11.2 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);
- 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:

- 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;
- 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;
- if no main power is available, it is reasonable to require that the third party provide its own power supply;
- where practical, the installation of the third party equipment should take into consideration and preserve the heritage value of the aid to navigation.

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

8.12 Human Resources Challenges

One of the aims of IALA is to foster the safe and efficient movement of vessels through the harmonization of 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'.*

Recommendations and Guidelines produced by IALA clearly identify the role that IALA has to play in ensuring harmonized delivery of AtoN services.

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 this aim in several ways, one of which is to recommend that Aids to Navigation and VTS Authorities ensure their staff receive a high standard of training. To assist with this approach, IALA Recommendation V-103 and E-141, together with associated model courses and supporting Guidelines, were developed. This approach provides a means to ensure VTS Personnel are trained to an agreed, minimum, level.

In addition, both the ARM and ENG Committees are currently developing the training requirements for AtoN Management and Engineering Personnel through the World Wide Academy (WWA).

8.12.1 Source of Skills

Competent Authorities should ensure that all employees have the knowledge, skills and training to perform their duties effectively, and with safety. 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. (See Section 8.7.1).

Refer to IALA publication:

- Recommendation R0141 - Recommendation on Standards for Training and Certification of AtoN Personnel.

Notes

[1] Reference SOLAS Consolidated edition 2014.
[2] For VTS issues, please refer to Chapter 5 of the NAVGUIDE and the IALA VTS Manual.
[3] For example with national, state, territory, and local governmental bodies and international organisations.
[4] Only where the opportunity arises and where both are engaged in substantially similar work.
[5] The quantity of mercury used in higher order optics is shown in section 8.11.1.

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Navguide: Annex A - Glossary of Acronyms

AIS	Automatic Identification System
AISM	Association Internationale de Signalisation Maritime (Title of IALA in French)
AtoN	Aid(s) to Navigation
COLREGS	International Regulations for Preventing Collisions at Sea
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
ENC	Electronic Navigation Chart
EEZ	Exclusive Economic Zone (Defined in UNCLOS)
GALILEO	Global Navigation Satellite System (EU)
GLONASS	Global Navigation Satellite System (Russia)
GLOSS	Global Sea Level Observing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (USA)
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IHO	International Hydrographic Organisation
IMO	International Maritime Organization
IMPA	International Maritime Pilots' Association
IMSO	International Mobile Satellite Organisation
INMARSAT	International Maritime Satellite Organisation
ISO	International Standards Organisation
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union – Radiocommunications Bureau
LRIT	Long Range Identification and Tracking
MRCP	IALA Maritime Radio Communications Plan
MTBF	Mean time between failures (in hours)
MTTR	Mean time to repair (in hours)
PIANC	The World Association for Waterborne Transport Infrastructure
PSSA	Particularly Sensitive Sea Area
RACON	Radar transponder beacon
RCDS	Raster chart display system
RNC	Raster navigation chart
SAR	Search and Rescue
SBAS	Satellite Based Augmentation System
SOLAS	IMO Convention on the Safety of Life at Sea 1974
SRS	Ship Reporting System

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UNCLOS	United Nations Convention on the Law of the Sea
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
VTSO	Vessel Traffic Service Officer
WWA	World Wide Academy

Navguide: Annex B - List of tables

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Navguide: Annex D - Maritime Buoyage System and other Aids to Navigation

Historical Background

Prior to 1976

There was once more than thirty different buoyage systems in use world-wide, many of these systems having rules in complete conflict with one another.

There has long been disagreement over the way in which buoy lights should be used since they first appeared towards the end of the 19th century. In particular, some countries favoured using red lights to mark the port hand side of channels and others favoured them for marking the starboard hand.

Another major difference of opinion revolved around the principles to be applied when laying out marks to assist the mariner. Most countries adopted the principle of the Lateral system whereby marks indicate the port and starboard sides of the route to be followed according to some agreed direction. However, several countries also favoured using the principle of Cardinal marks whereby dangers are marked by one or more buoys or beacons laid out in the quadrants of the compass to indicate where the danger lies in relation to the mark, this system being particularly useful in the open sea where the Lateral buoyage direction may not be apparent.

The nearest approach to international agreement on a unified system of buoyage was reached at Geneva in 1936. This Agreement, drawn up under the auspices of the League of Nations, was never ratified due to the outbreak of World War II. The Agreement proposed the use of either Cardinal marks or Lateral marks but separated them into two different systems. It provided for the use of the colour red on port hand marks and largely reserved the colour green for wreck marking.

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At the end of World War II many countries found their aids to navigation destroyed and the process of restoration had to be undertaken urgently. In the absence of anything better, the Geneva rules were adopted with or without variation to suit local conditions and the equipment available. This led to wide and sometimes conflicting differences particularly in the crowded waters of North Western Europe.

In 1957 the, then, International Association of Lighthouse Authorities (IALA) was formed in order to support the goals of the technical lighthouse conferences which had been convening since 1929.

Attempts to bring complete unity had little success. Fresh impetus was given to the task of the IALA Technical Committee, by a series of disastrous wrecks in the Dover Strait area in 1971. These wrecks, situated in one lane of a traffic separation scheme, defied all attempts to mark them in a way that could be readily understood by mariners.

There were three basic issues to address:

1. the need to retain existing equipment as far as possible to avoid undue expense
2. the need to define how the colours green and red were to be used when marking channels
3. the need to combine Lateral and Cardinal rules.

To meet the conflicting requirements, it was thought necessary as a first step to formulate two systems, one using the colour red to mark the port hand side of the channels and the other using the colour red to mark the starboard hand side of channels. These were called System A and System B, respectively.

The rules for System A, which included both cardinal and lateral marks, were completed in 1976 and agreed by the International Maritime Organization (IMO). The System was introduced in 1977 and its use has gradually spread throughout Europe, Australia, New Zealand, Africa, the Gulf and some Asian Countries.

From 1980

The rules for System B were completed in early 1980. These were considered to be suitable for application in North, Central and South America, Japan, Republic of Korea and Philippines.

The rules for the two Systems were so similar that the IALA Executive Committee was able to combine the two sets of rules into one, known as "The IALA Maritime Buoyage System". This single set of rules allows Lighthouse Authorities the choice of using red to port or red to starboard, on a regional basis; the two regions being known as Region A and Region B.

At a Conference convened by IALA in November 1980 with the assistance of IMO and the International Hydrographic Organization (IHO), Lighthouse Authorities from 50 countries and the representatives of nine International Organisations concerned with aids to navigation met and agreed to adopt the rules of the new combined System. The boundaries of the buoyage regions were also decided and illustrated on a map annexed to the rules. The Conference underlined the need for cooperation between neighbouring countries and with Hydrographic Services in the introduction of the new System.

From 2010

Although the maritime buoyage system (MBS) has served the maritime community well since its inception in the 1970s, after the 2006 IALA Conference in Shanghai, China, it was decided to review the system in light of changes in the navigation environment and the further development of electronic aids to navigation.

Worldwide consultation revealed that the fundamental principles of the MBS should be retained. However, due to changes in navigation practices and patterns, as well as innovations and technological developments, some enhancements to the MBS were needed.

Ideally, a unified marking arrangement would, in principle, be desirable for Regions A and B. All IALA Members view this change as impractical, detrimental to safety, and probably unachievable. However, with the aim of improving navigational safety, advances towards a global unified system can be achieved through adoption of common characteristics, such as consistent lighting rhythms, on port and starboard hand marks regardless of region.

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The most significant changes in the 2010 revision are the inclusion of aids to navigation used for marking recommended by IALA that are additional to the floating buoyage system previously included. This is aimed at providing a more complete description of aids to navigation that may be used. It includes the Emergency Wreck Marking Buoy, descriptions of other aids to navigation specifically excluded from the original MBS, and the integration of electronic marks via radio transmission. With regards to aids to navigation, the changes provided by this revision will allow the emerging e-Navigation concept to be based upon the marks provided by this booklet.

Thus, the IALA Maritime Buoyage System will continue to help all Mariners, navigating anywhere in the world, to fix their position and avoid dangers without fear of ambiguity, now and for the years to come.

Continuity and harmonization of Aids to Navigation Marking is to be encouraged by all competent maritime authorities.

General principles of the System

The responsibility for safe navigation resides with the mariner, through the appropriate use of aids to navigation in conjunction with official nautical documents and prudent seamanship, including voyage planning as defined in IMO Resolutions. This booklet provides guidance on the Maritime Buoyage System and other aids to navigation for all users.

The IALA Aids to Navigation system has two components: The Maritime Buoyage System and other aids to navigation comprised of fixed and floating devices. This is primarily a physical system, however all of the marks may be complemented by electronic means.

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

These marks are described below:

Lateral Marks

Following the sense of a ‘conventional direction of buoyage’, lateral marks in Region A utilize red and green colours (refer to section 2.4) by day and night to denote the port and starboard sides of channels respectively. However, in Region B (refer to section 2.5) these colours are reversed with red to starboard and green to port.

A modified lateral mark may be used at the point where a channel divides to distinguish the pre- ferred channel, that is to say the primary route or channel that is so designated by the competent authority.

Cardinal Marks

Cardinal marks indicate that the deepest water in the area lies to the named side of the mark. This convention is necessary even though for example, a North mark may have navigable water not only to the North but also East and West of it. The mariner will know it is safe to the North, but shall consult the chart for further guidance.

Cardinal marks do not have a distinctive shape but are normally pillar or spar. They are always painted in yellow and black horizontal bands and their distinctive double cone top-marks are always black.

An aide-memoire to their colouring is provided by regarding the top-marks as pointers to the positions of the black band(s):

- **North:**

  Top-marks pointing upward:

  black band above yellow band;

- **South:**

  Top-marks pointing downward:

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black band below yellow band;

- **East:**

    Top-marks pointing away from each other:

    black bands above and below a yellow band;

- **West:**

    Top-marks pointing towards each other:

    black band with yellow bands above and below.

Cardinal marks also have a special system of flashing white lights. The rhythms are basically all "**very quick**" (VQ) or "**quick**" (Q) flashing but broken into varying lengths of the flashing phase. "**Very quick flashing**" is defined as a light flashing at a rate of either 120 or 100 flashes per minute, "**quick flashing**" is a light flashing at either 60 or 50 flashes per minute.

The characters used for Cardinal marks will be seen to be as follows:

- **North:**

    Continuous very quick flashing or quick flashing;

- **East:**

    Three "**very quick**" or "**quick**" flashes followed by darkness;

- **South:**

    Six "**very quick**" or "**quick**" flashes followed immediately by a long flash, then darkness;

- **West:**

    Nine "**very quick**" or "**quick**" flashes followed by darkness.

The concept of three, six, nine is easily remembered when one associates it with a clock face. The long flash, defined as a light appearance of not less than 2 seconds, is merely a device to ensure that three or nine "**very quick**" or "**quick**" flashes cannot be mistaken for six.

It will be observed that two other marks use white lights; Isolated Danger marks and Safe Water marks. Each has a distinctive light rhythm that cannot be confused with the very quick or quick flashing light of the Cardinal marks.

Isolated Danger Marks

The Isolated Danger mark is placed on, or near to a danger that has navigable water all around it. Because the extent of the danger and the safe passing distance cannot be specified for all circumstances in which this mark may be used, the mariner shall consult the chart and nautical publications for guidance. Distinctive double black spherical top-marks and Group flashing (2) white lights, serve to distinguish Isolated Danger marks from Cardinal marks.

Safe Water Marks

The Safe Water mark has navigable water all around it, but does not mark a danger. Safe Water marks can be used, for example, as fairway, mid-channel or landfall marks.

Safe Water marks have an appearance different from danger marking buoys. They are spherical, or alternatively pillar or spar with red and white vertical stripes and a single red spherical top-mark. Their lights, if any, are white using isophase, occulting, one long flash or Morse "A" (● -) rhythms.

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Special Marks

Special marks are used to indicate a special area or feature whose nature may be apparent from reference to a chart or other nautical publication. They are not generally intended to mark channels or obstructions where the MBS provides suitable alternatives.

Special marks are yellow. They may carry a yellow "X" top-mark, and any light used is also yellow. To avoid the possibility of confusion between yellow and white in poor visibility, the yellow lights of Special marks do not have any of the rhythms used for white lights.

Their shape will not conflict with that of navigational marks. This means, for example, that a special buoy located on the port hand side of a channel may be cylindrical but will not be conical. Special marks may be lettered or numbered, and may also include the use of a pictogram to indicate their purpose using the IHO symbology where appropriate.

Marking New Dangers

"**New Dangers**" are newly discovered hazards, natural or man-made, that may not yet be shown in nautical documents and publications, and until the information is sufficiently promulgated, should be indicated by:

- marking a new danger using appropriate marks such as; Lateral, Cardinal, Isolated Danger marks, or equally
- using the Emergency Wreck Marking Buoy (EWMB)

If the competent authority considers the risk to navigation to be especially high at least one of the marks should be duplicated.

The Emergency Wreck Marking Buoy has blue and yellow vertical stripes in equal number, with a vertical/perpendicular yellow cross top-mark, and displays a blue and yellow alternating light.

Marking of a new danger may include use of a Racon coded Morse "**D**" (- ●●) or other radio transmitting device such as automatic identification systems as an Aid to Navigation (AIS as an AtoN).

Marking of a new danger may be discontinued when the appropriate competent Authority is satisfied that information concerning the "**New Danger**" has been suf- ficiently promulgated or the danger has been resolved

Other Marks

Other Marks include lighthouses, beacons, sector lights, leading lines, major floating aids, and auxiliary marks. These visual marks are intended to aid navigation as information to mariners, not necessarily regarding channel limits or obstructions.

- Lighthouses, beacons and other aids of lesser ranges are fixed aids to navigation that may display different colours and/or rhythms over designated arcs. Beacons may also be unlighted.
- Sector lights display different colours and/or rhythms over designated arcs.

The colour of the light provides directional information to the mariner.

- Leading lines / Ranges allow ships to be guided with precision along a portion of a straight route using the alignment of fixed lights (leading lights) or marks (leading marks), in some cases a single directional light may used.
- Major floating aids include lightvessels, light floats and large navigational buoys intended to mark approaches from off shore.
- Auxiliary Marks are those other marks used to assist navigation or provide information. These include aids of non-lateral significance that are usually of defined channels and otherwise do not indicate the port and starboard sides of the route to be followed as well as those used to convey information for navigational safety.
- Port or Harbour Marks such as breakwater, quay/jetty lights, traffic signals, bridge marking and inland waterways aids to navigation (further described in section 8.7).

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SOLAS CHAPTER V,
Regulation 13 - Consolidated edition 2009

Establishment and operation of aids to navigation

1. 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.

2.  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 such
aids.

3.  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.

* Refer to the appropriate Recommendations and guidelines of IALA and
to SN/Circ.107, Maritime Buoyage System.
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1. General

1.1 Scope

The Maritime Buoyage System and other aids to navigation provide rules that apply to all fixed, floating and electronic marks serving to indicate:

- **1.1.1** The lateral limits of navigable channels.
- **1.1.2** Natural dangers and other obstructions such as wrecks.
- **1.1.3** Landfall, course to steer, and other areas or features of importance to the mariner.
- **1.1.4** New dangers.

1.2 Types of marks

A Mark is defined as a signal available to the Mariner to convey guidance in safe navigation. The Maritime Buoyage System and other aids to navigation provide the following types of marks that may be used in combination:

- **1.2.1** Lateral marks, used in conjunction with a "**conventional direction of buoyage**", generally employed for well defined channels. These marks indicate the port and starboard sides of the route to be followed. Where a channel divides, a modified lateral mark may be used to indicate the preferred route. Lateral marks differ between Buoyage Regions A and B as described in MBS Sections 2 and 8.
- **1.2.2** Cardinal marks, used in conjunction with the mariner's compass, to indicate where the mariner may find navigable water.
- **1.2.3** Isolated Danger marks to indicate isolated dangers of limited size that have navigable water all around them.
- **1.2.4** Safe Water marks to indicate that there is navigable water all around their position, e.g. mid-channel marks.

- **1.2.5** Special marks to indicate an area or feature referred to in nautical documents, not generally intended to mark channels or obstructions.
- **1.2.6** Other marks used to provide information to assist navigation.

1.3 Method of characterising marks The significance of the mark depends upon one or more of the following features:

- **1.3.1** By night, colour and rhythm of light and/or illumination enhancement.
- **1.3.2** By day, colour, shape, top-mark, and/or light (including colour and rhythm).
- **1.3.3** By electronic (digital) symbology, e.g. as a complement to physical marks.
- **1.3.4** By electronic (digital) symbology solely.

2. Lateral Marks

2.1 Definition of 'conventional direction of buoyage'

The 'conventional direction of buoyage', which must be indicated in appropriate nautical charts and documents, may be either:

- **2.1.1** The general direction taken by the mariner when approaching a harbour, river, estuary or other waterway from seaward, or
- **2.1.2** The direction determined by the proper authority in consultation, where appropriate, with neighbouring countries. In principle, it should follow a clockwise direction around land masses.

2.2 Buoyage Regions

- **2.2.1** There are two international Buoyage Regions A and B, where lateral marks differ. The current geographical divisions of these two Regions are shown on the world map, below.

2.3 General Rules for Lateral Marks

- **2.3.1 Colour**

The colour of lateral marks must comply with the IALA MBS Regions as specified in Sections 2.4 and 2.5.

- **2.3.2 Shapes**

Lateral marks should be of cylindrical and conical shape. However, where they do not rely on a distinctive shape for identification, they should, where practicable, carry the appropriate topmark.

- **2.3.3 Numbering or lettering**

If marks at the sides of a channel are numbered or lettered, the numbering or lettering shall follow the 'conventional direction of buoyage' i.e. numbered from seaward. The protocol for numbering lateral marks, especially in confined waterways, should be 'even numbers on red ~ odd numbers on green'.

- **2.3.4 Synchronisation**

If appropriate, synchronised lights (all flash at the same time) or sequential lights (flash one after another) or a combination of both may be utilized.

2.4 Description of Lateral Marks used in Region A

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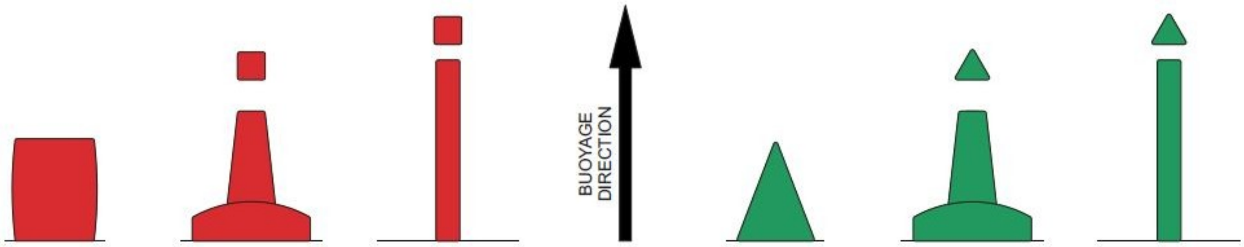
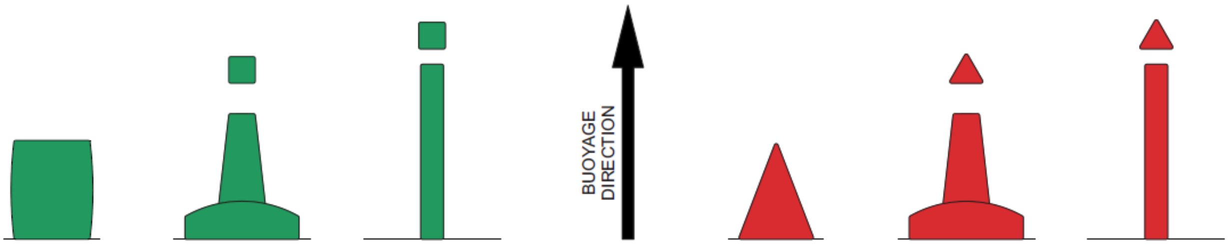


	2.4.1 Port hand Marks	2.4.2 Starboard hand Marks
Colour	Red	Green
Shape of buoy	Cylindrical (can), pillar or spar	Conical, pillar or spar
Topmark (if any)	Single red cylinder (can)	Single green cone, point upward
Light (when fitted)		
Colour	Red	Green
Rhythm	Any, other than that described in section 2.4.3.	Any, other than that described in section 2.4.3.

- **2.4.3** At the point where a channel divides, when proceeding in the "conventional direction of buoyage," a preferred channel may be indicated by a modified Port or Starboard lateral mark as follows:

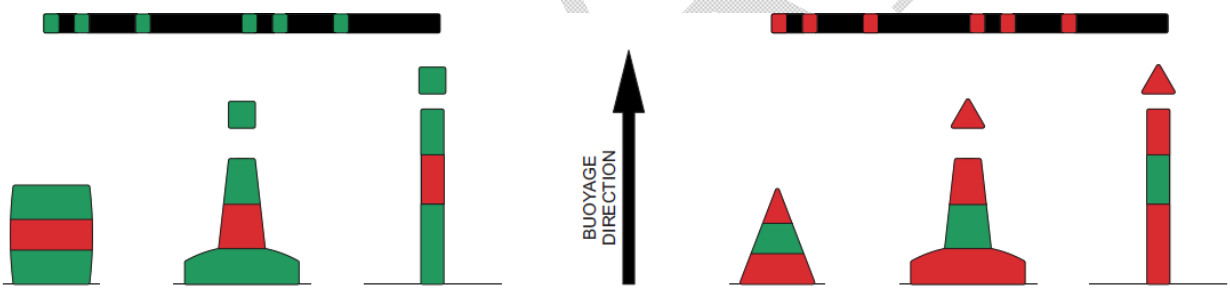
	2.4.3.1 Preferred channel to Starboard	2.4.3.2 Preferred channel to Port
Colour	Red with one broad green horizontal band	Green with one broad red horizontal band
Shape of buoy	Cylindrical (can), pillar or spar	Conical, pillar or spar
Topmark (if any)	Single red cylinder (can)	Single green cone, point upward
Light (when fitted)		
Colour	Red	Green
Rhythm	Composite group flashing (2 + 1)	Composite group flashing (2 + 1)

2.5 Description of Lateral Marks used in Region B



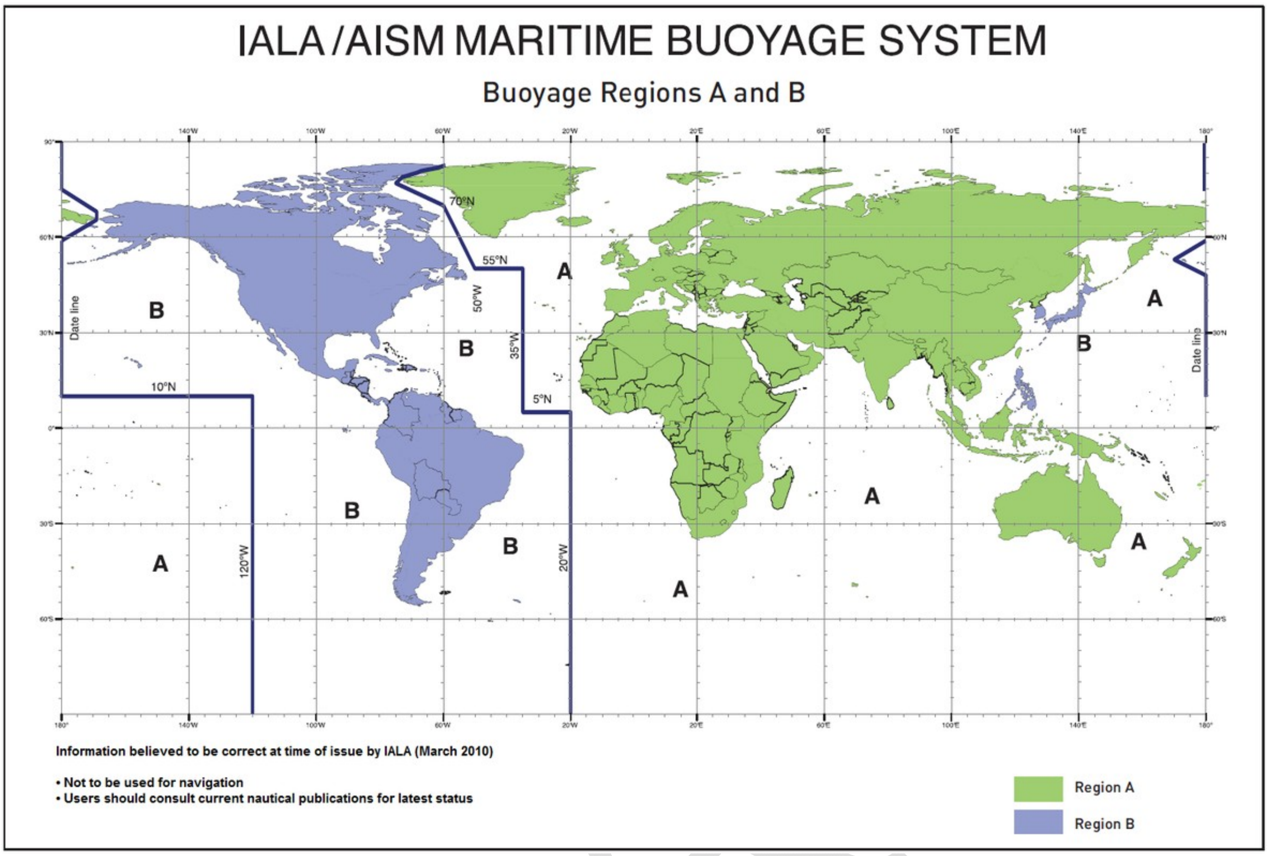
	2.5.1 Port hand Marks	2.5.2 Starboard hand Marks
Colour	Green	Red
Shape of buoy	Cylindrical (can), pillar or spar	Conical, pillar or spar
Topmark (if any)	Single green cylinder (can)	Single red cone, point upward
Light (when fitted)		
Colour	Green	Red
Rhythm	Any, other than that described in section 2.5.3.	Any, other than that described In section 2.5.3.

- **2.5.3** At the point where a channel divides, when proceeding in the "conventional direction of buoyage," a preferred channel may be indicated by a modified Port or Starboard lateral mark as follows:



	2.5.3.1 Preferred channel to Starboard	2.5.3.2 Preferred channel to Port
Colour	Green with one broad red horizontal band	Red with one broad green horizontal band
Shape of buoy	Cylindrical (can), pillar or spar	Conical, pillar or spar
Topmark (if any)	Single green cylinder (can)	Single red cone, point upward
Light (when fitted)		
Colour	Green	Red
Rhythm	Composite group flashing (2 + 1)	Composite group flashing (2 + 1)

IALA /AISM Maritime Buoyage System Regions



3. Cardinal Marks

3.1 Definition of Cardinal quadrants and marks

The four quadrants (North, East, South and West) are bounded by the true bearings NW-NE, NE-SE, SE-SW, and SW-NW, taken from the point of interest.

- **3.1.1** A Cardinal mark is named after the quadrant in which it is placed
- **3.1.2** The name of a Cardinal mark indicates that it should be passed to the named side of the mark.
- **3.1.3** The Cardinal marks in Region A and Region B, and their use, are the same.

3.2 Use of Cardinal Marks

A Cardinal mark may be used, for example:

- **3.2.1** To indicate that the deepest water in that area is on the named side of the mark.
- **3.2.2** To indicate the safe side on which to pass a danger.
- **3.2.3** To draw attention to a feature in a channel such as a bend, a junction, a bifurcation or the end of a shoal.
- **3.2.4** Competent authorities should consider carefully before establishing too many cardinal marks in a waterway or area as this can lead to confusion, given their white lights of similar characteristics.

3.3 Description of Cardinal Marks

	3.3.1 North Cardinal Mark	3.3.2 East Cardinal Mark
Topmark [a]	2 black cones, one above the other, points upward	2 black cones, one above the other, base to base
Colour	Black above yellow	Black with a single broad horizontal yellow band
Shape of buoys	Pillar or spar	Pillar or spar
Light (when fitted)		
Colour	White	White
Rhythm	VQ(3) or Q Long flash every 15s	VQ(3) every 10s or Q(3) every 15s

	3.3.3 South Cardinal Mark	3.3.4 West Cardinal Mark
Topmark [a]	2 black cones, one above the other, points downward	2 black cones, one above the other, point to point
Colour	Yellow above black	Yellow with a single broad horizontal black band
Shape of buoys	Pillar or spar	Pillar or spar
Light (when fitted)		
Colour	White	White
Rhythm	VQ(6) + Long flash every 10s or Q(6) + Long flash every 15s	VQ(9) every 10s or Q(9) every 15s

Note (a): The double cone top-mark is a very important feature of every Cardinal mark by day, and should be used wherever practicable and be as large as possible with a clear separation between the cones.

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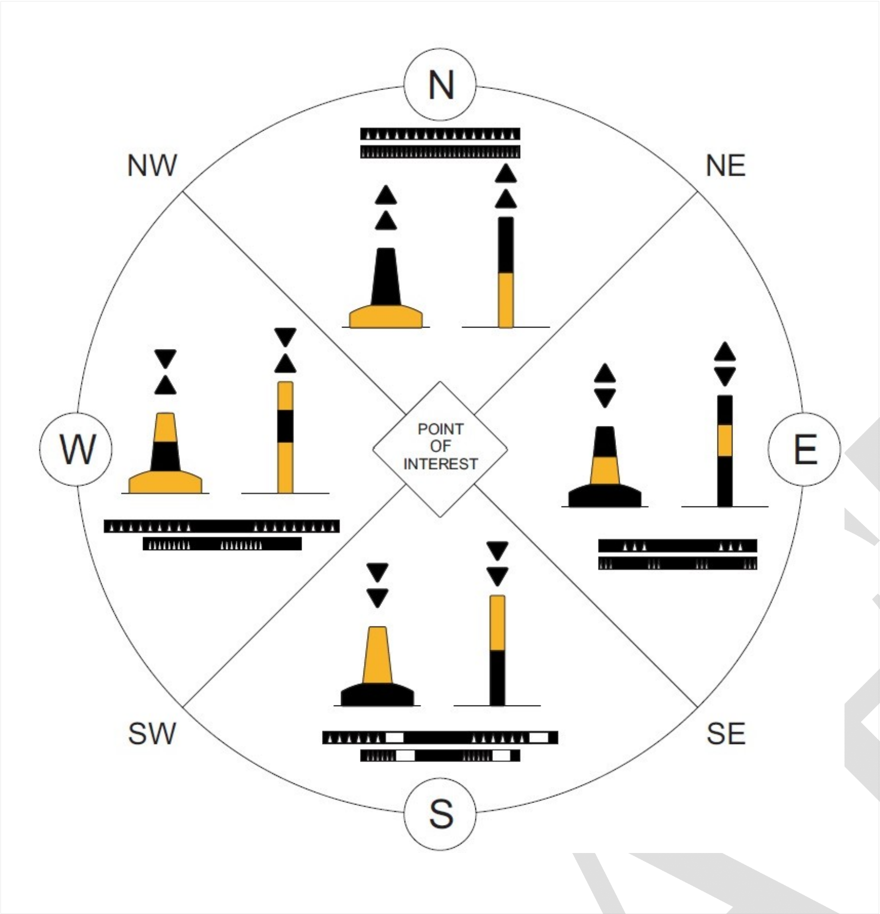

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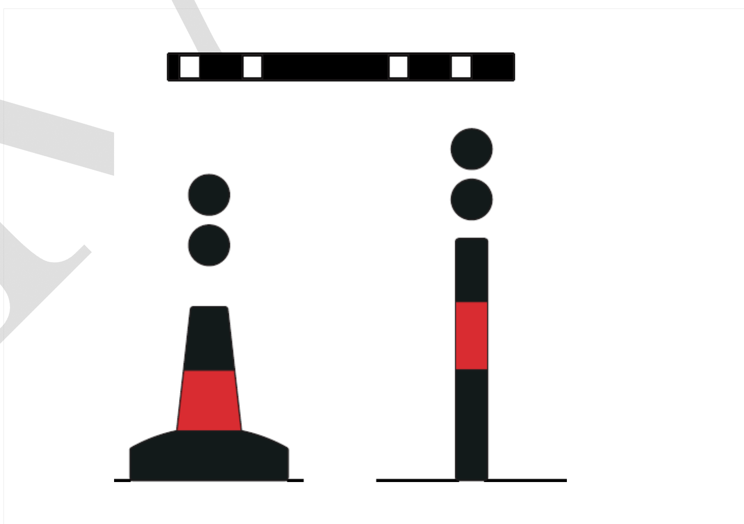
4. Isolated Danger Marks

4.1 Definition of Isolated Danger Marks

An isolated Danger mark is a mark erected on, or moored on or above, an isolated danger which has navigable water all around it.



4.2 Description of Isolated Danger Marks

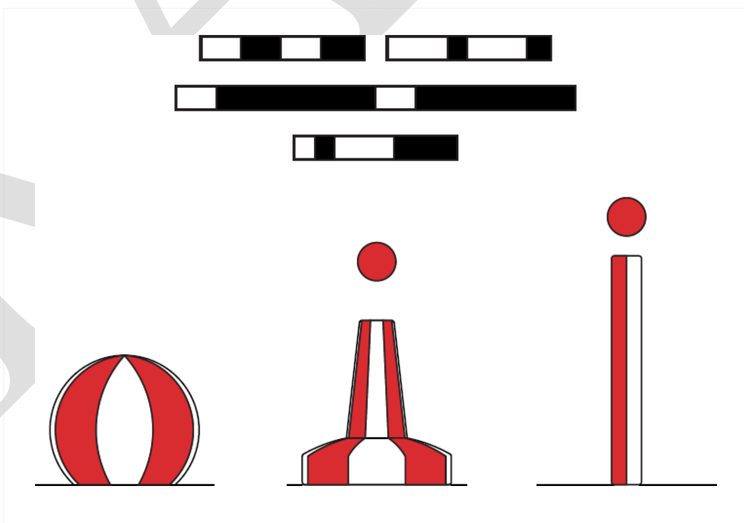
	Description
Top-mark [b]	Two black spheres, one above the other
Colour	Black with one or more broad horizontal red bands
Shape of buoy	Optional, but not conflicting with lateral marks; pillar or spar preferred
Light (when fitted)	
Colour	White
Rhythm	Group flashing (2)

Note (b): The double sphere topmark is a very important feature of every Isolated Danger mark by day, and should be used wherever practicable and be as large as possible with a clear separation between the spheres.

5. Safe Water Marks

5.1 Definition of Safe Water Marks

Safe Water marks serve to indicate that there is navigable water all round the mark. These include centre line marks and mid-channel marks. Such a mark may also be used to indicate channel entrance, port or estuary approach, or landfall. The light rhythm may also be used to indicate best point of passage under bridges.



5.2 Description of Safe Water Marks

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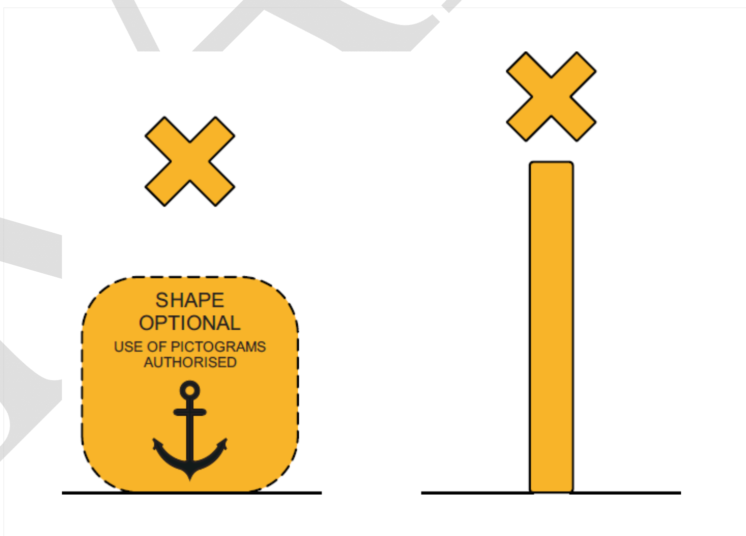
Description	
Colour	Red and white vertical stripes
Shape of buoy	Spherical; pillar or spar with spherical topmark
Top-mark (if any)	Single red sphere
Light (when fitted)	
Colour	White
Rhythm	Isophase, occulting, one long flash every 10s or Morse "A"

6. Special Marks

6.1 Definition of Special Marks

Marks used to indicate a special area or feature whose nature may be apparent from reference to a chart or other nautical publication. They are not generally intended to mark channels or obstructions where other marks are more suitable.



Some examples of uses of Special Marks:

- **6.1.1** Ocean Data Acquisition Systems (ODAS) marks.
- **6.1.2** Traffic separation marks where use of conventional channel marking may cause confusion.
- **6.1.3** Spoil Ground marks.
- **6.1.4** Military exercise zone marks.
- **6.1.5** Cable or pipeline marks.
- **6.1.6** Recreation zone marks.
- **6.1.7** Boundaries of anchorage areas
- **6.1.8** Structures such as offshore renewable energy installations
- **6.1.9** Aquaculture

6.2 Description of Special Marks

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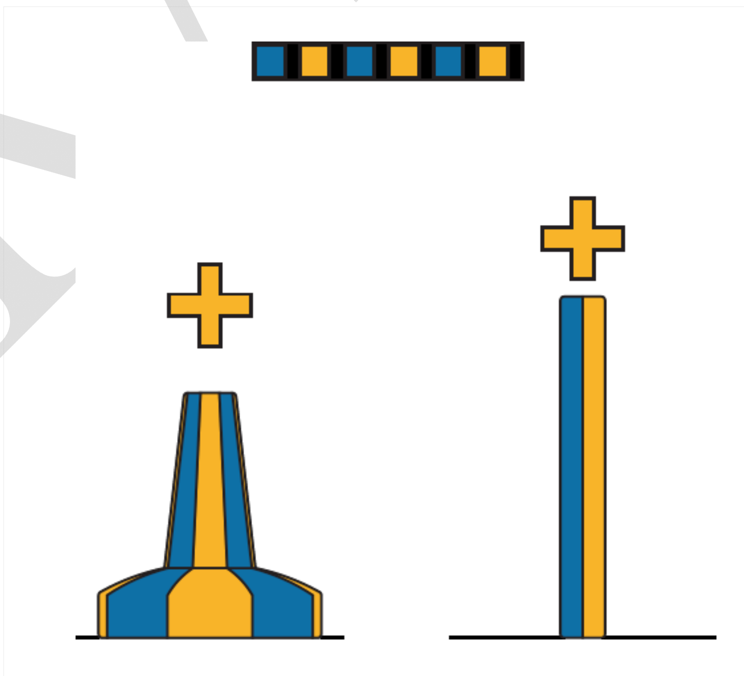
Description	
Colour	Yellow
Shape of buoy	Optional, but not conflicting with lateral marks
Top-mark (if any)	Single yellow "X" shape
Light (when fitted)	
Colour	Yellow
Rhythm	Any, other than those reserved for cardinal, isolated danger and safe water marks.
Pictogram	The use of pictograms is authorized, as defined by a competent authority.

7. Marking New Dangers

7.1 Definition of New Dangers

The term "New Danger" is used to describe newly discovered hazards not yet shown in nautical documents. 'New Dangers' include naturally occurring obstructions such as sandbanks or rocks or man-made dangers such as wrecks.



7.2 Marking of New Dangers

- **7.2.1** 'New Dangers' should be appropriately marked using Lateral, Cardinal, Isolated Danger marks or by using the Emergency Wreck Marking Buoy. If the Authority considers the risk to navigation to be especially high, at least one of the marks should be duplicated.
- **7.2.2** If using a Lateral lighted mark for this purpose a VQ or Q light character shall be used.
- **7.2.3** Any duplicate mark shall be identical to its partner in all respects.
- **7.2.4** In addition it may be marked by a Racon, coded Morse "D"(- ● ●)

- **7.2.5** In addition it may be marked by other electronic means, such as automatic identification system (AIS as an AtoN).
- **7.2.6** Virtual Aids to Navigation may be deployed solely or in addition to physical Aids to Navigation.
- **7.2.7** The marking of the new danger may be removed when the competent Authority is satisfied that information concerning the "New Danger" has been sufficiently promulgated or the danger otherwise resolved.

7.3 Description of New Dangers Marks

Description	
Colour	Blue/Yellow vertical stripes in equal number dimensions (minimum 4 stripes and maximum 8)
Shape of buoy	Pillar or spar
Top-mark (if any)	Vertical/perpendicular Yellow cross
Light	
Colour	Yellow/blue alternating
Rhythm	One second of blue light and one second of yellow light with 0.5 sec. of darkness between

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8. Other Marks

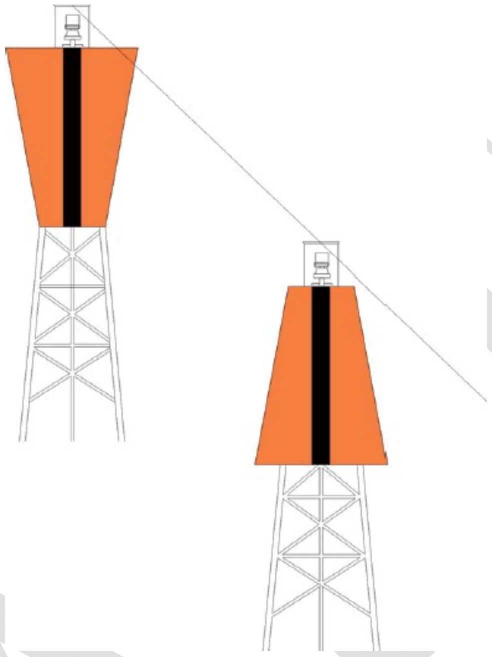
8.1 Leading Lines/Ranges

8.1.1 Definition of Leading Lines/Ranges

A group of two or more marks or lights, in the same vertical plane such that the navigator can follow the leading line on the same bearing.

8.1.2 Description of Leading Lines

Leading Line structures can be any colour or shape that provides a distinctive mark that cannot be confused with adjacent structures.

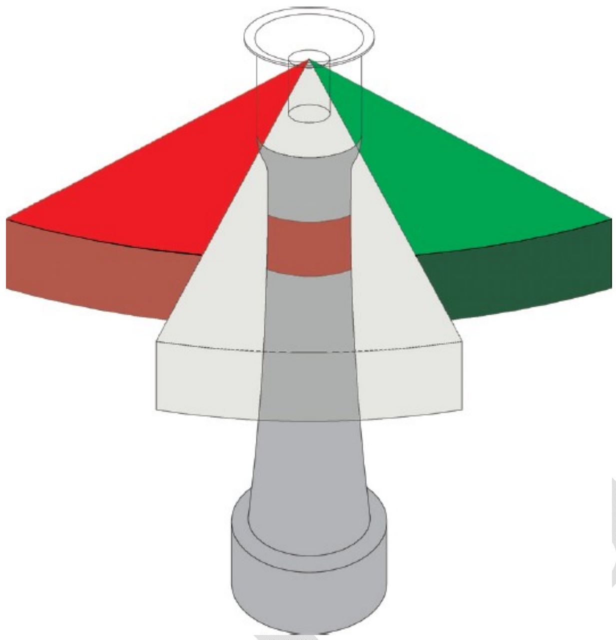


Description	
Colour	No colour significance. Competent authority determines the optimum colours to contrast with the dominant background colour at the location
Shape	No shape significance. Rectangular or triangular figures are recommended.
Light (when fitted)	
Colour	Any colour. Competent authority determines the optimum colour to contrast with the dominant back ground colour at the location.
Rhytm	Any, however fixed characteristics should be used sparingly and the use of synchronisation can assist in the overcoming background light.

8.2 Sector Lights

8.2.1 Definition of Sector Lights

A sector light is a fixed aid to navigation that displays a light of different colours and/or rhythms over designated arcs. The colour of the light provides directional information to the mariner.



8.2.2 Description of Sector Lights

A sector light may be used:

- To provide directional information in a fairway;
- To indicate a turning point, a junction with other channels, a hazard or other items of navigational importance;
- To provide information on hazard areas that should be avoided;
- In some cases a single directional light may be used.

Description	
Colour	Not applicable
Shape	None, light only
Light	
Colour	If using to mark channel limits follow convention for IALA region indicated in Section 2. Lights may have oscillating boundaries
Rhythm	As appropriate

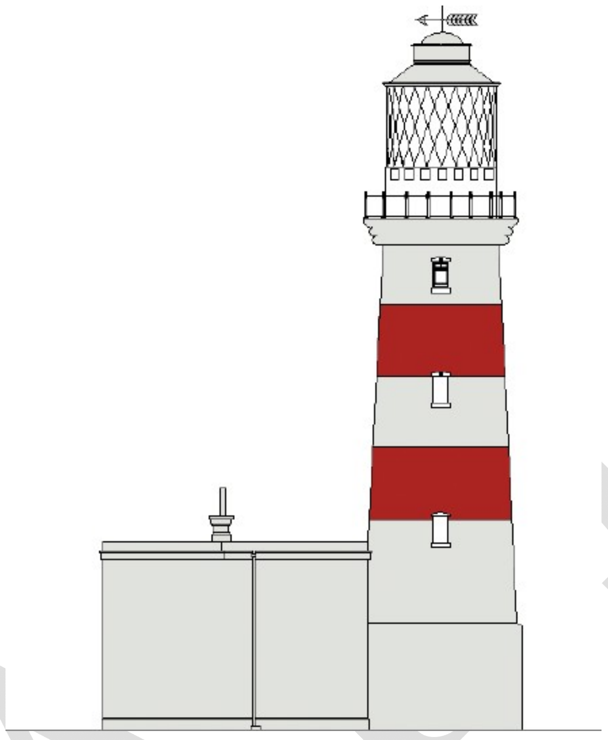
8.3 Lighthouses

8.3.1 Definition of a Lighthouse

A lighthouse is a tower, or substantial building or structure, erected at a designated geographical location to carry a signal light and provides a significant daymark. It provides a long or medium range light for identification by night.

8.3.2 Description of a Lighthouse

It may provide a platform for other AtoN such as DGNSS, racon or AIS as an Aids to Navigation to assist marine navigation. A lighthouse is a structure that may provide a daymark for identification by day. A sector light may also be incorporated into the structure.

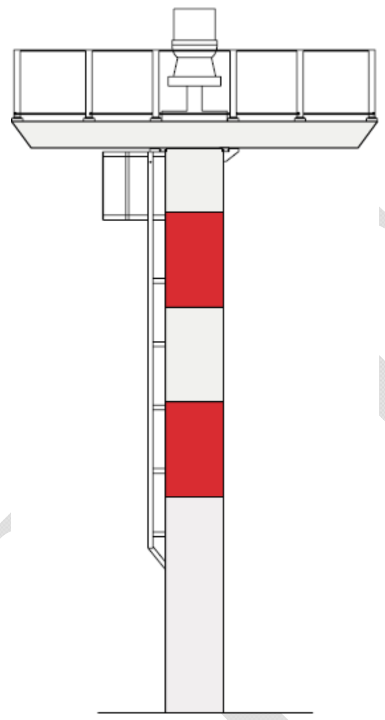


Description	
Colour/Shape	Lighthouse structures can be of any colour, shape, or material generally designed to provide a distinctive daymark.
Light	
Colour	White, Red, or Green
Rhythm	Any number of flashes, isophase or occulting or as appropriate, to allow light to be readily identifiable.

8.4 Beacons

8.4.1 Definition of a Beacon

A fixed man-made navigation mark that can be recognised by its shape, colour, pattern, topmark, or light character, or a combination of these.



8.4.2 Description of a Beacon

- Can carry a signal light and in this case is termed a light beacon or lighted beacon;
- If not fitted with a light it is termed an unlighted or unlit beacon and provides only a day mark;
- As a leading line/range or conspicuous radar mark;
- It may also carry a topmark.

Description	
Colour	Any
Shape	As appropriate, including cardinal mark
Topmark (if any)	As appropriate
Light (when fitted)	
Colour	White, Red, or Green
Rhythm	As appropriate

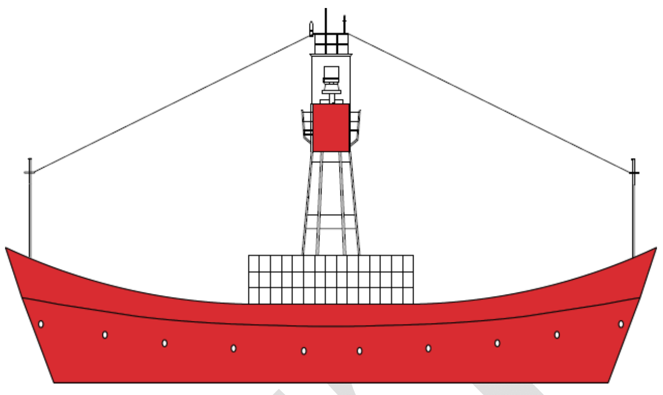
8.5 Major Floating Aids

8.5.1 Definition of Major Floating Aids

Major floating aids include lightvessels, light floats and large navigational buoys.

8.5.2 Description of Major Floating Aids

Major floating aids are generally deployed at critical locations, intended to mark approaches from offshore areas, where shipping traffic concentrations are high. It may provide a platform for other Aids to Navigation such as, racon or AIS as an Aids to Navigation to assist marine navigation.



Description	
Colour	As appropriate - predominantly red
Shape	Vessel or buoy shape with light tower
Light (when fitted) including off station lights	
Colour	As appropriate
Rhythm	As appropriate

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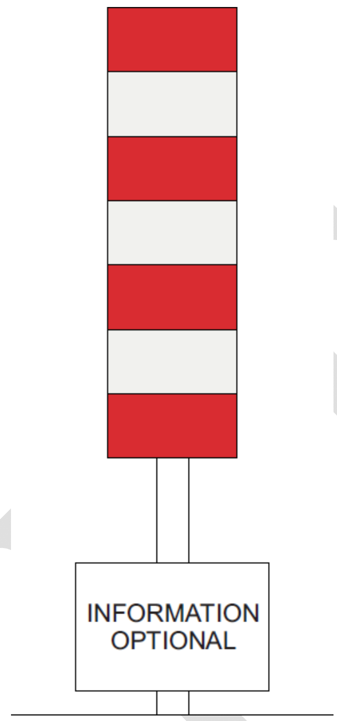
8.6 Auxiliary Marks

8.6.1 Definition of Auxiliary Marks

Minor aids that have not been previously described.

8.6.2 Description of Auxiliary Marks

These marks are usually outside of defined channels and generally do not indicate the port and starboard sides of the route to be followed or obstructions to be avoided. They also include those marks used to convey information related to navigation safety. These marks shall not conflict with other navigational marks and shall be promulgated in appropriate nautical charts and documents. Should not generally be used if a more appropriate mark is available within the MBS.



8.7 Port or Harbour Marks

Mariners should be careful to take account of any local marking measures that may be in place and will often be covered by Local Regulations or by-laws. Before transiting an area for the first time, mariners should make themselves aware of local marking arrangements.

Local Aids to Navigation may include, but not be restricted to, marking of:

- breakwaters, quays and jetties;
- bridges and traffic signals;
- leisure areas.

and other river, channel, canal, lock and waterways mar- ked within the responsibilities of competent authorities.

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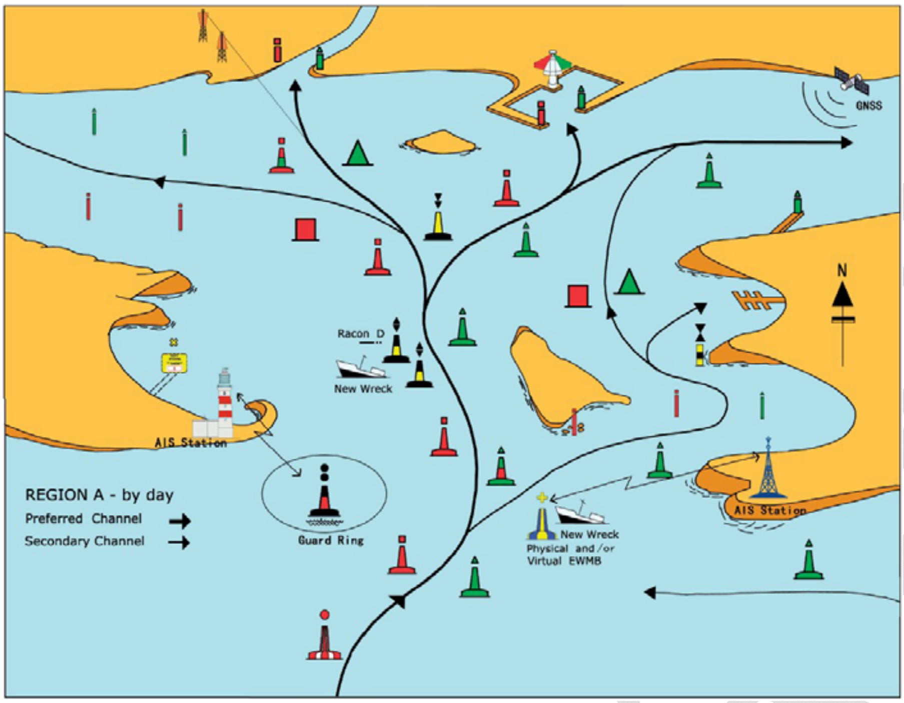
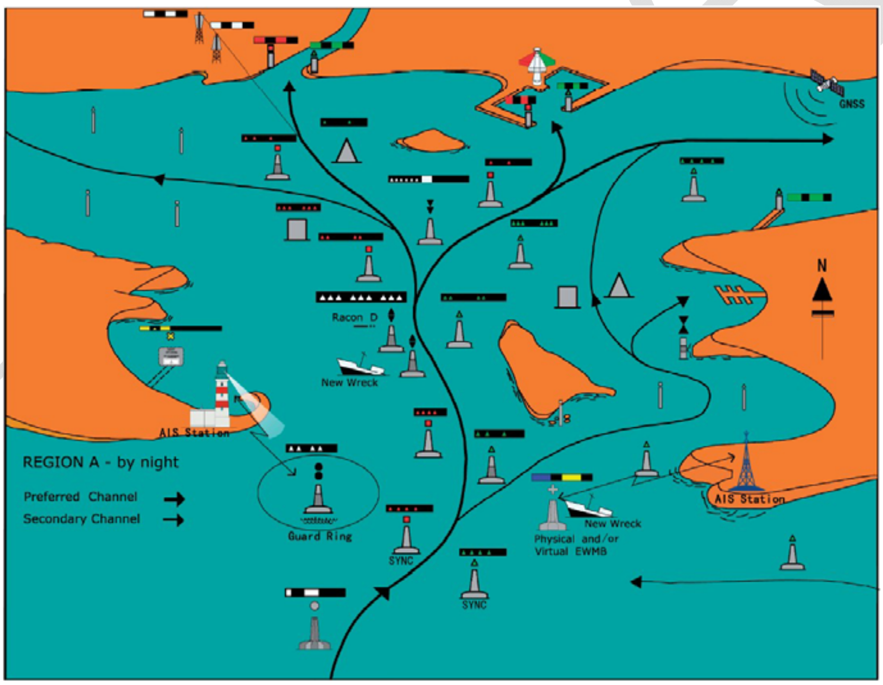
9. IALA Recommendations and Guidelines

IALA Recommendations and Guidelines provide information on planning, operating, managing, and implementing the marks authorized by the MBS and can be found via the IALA website at: **www.iala-aism.org**.

Region A by Day & Night





Region B by Day & Night