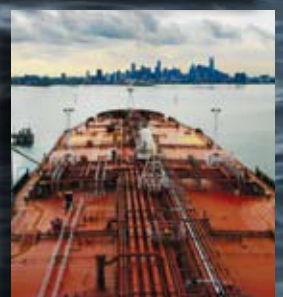




# NAVGUIDE

Aids to Navigation Manual



2010 Edition



# **IALA Aids to Navigation Manual NAVGUIDE 2010**

AISM-IALA : 20 ter rue Schnapper - 78100 Saint-Germain en Laye - France

Telephone: + 33 1 34 51 70 01 - fax: + 33 1 34 51 82 05

e-mail : [iala-aism@wanadoo.fr](mailto:iala-aism@wanadoo.fr) - internet: [www.iala-aism.org](http://www.iala-aism.org)

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# FOREWORD



The IALA NAVGUIDE 2010 will be of interest and assistance to all organisations, training institutions and individuals who are associated with aids to navigation (AtoN). This sixth edition has been developed over the past four years (2006 – 2010), and represents a continuing commitment to excellence and clarity of presentation.

A key change from the 2006 version is the focus on e-navigation in recognition of the extensive conceptual work done to date, the central role e-navigation is expected to play in the future work program of IALA and its impact on the way Competent Authorities provide an aids to navigation service to mariners in the longer term.

The IALA Aids to Navigation Management (ANM) Committee has coordinated the review of the IALA NAVGUIDE. All sections have been reviewed and revisions made through expert input from all of the IALA Committees – ANM, Engineering, Environment and Preservation (EEP), e-Navigation (e-NAV) and Vessel Traffic Services (VTS).

This NAVGUIDE is a tribute to professionals already very busy in their own organisations worldwide, who are happy to share their expertise with other members of the international maritime community to assist in reaching the ultimate goal of harmonization of maritime aids to navigation. It is a testimony to the effort of all the members of the IALA Committees.

IALA welcomes feedback about its publications. Readers are invited to send comments or suggestions, which will be taken into account when considering the publication of the next edition. Please forward comments to: [iala-aism@wanadoo.fr](mailto:iala-aism@wanadoo.fr) attention IALA Technical Coordination Manager.

*Torsten Kruuse, IALA Secretary General*

*March 2010*

# ACKNOWLEDGEMENT



The photographs in this manual were provided by members of the various IALA Committees and Industrial Members of IALA acting either in their capacity as representatives of a member organisation or as private individuals. The photographs were accompanied by permission to publish them in this manual; IALA wishes to acknowledge these donations and the copyright of donors.

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# 1

## AN INTRODUCTION TO IALA - AISM

### 1.1 Purpose and Scope

The purpose of this manual is to assist Aids to Navigation (AtoN) authorities in the harmonisation of marine 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 IALA, IMO and related organisations on specific topics.

### 1.2 Background

Shipping is an international industry that is regulated through various organisations. Nations have recognised that it is both effective and appropriate to regulate and manage shipping on an international basis. These organisations may be inter-governmental (i.e. International Maritime Organization (IMO) or International Telecommunications Union (ITU)) or non-governmental.

The International Association of Marine Aids to Navigation and Lighthouse Authorities<sup>1</sup> (IALA) is a non-profit, non-governmental organization devoted to the harmonization of marine aids to navigation. IALA was formed in 1957 as a technical association to provide a framework for aids to navigation authorities, manufacturers and consultants from all parts of the world to work with a common effort to:

- harmonise standards for aids to navigation systems worldwide;
- facilitate the safe and efficient movement of shipping, and;
- enhance the protection of the maritime environment.

The functions of IALA include:

- developing international cooperation by promoting close working relationships and assistance between members;
- collecting and communicating information on recent developments and matters of common interest in regard to aids to navigation including service delivery quality and efficiency, equipment reliability and contractor performance;
- liaising with relevant inter-governmental, international and other organisations. For example, the International Maritime Organisation (IMO), the International Hydrographic Organisation (IHO), the World Association for Waterborne Transport Infrastructure (PIANC), the Commission on Illumination CIE, and the International Telecommunications Union (ITU);
- liaising with organisations representing the aids to navigation users;
- addressing emerging navigational technologies, hydrographic matters (as reflect aids to navigation issues) and vessel traffic management;

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<sup>1</sup>Formerly called the International Association of Lighthouse Authorities

- providing specialist advice or assistance on aids to navigation issues (including technical, organisational or training matters);
- establishing Committees or Working Groups to:
  - formulate and publish appropriate IALA recommendations and guidelines;
  - contribute to the development of international standards and regulations;
  - study specific issues;
- encouraging IALA members to develop policies that address the social and environmental issues associated with establishing and operating aids to navigation, including issues such as:
  - preservation of historic lighthouses, and;
  - use of aids to navigation as a base for the collection of data for other governmental or commercial services;
- organising Conferences, Symposiums, Seminars, Workshops and other events relevant to aids to navigation activities.

### 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, organisation 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 organisations providing aids to marine navigation services or technical advice under contract;

**Honorary Membership:** may be conferred for life by the IALA Council to any individual who is considered to have made an important contribution to the work of IALA.

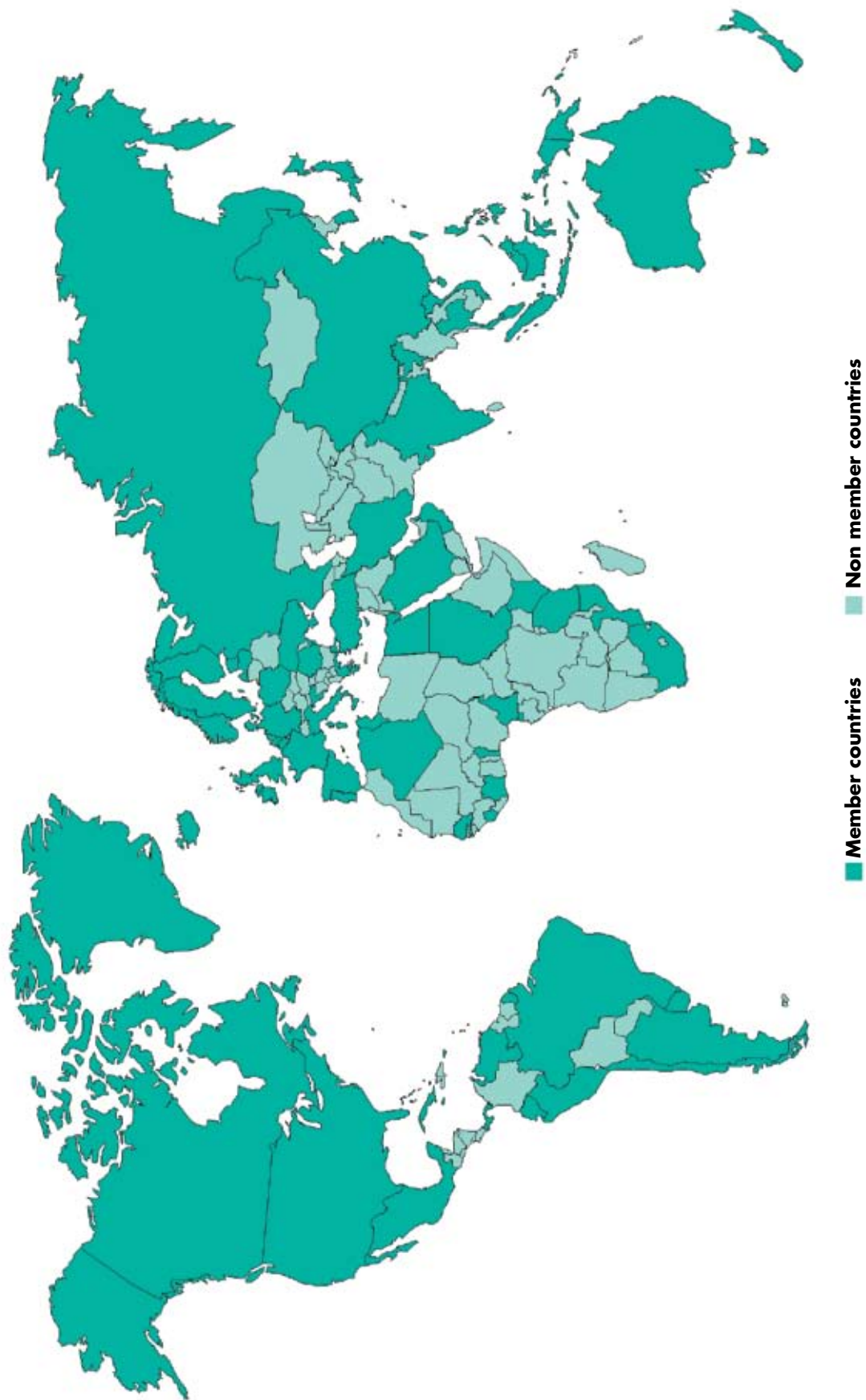


Figure 1 - IALA National Members

## 1.4 IALA Structure

The organisational structure of IALA is shown in Figure 2.

### 1.4.1 IALA Council

IALA is administered by a Council of up to twenty-two elected and two non-elected councillors:

The elected positions are determined by a ballot of all national members attending a General Assembly. Only one national member from any country may be elected to the Council and there is a general aim to draw councillors from different parts of the world to achieve a broad representation on the Council.

The non-elected positions are held by the head of the national authority that will host the next IALA Conference and the head of the national authority that hosted the last IALA Conference.

The Council members elect a President, Vice President and a Financial Advisory Committee for the 4 (four) year term between Conferences. The Council also appoints a Secretary General to act as legal representative and chief executive of IALA.

The Council meets at least once each year and can be convened by either the President, the Vice President, the Secretary General, or at the request of any two councillors.

The functions of the Council are to:

- implement the overall policy of IALA as defined by its aims or by the General Assembly;
- establish Committees relevant to the aims of IALA and approve the positions of Chairman and Vice Chairman on each Committee;
- determine rules of procedure for Committees and their terms of reference;
- determine and review the strategic direction of IALA;
- approve IALA recommendations, guidelines and manuals;
- decide the venue and the year of the next IALA Conference;
- establish rules for participation in IALA Conferences;
- convene General Assemblies;
- approve the annual budget and accounts;
- decide membership matters; and
- determine the rate of subscriptions.

### 1.4.2 General Assembly

The General Assembly of the members of IALA is convened by the IALA Council and is normally concurrent with IALA Conferences, held every 4 yrs (Section 1.4.5 refers).

The General Assembly, among other things, decides the overall policy of IALA and its Constitution and elects the members of the Council.

National Members have voting rights at a General Assembly.

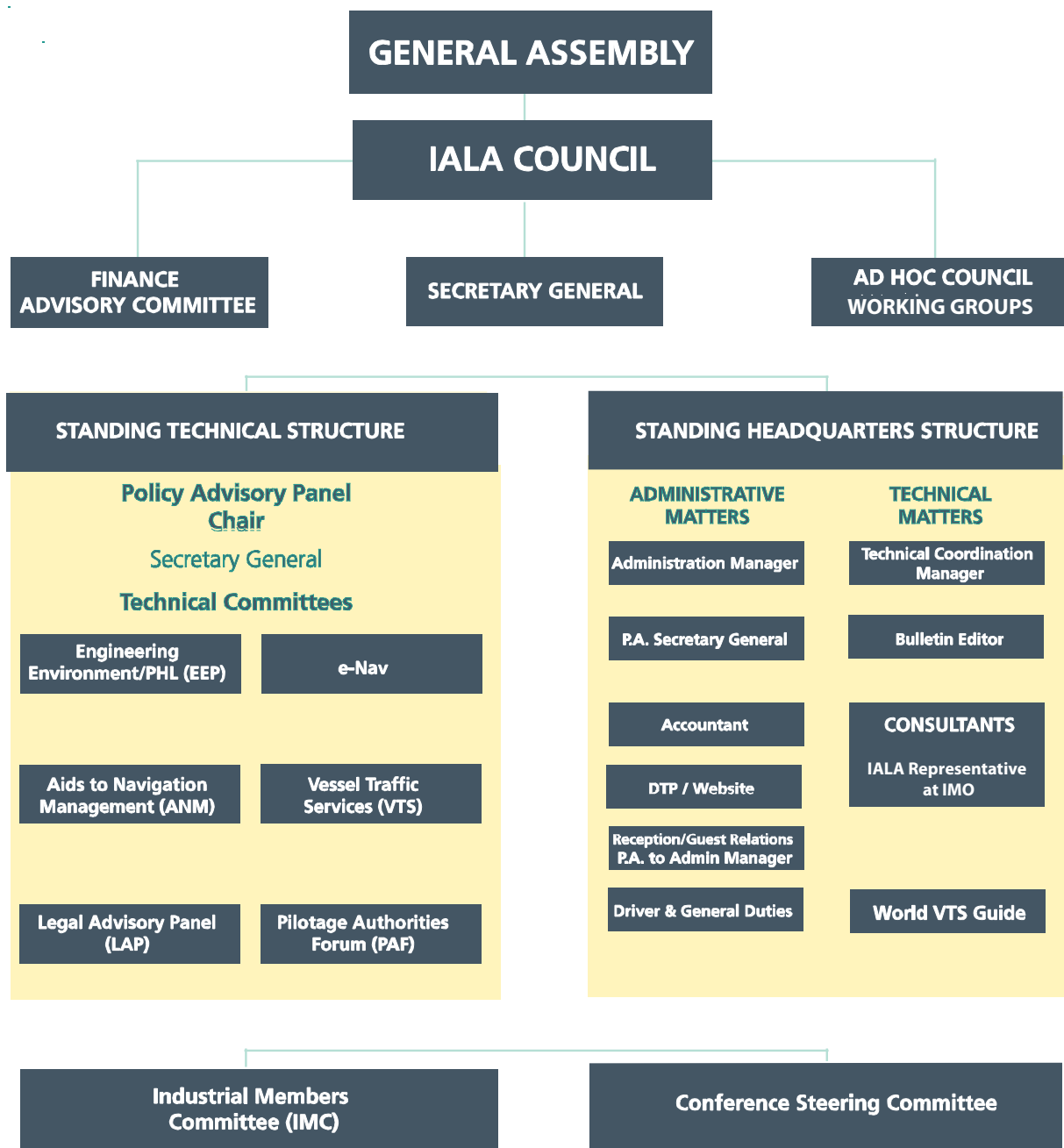


Figure 2 – IALA Organisational Structure



### 1.4.3 Policy Advisory Panel

The Policy Advisory Panel (PAP) is a group that comprises the Secretary General, Technical Director, the Chairs and vice-Chairs of each Committee and special advisors to IALA. The Panel meets at least once a year to review the work being done by the Committees.

The role of the PAP is to:

- identify any overlap of work between the Committees and to ensure that the work of the Committees is on schedule;
- review the general operation of the Committees, and
- advise the IALA Council about the facilities at the Headquarters.

### 1.4.4 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 IALA members. In addition, the Committees prepare submissions to International Organisations. A Committee may also be asked to provide continuous monitoring of elements of subjects that could influence decisions concerning the provision of Aids to Navigation, including VTS.

The Council develops terms of reference for each Committee when it is established. The Council then reviews and amends terms of reference, as necessary, immediately prior to each Conference.

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 IALA 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 IALA Council.


All IALA members are invited to participate in the IALA Committees.

The IALA Committees that have operated over the four years leading up to the 2010 IALA Conference were:

- Engineering, Environment and Preservation (EEP);
- Aids to Navigation Management (ANM);
- e-Navigation (e-NAV) (incorporating the former Radionavigation (RNAV) and Automatic Identification System (AIS) Committees; and
- Vessel Traffic Services (VTS).

In addition to the Committees, IALA also convened two new advisory forums during the 2006-2010 period:

- **Legal Advisory Panel (LAP)** - LAP is a group that comprises a chairperson (as appointed by the Council), IALA members with interest in legal affairs, representatives of relevant



international organisations (as approved by the Secretary-General), and experts (as appointed by the Secretary-General). The role of LAP is to:

- provide support to IALA on legal issues affecting IALA national members;
- provide support to IALA as an organisation on legal issues; and
- provide guidance to the membership on best practices in the provision of aids to navigation services.

LAP is providing a forum to discuss legal matters of common interest with regards to the provision of aids to navigation services and identify where external legal advice may be needed.

LAP is responding to issues and concerns that may be raised through the IALA Secretariat with respect to the development and providing guidance on the provision of aids to navigation services;

Furthermore LAP is identifying and maintaining a work programme to respond to changing issues within the aids to navigation environment.

- Pilotage Authority Forum (PAF) - PAF is a group that comprises a chairperson (as appointed by the Council), IALA members, competent pilotage authorities (as invited by the Secretary-General), representatives of relevant international organisations (as approved by the Secretary-General) and the Secretary-General of IMPA (observer status). The role of PAF is to:
  - identify IALA members who have responsibility for pilotage services;
  - provide a forum for competent pilotage authorities in order to discuss pilot matters; and
  - list key issues of common concern for competent pilotage authorities.

PAF is providing a forum for competent pilotage authorities to discuss pilotage matters with an aim to harmonize pilotage services on an international basis. PAF is identifying an action plan to work proactively with related international organisations to promote harmonization of service delivery.

‘Competent pilotage authority means the national or regional governments legally responsible for the provision of a pilotage system.’

#### **1.4.5 Conferences, Symposiums and Exhibitions**

IALA holds a general aids to navigation Conference every four (4) years. These Conferences may be attended by IALA members and also by non-member 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 Members’ Committee traditionally organizes an Industrial Exhibition in conjunction with the Conference.

IALA traditionally holds the General Assembly in conjunction with the Conference. The IALA work term traditionally spans the four (4) years between Conferences.



In addition, IALA may hold a Symposium on a specific topic of interest to the members.

An example is the IALA VTS Symposium, held every four (4) years, two years separated from the IALA Conference.

#### 1.4.6 Workshops and Seminars

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

A **Workshop** is a special meeting 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; or,
- To enable skills and comprehension of new techniques to be learned by detailed lectures combined with simulation or similar “hands on” methods.

A **Seminar** is a small meeting 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 published internal guidelines on the preparation of a Workshop or Conference. Approval to convene a Workshop or Seminar may be given by the Council on the recommendation of the Secretary General.

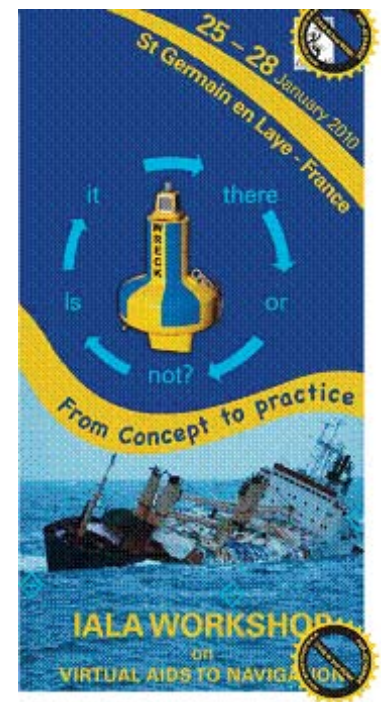
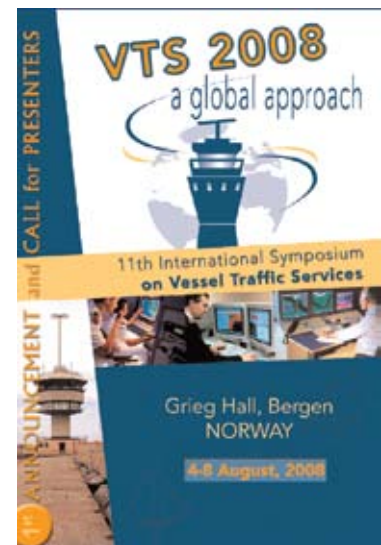
### 1.5 IALA Publications

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 signalling systems worldwide. The types of publications include:

**IALA Recommendations:** These documents represent the highest level of IALA documentation equivalent to a ‘standard’ in an intergovernmental organization). Recommendations provide direction to IALA members on uniform procedures and processes that will facilitate IALA objectives. IALA recommendations contain information on how members should plan, operate and manage Aids to Navigation. Recommendations may reference relevant International Standards and IALA Guidelines.

**IALA Guidelines:** These documents provide detailed information on an aspect of a specific subject, indicating options, best practices and suggestions for implementation. IALA Guidelines relate to planning, operating and managing Aids to Navigation.

**IALA Manuals:** These documents provide 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 IALA Recommendations;

**Visibility** - presentation of documents should present a ‘common look and feel’, providing a visual indication of an IALA 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 IALA web.

For more information refer to internal *Recommendation on IALA Documentation Hierarchy*.

### 1.5.1 IALA Recommendations

IALA Recommendations represent the highest level of IALA documentation. Recommendations provide direction to IALA members on uniform procedures and processes that will facilitate IALA objectives. IALA recommendations contain information on how the members should plan, operate and manage Aids to Navigation and may reference relevant International Standards and IALA Guidelines.

Recommendations are identified by an alphanumeric (hundred series) number:

- **A-###** representing recommendations relating to AIS issues.
- **E-###** representing recommendations relating to Engineering and Environmental issues.
- **e-NAV-###** representing recommendations relating to e-Navigation issues.
- **H-###** representing recommendations relating to Heritage issues (i.e. Lighthouse Preservation).
- **O-###** representing recommendations relating to Operational and Management issues.
- **R-###** representing recommendations relating to Radio-navigation issues.
- **V-###** representing recommendations relating to VTS issues.

IALA Recommendations are available in PDF format on the IALA website, for download by interested parties, free of charge. ([www.iala-aism.org](http://www.iala-aism.org))

There is an implicit expectation that individual national members will observe and implement IALA Recommendations.

### 1.5.2 IALA Guidelines

These documents provide detailed, in-depth information on an aspect of a specific subject, indicating options, best practices and suggestions for implementation. IALA Guidelines relate to planning, operations and managing Aids to Navigation.

Guidelines are identified with a sequential numerical reference (thousand series), but with no letter indication. They continue to be identified by their title – e.g. ‘IALA Guideline 1035 on Availability and Reliability of Aids to Navigation’.

IALA Guidelines are available in pdf format on the IALA website, for download by interested parties, free of charge. ([www.iala-aism.org](http://www.iala-aism.org))

### 1.5.3 IALA Manuals

IALA Manuals provide members, non-members and training institutions with an overall view of a large subject area – for example the NAVGUIDE and the IALA VTS Manual. While introducing the subject to a varied audience, reference is also made to IALA Guidelines and IALA Recommendations, as well as other related international documentation.

IALA Manuals are available from IALA Headquarters, at a nominal charge to cover printing and shipping costs.

### 1.5.4 IALA Dictionary

The IALA Dictionary (next edition due 2010) provides a listing of words and phrases used to explain and describe planning, operations, management, equipment, systems and scientific terms relevant to AtoN.

### 1.5.5 Other Documentation

Other documentation that is available from IALA on request includes:

- Conference Proceedings;
- Reports (meetings, workshops, seminars, etc.);
- IALA Bulletin (a quarterly magazine); and
- IALA List of Publications.

IALA endeavours to provide all publications at no, or minimal cost.

### 1.5.6 Related Organisations

IALA works in close cooperation with a number of other international maritime organisations to further its objective of harmonising marine AtoN.

#### International Maritime Organisation (IMO)

The IMO is a specialist agency of the United Nations with 168 Member States and three Associate Members. IMO is based in the United Kingdom with over 300 staff. IMO's main task is to maintain a comprehensive regulatory framework for shipping. Its remit today includes safety, environment concerns, legal matters, technical cooperation, maritime security and the efficiency of shipping.

IMOs specialised committees and sub-committees are the focus for the technical work to update existing legislation or develop and adopt new regulations. IMO is attended by maritime experts from Member governments and interested intergovernmental and non-government organisations.

IMO is responsible for key treaties such as Safety of Life at Sea 1974 (SOLAS), the MARPOL convention for the prevention of pollution by ships and the STCW convention on standards of training of seafarers.

#### PIANC (The World Association for Waterborne Transport Infrastructure)

PIANC is a global, non-political and non-profit organisation providing guidance for sustainable waterborne transport infrastructure for ports and waterways. PIANC is a forum where professionals around the world join forces to provide expert advice on cost-effective, reliable and sustainable infrastructure to facilitate the growth of waterborne transport. Established in 1885, PIANC is the leading partner for government and private sector in the design, development and maintenance of ports, waterways and coastal areas. Members include national governments and public authorities, corporations and interested individuals.



### **International Electrotechnical Commission (IEC)**

The IEC is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardisation and as references when drafting international tenders and contracts.

The IEC charter embraces all electrotechnologies including electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety and the environment.

Further information on the work of the IEC can be found at [www.iec.ch/helpline/sitetree/about/](http://www.iec.ch/helpline/sitetree/about/)

### **International Telecommunications Union (ITU)**

The ITU is the leading United Nations agency for information and communication technology issues, and the global focal point for governments and the private sector in developing networks and services. Established for approximately 145 years, ITU is based in Geneva, Switzerland, and its membership includes 191 Member States and more than 700 Sector Members and Associates.

ITU coordinates the shared global use of the radio spectrum, promotes international cooperation in assigning satellite orbits, works to improve telecommunication infrastructure in the developing world, establishes the worldwide standards that foster seamless interconnection of a range of communications systems and addresses global challenges, such as mitigating climate change and strengthening cybersecurity.

### **International Hydrographic Organization**

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

The object of the Organization is to bring about: the coordination of the activities of national hydrographic offices; the greatest possible uniformity in nautical charts and documents; the adoption of reliable and efficient methods of carrying out and exploiting hydrographic surveys and the development of the sciences in the field of hydrography and the techniques employed in descriptive oceanography

The official representative of each Member Government within the IHO is normally the national Hydrographer, or Director of Hydrography, who, together with their technical staff, meet at 5-yearly intervals in Monaco for an International Hydrographic Conference. The Conference reviews the progress achieved by the Organization through its committees, sub committees and working groups, and adopts the programmes to be pursued during the ensuing 5-year period. A Directing Committee of three senior hydrographers is elected to administer the work of the Organization during that time. The Directing Committee, together with a small international staff of technical experts in hydrography and nautical cartography, makes up the International Hydrographic Bureau in Monaco. The IHB is the secretariat of the IHO, coordinating and promoting the IHO's programmes and providing advice and assistance to Member States and others.

## Definitions

Aid to Navigation (AtoN)	Any device or system, external to a vessel, which is provided to help a mariner determine position and course, to warn of dangers or of obstructions, or to give advice about the location of a best or preferred route.
Automatic Identification System (AIS)	A broadcast transponder system, operating in the VHF maritime mobile band by which a vessel communicates a range of ship and voyage information.
Competent Authority	The authority made responsible, in whole or in part, by the Government for the safety, including environmental safety, and efficiency of vessel traffic and the protection of the environment in the area. (IMO Resolution A.857(20))
Mandatory Ship Reporting System	A ship reporting system that requires the participation of specified vessels or classes of vessels, and that is established by a government or governments after adoption of a proposed system by the International Maritime Organization (IMO) as complying with all requirements of regulation V/8-1 of the International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS), except paragraph (e) thereof.
Stakeholder(s)	Any individual, group, or organization able to affect, be affected by, or believe it might be affected by a decision or activity. The decision maker(s) is a stakeholder.
Under keel clearance	The minimum distance between the bottom of a ship and the seabed
Vessel Traffic Management	“Vessel Traffic Management is the functional framework of harmonized measures and services to enhance the safety, security and efficiency of shipping and the protection of the marine environment in all navigable waters”.
Vessel Traffic Service	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.
VTS area	The delineated, formally declared service area of the VTS. A VTS area may be subdivided in sub-areas or sectors.
VTS centre	The centre from which the VTS is operated. Each sub-area of the VTS may have its own sub-centre.
VTS operator	An appropriately qualified person carrying out VTS operations on behalf of a VTS authority. (VTSO)



## Glossary of Abbreviations

AIS	Automatic Identification System
AISM (see IALA)	Association Internationale de Signalisation Maritime (Title of IALA in the French language)
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)
GLONASS	Global Navigation Satellite System
GLOSS	Global Sea Level Observing System
GPS	Global Positioning System
IALA (see AISM)	International Association for 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
SOLAS	IMO Convention on the Safety of Life at Sea 1974
SRS	Ship Reporting System
UNCLOS	United Nations Convention on the Law of the Sea
UTC	Universal Time Co-ordinated
VHF	Very High Frequency (radio in the 30-300 MHz band)
VTM	Vessel Traffic Management
VTS	Vessel Traffic Service
VTSO	Vessel Traffic Service Officer

# 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 Navigational 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”<sup>2</sup>.

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 positions determined by 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, GPS, DGPS).

Wherever possible, it is recommended that reliance on a single method of determining position is avoided.

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<sup>2</sup>IMO Resolution A.915(22), Appendix 1.

## 2.2 Accuracy Standards for Navigation

IMO Resolution A.915(22), adopted in January 2002, established accuracy standards for maritime navigation.

Table 1 presents the relevant standards adopted in Appendixes 2 and 3 of IMO Resolution A.915(22).

**Table 1 – Minimum Maritime User Requirements**

Application	Absolute horizontal accuracy (95%) / (m)
<b>General Navigation:</b>	
Ocean	10-100 <sup>3</sup>
Coastal	10
Restricted waters	10
Port	1
Inland waterways	10
<b>Hydrography</b>	1-2
<b>Oceanography</b>	10
<b>Aids to navigation management</b>	1
<b>Port operations:</b>	
Local VTS	1
Container/cargo management	1
Law enforcement	1
Cargo handling	0.1

## 2.3 Phases of Navigation

Typically, navigation has been 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 guide.

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

<sup>3</sup>IMO Resolution A.915(22) includes in its Appendix 2 the requirement for an accuracy of 10 m on ocean navigation, while IMO Resolution A.953(23) mentions that “where a radionavigation system is used to assist in the navigation of ships in ocean waters, the system should provide [an accuracy of] 100 m with a probability of 95%”.



### 2.3.1 Ocean Navigation

In this phase, the vessel is typically (one or more of the following may apply):

- 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 adopted more strict accuracy requirements (see Table 1) the minimum navigation 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.

### 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 metres 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 ship 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 adopted more strict accuracy requirements (see Table 1), international studies have established that the minimum navigation requirements for commercial trading vessels operating in the Coastal Phase is a navigation system capable of providing fix positioning to an accuracy of 0.25 nautical miles, 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 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 achieving in excess of 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 trafficked waters near and/or within the entrance to a bay, river, or harbour; and
- navigator is confronted with a requirement for more frequent position fixing and manoeuvring the vessel to avoid collision with other traffic and grounding dangers.

The vessel will generally be within:

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

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

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 ECS and ECDIS technology.

### 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 DGPS (and in the future in some areas enhanced Loran (eLORAN)) and ECS or ECDIS technology.



*Photo courtesy of IALA*

## **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: (or fixed or bias errors) 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 compensation applied.
- Random errors: cause readings to take random values either side of some mean value. They may be due to the observer/operator or the equipment and are revealed by taking repeated readings. This type of error can neither be foreseen nor totally compensated for.
- Faults and mistakes: errors of this type 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 accuracy 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 is of more interest to fishermen, the offshore oil and gas industry, ships making regular trips into an area of restricted waters and lighthouse authorities when positioning floating aids to navigation.

### 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 a number of ways of analysing the error boundary, however the radial position error relative to the true position, taken at the 95% probability level, has been adopted as the preferred method.



## Navigational Position Fixing Measurements

Table 2 shows the typical accuracy (95% probability) achieved using common navigational instruments or techniques.

**Table 2 – Accuracy of some position-fixing processes and systems**

Process	Typical accuracy (95% probability)	Accuracy at 1 NM (metres)
Magnetic compass bearing on a light or landmark	±3° The accuracy may deteriorate in high latitudes	93
Gyro-compass bearing on a light or landmark	0.75° X secant latitude (below 60° of latitude)	< 62
Radio direction finder	±3° to ±10°	93 - 310
Radar bearing	±1° Assuming a stabilized presentation and a reasonably steady craft	31
Radar distance measurement	1% of the maximum range of the scale in use or 30 metres, whichever is the greater	
LORAN-C / CHAYKA	0.25 nm	
GPS	13 – 36 metres	
DGPS (GNSS) (ITU-R M.823/1 Format)	1 – 3 metres	
Dead Reckoning (DR)	Approximately 1 nautical mile for each hour of sailing	

## 2.5 Hydrographic Considerations

### 2.5.1 Charts

The IMO definition<sup>4</sup> 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 of navigation and the protection of the marine environment. The IHO is responsible for determining international standards for the quality of hydrographic surveys and chart production.

Electronic charts provide significant benefits in terms of navigation safety and improved operational efficiency. An electronic chart is a real-time navigation system that integrates a variety of information that is displayed and interpreted by the mariner. It is an automated decision aid capable of continuously determining a vessel's position in relation to land, charted objects, aids-to-navigation, and unseen hazards. There are two basic types of systems using electronic charts systems. Those that

<sup>4</sup>SOLAS Chapter V Regulation 2.



comply with the International Maritime Organization (IMO) requirements for vessels, known as the Electronic Chart Display and Information System (ECDIS), and all other types of electronic charts, regarded generically as Electronic Chart Systems (ECS). Further information on ECDIS and ECS is contained in section 4.27.

The object of the IHO is to bring about:

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

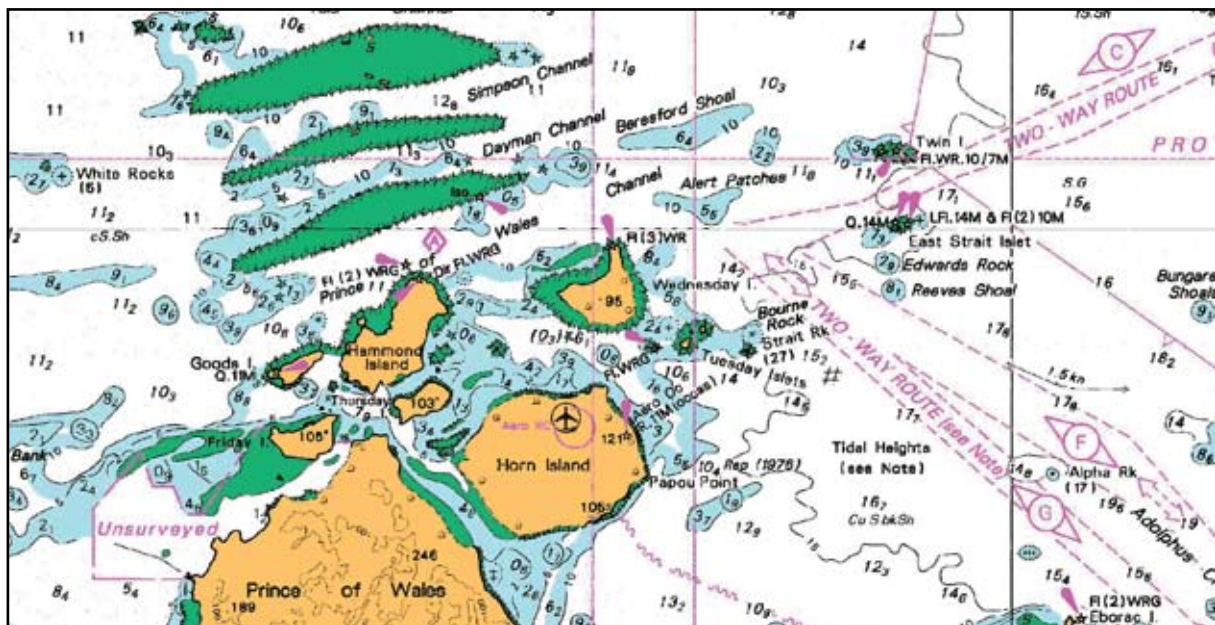


Figure 3 – Nautical chart (courtesy of Australian Hydrographic Office)

### 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<sup>5</sup> that would be assumed by the sea level in the absence of tides, currents, water density variations and atmospheric effects.

<sup>5</sup>These have the same potential gravity at each point.



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

## 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 High High Water** (where there are predominantly diurnal tides)<sup>6</sup>;
- clearance heights for bridges are generally referenced to **Highest Astronomical Tide**.

These levels are depicted in Figure 4. The definition of these levels and other related levels are provided in Table 3.

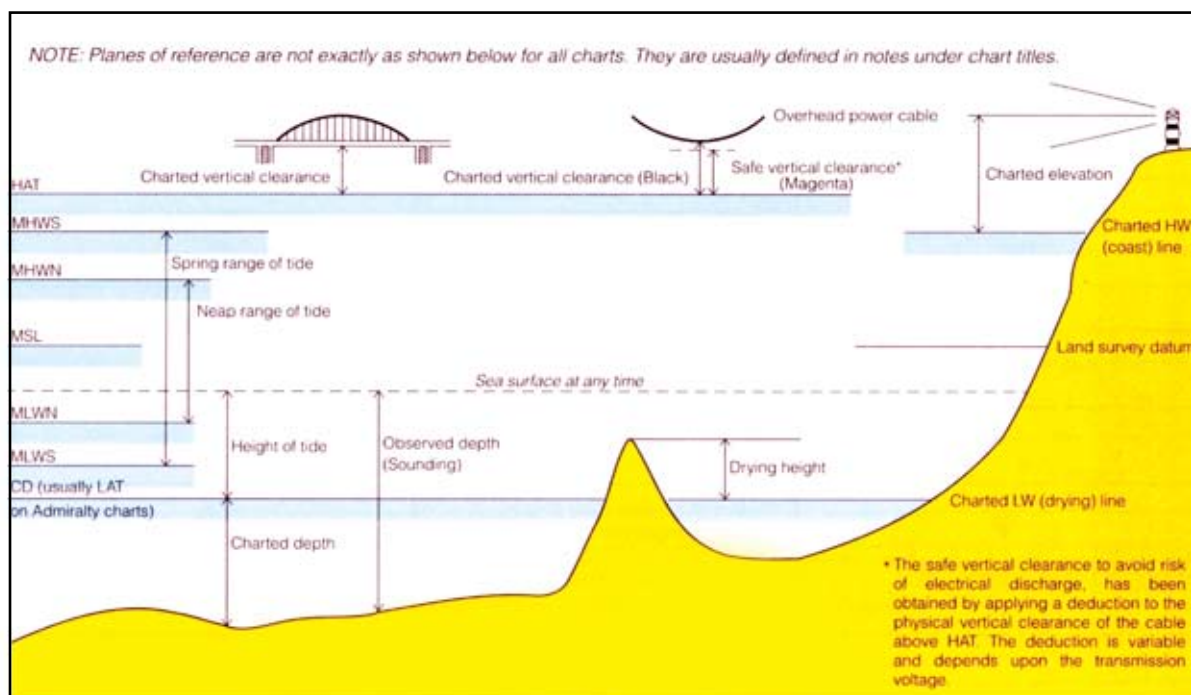


Figure 4 – Levelling or Vertical Control Datums (courtesy of UK Hydrographic Office)

<sup>6</sup>It should be noted that elevations of land features on maps are generally referenced to Mean Sea Level.

Table 3 – Description of some common levels relevant to navigation in coastal and restricted waters

Levels and Description	Abbreviation
<b>highest astronomical tide:</b> - 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
<b>mean higher high water:</b> - the average height of higher high waters at a place over a 19-year period. (IHO Dictionary, S-32, 5th Edition, 3140)	MHHW
<b>mean high water springs:</b> - the average height of the high waters of spring tides. Also called spring high water. (IHO Dictionary, S-32, 5th Edition, 3144)	MHWS
<b>mean sea level:</b> - 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. (IHO Dictionary, S-32, 5th Edition, 3156)	MSL
<b>mean low water springs:</b> - the average height of the low waters of spring tides. Also called spring low water. (IHO Dictionary, S-32, 5th Edition, 3150)	MLWS
<b>mean lower low water:</b> - the average height of the lower low waters at a place over a 19-year period. (IHO Dictionary, S-32, 5th Edition, 3145)	MLLW
<b>Indian spring low water:</b> - a tidal datum approximating the level of the mean of the lower low water at spring tides. Also called Indian tidal plane. (IHO Dictionary, S-32, 5th Edition, 2427) ISLW was defined by G.H. Darwin for the tides of India at a level below MSL and is found by subtracting the sum of the harmonic constituents M2, S2, K1 and O1 from Mean Sea Level	ISLW
<b>lowest astronomical tide:</b> - 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

### Chart Datum Issues

Until the advent of satellite navigation, nautical charts were generally produced to local and national data. The now widely used GPS positioning system uses an earth centred datum referred to as World Geodetic System<sup>7</sup> 1984 (WGS-84) 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 DGPS stations using the ITU-R M.823/1 signal format.

The IHO Technical Resolution B1.1 recommends that all countries that issue national navigational charts should base these on the WGS 84 geodetic system. For many countries this simple objective

<sup>7</sup>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)).



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 GPS 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 GPS 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 style of note found on some charts<sup>8</sup> are shown in Figure 5.

<p><b>SATELLITE-DERIVED POSITIONS</b></p> <p>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.</p>	<p><b>SATELLITE-DERIVED POSITIONS</b></p> <p>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 therefore advised to use alternative sources of positional information, particularly when closing the shore or navigating in the vicinity of dangers.</p>
<p><b>SATELLITE-DERIVED POSITIONS</b></p> <p>Positions obtained from the Global Positioning System (GPS) in the WGS 1984 Datum can be plotted directly onto this chart.</p>	

Figure 5 – GPS Notes on Charts

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<sup>8</sup>Examples taken from Australian 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 or mix of aids to navigation provided, and the available charts are appropriate for mariners to navigate safely.

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.

Table 4 shows chart scales with the corresponding accuracy requirements recommended by IHO and the equivalent dimension of a 0.5 mm dot on a chart.

**Table 4 – Chart scales, applications and related accuracy considerations**

Chart scale <sup>9</sup>	Corresponding need for accuracy (metres)	Approximate pencil width (0.5 mm) equivalence (metres) <sup>10</sup>	Application
1:10,000,000	10,000	5000	
1:2,500,000	2,500	1250	Ocean navigation
1:750,000	750	375	Ocean navigation
1:300,000	300	150	Coastal navigation
1:100,000	100	50	Coastal navigation
1:50,000	50	25	Approach
1:15,000	15	7.5	Approach
1:10,000	10	5	Restricted waters
1:5,000	5	2.5	Harbour plans

### 2.5.4 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 an infallible navigation mark, 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.

<sup>9</sup>The chart scale is generally referenced to a particular latitude eg. 1:300,000 at lat 27° 15' S.

<sup>10</sup>This information may be helpful in assessing the practical accuracy requirements for laying buoy moorings.

# 3

## AIDS TO NAVIGATION

A marine **Aid to Navigation (AtoN)** is a device or system external to vessels that is designed and operated to enhance the safe and efficient navigation of 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. and 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.

During the period 2006-2010, the concept of e-Navigation gained significant momentum and a framework is being developed under the auspices of the IMO.

IALA has been requested by the IMO to develop the shore-based aspects of the conceptual framework and systems architecture for e-Navigation. Chapter 4 of the Navguide covers e-Navigation. Automatic Identification System (AIS), radio aids to navigation and Global Navigational Satellite Systems form a key element of the e-Navigation infrastructure and are therefore covered in Chapter 4.

### 3.1 Visual Aids to Navigation

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 vessel has a radar, or;
- 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); and
- the reliability and availability of the aid.

Visual aids to navigation can be distinguished by a wide range of characteristics such as:

- type; shape; size; colour; names, retro-reflective features; letters and numbers.
- lit/unlit; signal character; light intensity; sectors; inclusion of subsidiary aids;
- fixed structure; floating platform; construction materials; and
- location; elevation; relationship to other aids to navigation and observable features.



*Photo courtesy of IALA*

**Refer to IALA publications:**

*IALA Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation;*

*IALA Guideline 1035 on Availability and Reliability of Aids to Navigation.*



### 3.1.1 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. Although the colour regions defined in this IALA recommendation agree with those given in the International Commission on Illumination (CIE) Standard S 004/E 2001<sup>11</sup> “Colours of Light Signals”, the boundaries of each colour region differ in some cases. Furthermore, in their standard, CIE recommend that signal systems should normally comprise no more than four colours.

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<sup>12</sup>.
- Orange and fluorescent red, yellow, green or orange may be used for special purposes requiring high conspicuity.

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 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).

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.

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.

The CIE standard for signalling colours has recently been revised, with some adjustments to the boundaries of signal colours.

For further details on this issue please refer to CIE S 004/E-2001 Colours of Light Signals<sup>13</sup>.

**Refer to IALA publications:**

*IALA Recommendation E-106 for the use of retro-reflecting 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.*

*Recommendation E-200-3 on Marine Signal Lights - Measurement.*

<sup>11</sup>CIE S 004/E 2001 replaces CIE 2.2 - 1975, “Colours of Light Signals”.

<sup>12</sup>Blue surface colours may be used in inland waterways, estuaries and harbours where the colours 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.

<sup>13</sup>CIE web site address: [www.cie.co.at/cie](http://www.cie.co.at/cie)



Figure 6 –  
Illustration of the colour zones on the 1931 CIE chromaticity diagram.  
(Note that the colour rendering is only indicative and should not be taken as fully accurate)

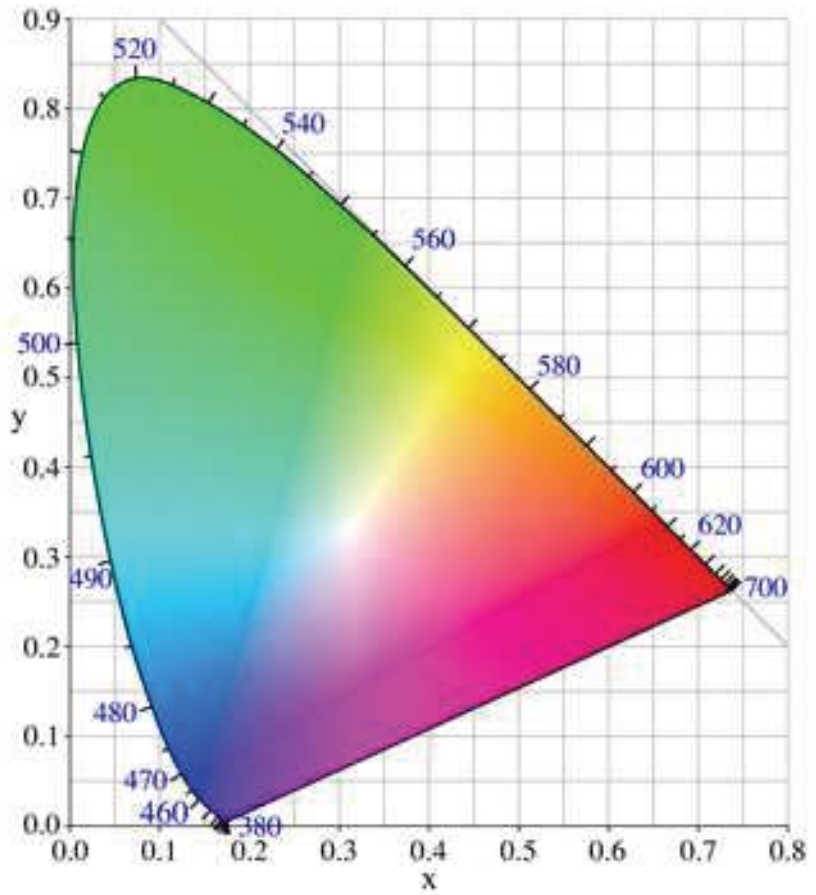
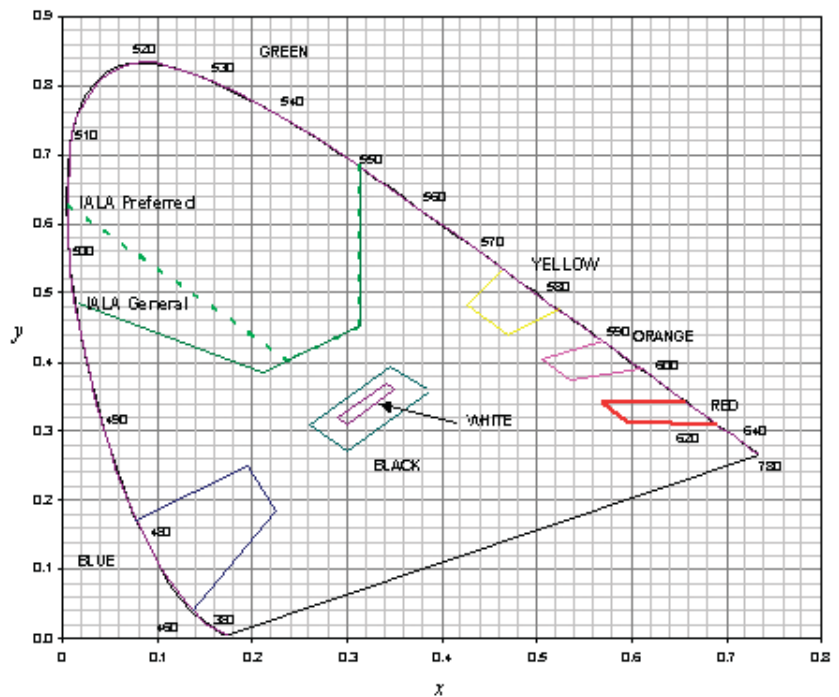


Figure 7 –  
IALA allowed chromaticity areas for red, orange, yellow, green, blue, white and black of Ordinary Surface Colours (As plotted on the 1983 CIE chromaticity diagram - Courtesy of CIE)





### 3.1.2 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 retro-reflecting material);
- contrast (Type of background – lighting, vegetation, snow, etc);
- mark lighted or unlit;
- intensity and character.



*Photo courtesy of Australian Maritime Safety Authority*

### 3.1.3 Meteorological Visibility

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

### 3.1.4 Atmospheric Transmissivity

The atmospheric transmissivity (T) is defined as the transmittance or proportion of light from a source that remains after passing through a specified distance through the atmosphere, at sea level.

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;
- a figure of  $T = 0.84$  is occasionally used in regions where the atmosphere is very clear.

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

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

### 3.1.5 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.

### 3.1.6 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<sup>2</sup>)

$L_o$  = luminance of object (cd/m<sup>2</sup>)

The contrast at which an object can be detected against a given background 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.



### 3.1.7 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:

- 7 x 50<sup>14</sup> type at night, and;
- 10 x 50 binoculars by day.

### 3.1.8 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.

### 3.1.9 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. (IALA International Dictionary of Aids to Marine Navigation).

A Geographical Range table is shown in Table 5.

**Table 5 – IALA Geographical Range Table**

Geographical Range in Nautical Miles											
Observer eye height 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

The values in Table 5 are derived from the formula:

where:  $R_g$  = geographical range (nautical miles)  $R_g = 2.03 \times \left( \sqrt{h_o} + \sqrt{H_m} \right)$   
 $h_o$  = elevation of observer's eye (metres)  
 $H_m$  = elevation of the mark (metres)

**Note** - 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.

<sup>14</sup>That is, a magnifying power of 7 and an objective lens of 50 mm diameter.

### 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 2700°K.

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

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

Where: V = meteorological optical range (nautical miles)

d = distance (nautical miles)

T = atmospheric transmissivity

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

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

### 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.

### 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 take into account the:

- height of the light;
- observer's height of eye; or
- curvature of the Earth.

### 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 Aids to Navigation Lights

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 the efforts to understand 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 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 have gas lights that burn acetylene or propane. However, the majority of aids to navigation lights use electric lamps of various types. Increasingly, these lamps draw their power from renewable energy sources such as solar, wind or wave power.

Electric lamps 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.

Light Emitting Diode (LED) technology is now used widely as an alternative to filament lamps.

### 3.2.1 Gas Lights

#### Acetylene

The acetylene light has a special place in the history of aids to navigation, primarily for being the first reliable means of automating lighthouses, buoys and beacons during the earlier part of the 20th century. Acetylene lighting systems originated from the inventions of Gustaf Dalén and were made by a number of suppliers. Acetylene gas has the unusual property of burning with a white flame when correctly mixed with air. This enabled the development of exceptionally reliable open flame lanterns.

Acetylene lighting technology was further enhanced by the development of the Dalen “mixer” that allowed gas and air to be drawn into a chamber and then consumed in an incandescent mantle to produce a brighter light source than the open flame type. The incandescent mantle can be operated as a flashing source inside a fixed lens or as a continuous source inside a rotating lens. Related developments included a gas-operated mechanism for rotating a lens and a clockwork powered automatic mantle changing device.

#### Propane and Butane

Propane and butane gases have been used as fuels for gas lighting systems. The lighting equipment has to use an incandescent mantle burner as both gasses burn with yellow / orange flames when an open flame burner is used.

Gas lighting installations continue to be used in some countries, where they are chosen for their robustness and simplicity of operation. They have been replaced by solar / electric installations in many countries generally resulting in considerable savings in operating costs.

**Refer to IALA publication:**

*Practical Note for the Safe Handling of Gases, October 1993.*

### 3.2.2 Electric Lights

#### Incandescent filament lamps

##### Tungsten filament

###### *Description of operation:*

- Can be operated directly from an appropriate electrical supply.
- Nominal voltage 6 to 240 Volt (V), both Alternating Current (AC) and Direct Current (DC).
- These light sources have been used in most countries from at least the early 1900s. Many special lamp designs have been used over the years, as filament size, shape, and location must be well matched to the lens system.

###### *Typical use:*

All types of lighted beacons (e.g. leading lights, sector lights, 360° lights and lanterns on light buoys) Some countries and manufacturers have adopted standard designs, with reference codes, for lamps designed specially for lighthouse applications. These designs typically include filament supports to maintain filament shape and ensure an even output over 360 degrees azimuth.

###### *Technical data:*

- Power: From 2 to 1000 Watt (3 500 W lamps have been used in the past)
- Efficiency: From 9 to 19 lumens/ W
- Operating life: From 300 to 1500 hours

###### *Advantages:*

- Coding can be easily achieved by interrupting the electrical supply.
- Filament geometry can be designed to match the optic.
- Diffusing envelope (e.g. pearl or etched) can improve lens illumination when used in older optics, but at the expense of reduced intensity.
- Broad colour spectrum provides good performance with most coloured filters.
- Output reasonably stable over lifetime, but lamp envelope may start to blacken before lamp failure.
- Remote monitoring by current sensing is simple.

###### *Disadvantages:*

- Relatively short lifetime.
- Specialist AtoN lamps are expensive.
- Colour rendering is not in the preferred white region (tends towards yellow).
- Efficiency poor.

###### *Safety:*

- High envelope temperature when in use.
- Operating voltage may be hazardous.
- Possible risk of arcing.
- General glass hazard.

###### *Disposal:*

Safe disposal appropriate for metal and glass waste.



## Tungsten halogen

### *Description of operation:*

The tungsten halogen lamp encloses a small amount of halide with inert gas, and the tungsten evaporating from the hot filament combines with the halogen to diffuse around the envelope wall. Due to careful design the envelope operates at high temperature, and this prevents deposition of tungsten on the glass. The tungsten-halide is then carried by convection towards the filament where it is decomposed and the tungsten metal deposited back onto the filament.

- Can be operated directly from an appropriate electrical supply.
- Nominal voltage 12 to 240 V, both AC and DC.

### *Typical use:*

All types of lighted beacons, but several lamps could be used in a cluster in large rotating optics, to produce a large light source similar to the original non-electric light source.

### *Technical data:*

- Power: From 5 to 1000 W, exceptionally 1500 and 2000 W
- Efficiency: 20 to 25 lumen/W
- Operating life: 300 to 4000 hours.

**Note** - some very bright lamps have a short working life

### *Advantages:*

- Coding can be easily achieved by interrupting the electrical supply, but see below.
- Higher luminance than tungsten lamps.
- Output very stable over lifetime.
- Colour rendering good in white preferred region.
- High performance general-purpose lamps available at low cost.
- Small lamp sizes (10 to 100W) are very mechanically robust.
- Envelope sizes are typically smaller than tungsten lamps, and may allow smaller optic system sizes.

### *Disadvantages:*

- The filament size is usually small hence the geometry is poor when modernising old lens systems.
- Generally low operating voltage results in high current requiring careful design of lamp holder and associated wiring.
- A cluster of several lamps will be required to match these small lamps to existing large optics.
- Lamps are not made specifically for AtoN use and specifications may be changed without notice.
- The flashing of tungsten halogen lamps may lead to the interruption of the halogen cycle with consequent blackening of the envelope and premature failure. Practical trials are recommended with the proposed operating voltage and duty cycle or consultation with other IALA members.
- Lamps should not be touched with bare hands due to consequential reduction in lamp life.

### *Safety:*

- Operating voltage may be hazardous.
- General glass hazards.
- Very high surface temperatures because of the small envelope size.
- Possible high Ultra Violet (UV) radiation risk (dependant on lamp type).
- Risk of explosion with high-pressure lamp types.

### *Disposal:*

Local and national waste disposal regulations should be consulted regarding tungsten halogen lamps.



## Discharge lamps

### Fluorescent

#### *Description of operation:*

110 to 240 V system voltage with control circuitry to provide a high starting voltage.

#### *Typical use:*

Direction arrows, signs and light tubes or bars used for leading lights. Applications where large areas of illumination are an advantage.

#### *Technical data:*

- Power: 8 to 100 W
- Efficiency: 80 to 100 lumen/W
- Operating life: Up to 20000 hours

#### *Advantages:*

- High luminous efficiency.
- Large illuminated area. In suitable applications no optical elements are needed thus providing a very low cost AtoN.
- Very wide range of commercially available products at low prices.
- Many colours available (no additional colour filters needed).

#### *Disadvantages:*

- Low luminance.
- Difficult to use with lens systems due to source size.
- Light output falls considerably over lifetime.
- Requires control circuitry matching lamp and supply voltage.
- Complex circuitry needed to flash.
- Possible Electromagnetic Compatibility (EMC) problems.

#### *Safety:*

- Mains voltage.
- General glass hazard.
- Internal tube coatings may be hazardous if exposed and they contain traces of gaseous mercury.
- High voltage due to starting equipment.

#### *Disposal:*

Tube coatings may be hazardous and contain traces of mercury. Consult local and national disposal regulations.

## Low-pressure sodium vapour lamps

#### *Description of operation:*

- 110 and 240 V AC with associated control circuitry.
- NOTE: Only available as yellow colour

#### *Typical use:*

- Flood lighting and external illumination of structures, towers, locks etc.

#### *Technical data:*

- Power: 20 to 180 W
- Efficiency: 180 lumen/W
- Operating life: 10 000 hour



*Advantages:*

- Long life.
- High luminous efficiency.
- Mercury free.
- Low envelope surface temperature.
- Can be used to provide yellow signal colour.
- Minimum attraction for insects.

*Disadvantages:*

- Only produces yellow light.
- Low luminance.
- Not practical to flash (code).
- Limited operating positions.

*Safety:*

- General glass hazards.
- High AC voltage.
- Chemical hazard due to sodium content.

*Disposal:*

- Consult local and national regulations regarding sodium disposal.

## **High Pressure Sodium Vapour Lamps**

*Description of operation:*

- 110 or 240 V AC with associated control circuitry.

*Typical Use:*

- White lamps may be used as AtoN light source.

*Technical Data:*

- Power: 50 to 400W
- Efficiency: 90 lumens/W
- Operating Life: 10000 hour

*Advantages:*

- Long life.
- Mercury free.
- High efficiency.
- Available in white.

*Disadvantages:*

- Can not be coded (flashed).
- Only practical as white Low red content makes colour filtering impractical.
- High strike voltage to start.
- Complex lamp changer required due to long warm-up period and cool-down necessary before restart.
- Arc tube geometry is poor for most optics.
- Light output falls over life and white colour degrades to yellow.

*Safety:*

- General glass hazards.
- High voltages.
- Chemical hazards giving rise to disposal or health problems.

*Disposal:*

- Consult national and local regulations regarding sodium disposal.

### Metal halide

#### *Description of operation:*

The metal halide lamp is one of a family of HID [High Intensity Discharge] lamps, and its arc tube is made of silica glass. The principle of emission is as follows: 1) High voltage from the ballast initiates current flow between the electrodes; 2) As the lamp temperature rises, metals in the lamp evaporate, and light emission occurs.

- Working with control circuitry allows input voltages of 12V to 240V for 110 and 240 V power sources.

#### *Typical use:*

- Used as a fixed light source in rotating optics, fixed lenses with rotating screens and general floodlighting.

#### *Technical data:*

- Power: 10 to 2000 W
- Efficiency: 80 to 110 lumen/W
- Operating life: 6 000 to 20 000 h

**Note:** Operating life is very dependant on the number of times that lamp is switched on

#### *Advantages:*

- High luminous efficiency.
- Clear envelope types have high illuminance.
- Coated envelope types have good geometry for traditional lenses.
- Long life.
- Many commercial lamp types available.
- Colour rendering is good, within IALA white preferred region.
- Absence of a filament means good resistance to vibration and shock.

#### *Disadvantages:*

- Not practical to code (flash).
- Initial warm-up is slow.
- Cooling time needed before re-strike hence complex lamp changer design.
- Difficult to remote monitor by simple current sensing.
- Light output falls with life.
- Red spectrum is limited so red filtering is possible but poor, green is good.

#### *Safety:*

- High voltage hazards.
- High UV radiation.
- Possible EMC problems.
- Possible explosion hazard.
- General glass hazard.
- May contain hazardous metal.

#### *Disposal:*

- Consult local and national regulations for these lamps, as there is some mercury content.



## **Xenon Lamps**

### *Description of operation:*

Xenon lamps are discharge lamps, with the xenon gas enclosed in a silica tube at high pressure. An electrical discharge through the xenon gas generates a high intensity white light. (Xenon discharge is commonly used in camera flash guns.)

- 110 and 240V typically.
- Charging DC supply requires complex control circuitry.
- Available as pulsed or continuous discharge types.

### *Typical use:*

- A specialised light source used where high intensity is of paramount importance. Can be used in fixed or rotating optics.

### *Technical data:*

- Power: 150 to 2000 W
- Efficiency: 35 lumens/W
- Operating life: 2000 h

### *Advantages:*

- High luminance enabling high intensities to be achieved with suitable optics.
- Broad white colour spectrum allowing good colour filtering.

### *Disadvantages:*

- Electrical control system is complicated.
- Lamp changer design is very complex.
- Short lamp life.
- Electronic control components have short life.
- Relatively expensive.
- Power consumption is variable due to the charging/discharging cycle of the system, resulting in varying loads on the power supply system.

### *Safety:*

- High voltages.
- Possible danger of explosion as the pressure in the lamp is high.
- High UV radiation
- High surface temperature
- General glass hazards

### *Disposal:*

- Check local and national regulations for the lamp type. There may be some mercury content.

### Light Emitting Diode (LED)

*Description of operation:*

#### Coloured LEDs

- LEDs are electronic semiconductor devices that produce near monochromatic light. The semiconductor junction is encapsulated in a clear plastic housing that usually incorporates a lens. Several LEDs may be grouped together in a cluster or an array to provide a light source of the required size and intensity with lamp redundancy. New high power LEDs allow short range lanterns using a single LED.
- LEDs operate from a low voltage DC supply. Correct operation depends on accurate control of the supply current.



*VLB-44 medium range LED  
– photo courtesy of Vega Industries*

#### White LEDs

- 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. Research is in progress on combining red and green LED lights to produce a white light within the IALA chromaticity specification.
- LED marine lanterns are sometimes reported as having intense colours and ranges longer than the current IALA calculation method would suggest. Current work by IALA is investigating this.



*LED 350  
– photo courtesy of  
Sabik Oy*

*Typical use:*

- Lighted beacons on buoys and other short 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 1mW to 5W  
LED cluster in lantern 1W to 60W or even higher.
- Efficiency: This depends on colour: Red and green – 25 to 30 lumen/W  
Yellow – 20 to 30 lumen/W  
White – 20 to 30 lumen/W  
Blue – 10 lumen/W
- Operating life: Depends on the LED junction operating temperature and operating environment  
Possible values in excess of 100,000 hours for a single diode

*Advantages:*

- Very long life (so long as input power and temperature is 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.
- Rise and fall times are very fast.
- Relatively cool operation.
- Ease of ability 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 outside the new CIE (2001) white colour region.
- 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.
- LED technology is not yet suitable for long range lights.

*Safety:*

- No special hazard.

*Disposal:*

- Consult National and local regulations regarding disposal of semiconductors.

**Note:** Extensive research in LED technology is continually providing more LED efficient products

## **Lasers**

A laser is a device that produces a coherent collimated beam of monochromatic light.

Their use has not been established in AtoN light systems, despite the work over some decades. However, research continues into the use of lasers to improve the visibility and sector distinction of fairway lighting including two areas of development:

1. **High power lasers** can be used to provide a line of light in the sky where particles of dust, water etc. are illuminated by the laser beam to provide a leading line. These devices require considerable electrical power (several kW). Detailed safety procedures are required for safe operation and servicing.
2. **Low power lasers**, where the laser is aimed directly at the mariner. Different coloured lasers are used to identify areas of navigational importance. The laser light is visible at useful range in daylight.

Power requirements are low (tens of Watts). The laser projectors are expensive and require complex control systems. Detailed procedures are required for safe servicing.

Laser trials are also taking place in Russia and Japan.

*Advantages:*

- Single wavelength.
- Strong directivity.
- Simple optic design.

*Disadvantages:*

- High power requirements for high power lasers.
- System complexity may be a problem at some locations.

*Safety:*

Possible eye damage under certain conditions, if appropriate ASTM safety standards are not applied.

**Refer to IALA publication:**

*IALA Guideline 1043 on Light Sources used in Visual Aids to Navigation.*

### 3.2.3 Photometry of Marine Aids to Navigation Signal Lights

#### Measurement of Light

**Refer to IALA publication:**

*IALA Recommendation E-200-3 on Maritime Signal Lights - Part 3 - Measurement.*

The behaviour of light, in physics, is normally seen in the context of either a form of electromagnetic radiation or particle motion. The latter includes the concept of “rays” of light that are used in analyzing the interactions of light and lenses.

The units of interest for electromagnetic applications of light are generally metres (wavelength) and watts (power).

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 6.

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 observers and  $V'(\lambda)$  for scotopic observers.

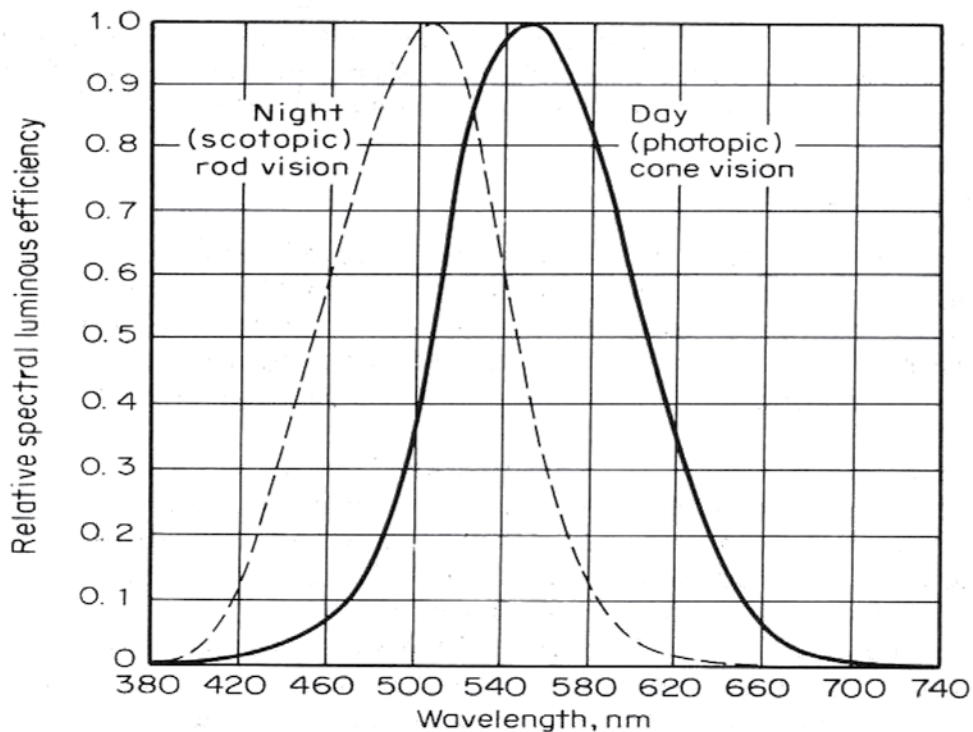


Figure 8 - Spectral sensitivity distributions or  $V(\lambda)$  and  $V'(\lambda)$  curves for the human observer also showing the difference between day and night vision



## Units of Measurement

Table 6 - Photometric units of measurement

Term	Description	Unit	Abbreviation
Luminous flux	<p>This is the total light emitted from the source (ie. lamp)</p> <p>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.</p>	lumens	lm
Luminous intensity	<p>This is the part of the luminous flux in a particular direction.</p> <p>Also expressed as the luminous flux per solid angle (or steradian<sup>15</sup>)</p>	candela	cd
Luminance (Brilliance)	<p>This is the portion of the luminous flux emitted in a specific direction by the surface area of a luminous body.</p> <p>This variable is an important term for rating the brightness impression of light sources and illuminated objects.</p>	<p>candelas per square metre and also as candelas per square centimetre</p>	<p>cd/m<sup>2</sup> cd/cm<sup>2</sup></p>
Illuminance	<p>This is the density of the luminous flux incident on a surface.</p> <p>It is the quotient of the luminous flux by the area of the surface when the surface is uniformly illuminated</p>	<p>lux (lumens/square metre)</p>	lx
Luminous efficacy	<p>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.</p>	lumens per watt of electrical power consumed	
Colour temperature	<p>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.</p> <p>The colour appearance of a tungsten filament lamp is similar to a black body at the same temperature.</p>	Kelvin	°K
Colour rendering index	<p>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.</p>		CRI

<sup>15</sup>The steradian is the equivalent in solid geometry to the definition of radian in plane geometry. The steradian is defined as the unit of measure of a solid angle with its vertex at the centre of a sphere and enclosing an area of the spherical surface equal to that of a square with sides equal in length to the radius. There are  $4\pi$  steradians in a sphere. For further explanation see IALA Recommendation E-200-3.



### 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 micro lux 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 micro lux<sup>16</sup> 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.

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.

#### Refer to IALA publication:

*IALA Recommendation E-200-2 on Maritime Signal Lights - Part 2 - Calculation, Definition and Determination of Luminous Range.*

### Luminous intensity

The luminous intensity of a navigation light is directly proportional to the luminance of the light source.

The size of the light source is inversely proportional to its luminance and directly proportional to the divergence of the optic system.

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

### 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 9, 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*.

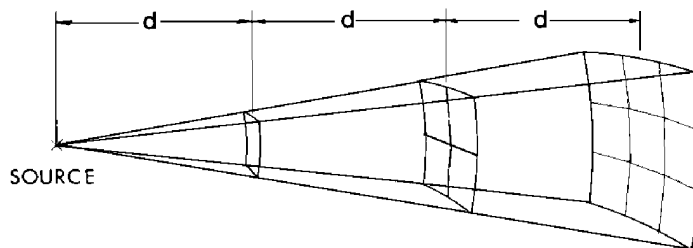


Figure 9 – Illustration of the Inverse-Square-Law concept.

<sup>16</sup>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.



## 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 Allard's Law:

$$E = \frac{I \times T^d}{d^2}$$

where:

- $E$  = illuminance at the observer's eye ( $\text{lm}/\text{m}^2$ )
- $I$  = effective intensity of the light source (cd)
- $T$  = atmospheric transmissivity
- $d$  = distance between the light source and the observer.

(Because  $T$  is measured per nautical mile,  $d$  in the numerator must also be in nautical miles. In the denominator,  $d$  is in metres)

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

Where average background luminance is large, as typically happens during the daytime, the equation becomes:

$$E = [I - (L - L')A] \times \frac{T^d}{d^2}$$

where:

- $L$  = luminance ( $\text{cd}/\text{m}^2$ ) of the background light, measured in the direction of the line of sight from a position near the AtoN light (e.g. a patch of sky next to the lighthouse)
- $L'$  = average luminance ( $\text{cd}/\text{m}^2$ ) of the unlighted AtoN measured in the direction of the line of sight from a position near the lighthouse (e.g. a luminance measurement of a lighthouse optic lens with the lamp switched off)
- $A$  = area ( $\text{m}^2$ ) of the AtoN light beam projected onto a plane normal to the line of sight (e.g. a measurement of the lit area of a lighthouse optic)
- $(L - L')A$  = Since  $I = LA$ , this is the light intensity required to make the average luminance of the projector equal to that of the background (cd)

Note 1: Luminance is equal to Intensity divided by Area ( $L = I / A$ ). Luminance measurements can be carried out with a luminance meter; typically these are devices that measure a quantity of light through a fixed aperture of known area.

Note 2: When the AtoN light exhibited is of a significantly different colour to the background light, Allard's Law may not apply.

## 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 spectroradiometer, known as '**array-based spectroradiometers**', are now available. Instead of a single photoreceptor and a rotating monochromator, a fixed monochromator has its output directed at an array of charge-coupled devices (CCDs). Such devices are capable of much faster measurement speeds than stepping monochromators.

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

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.

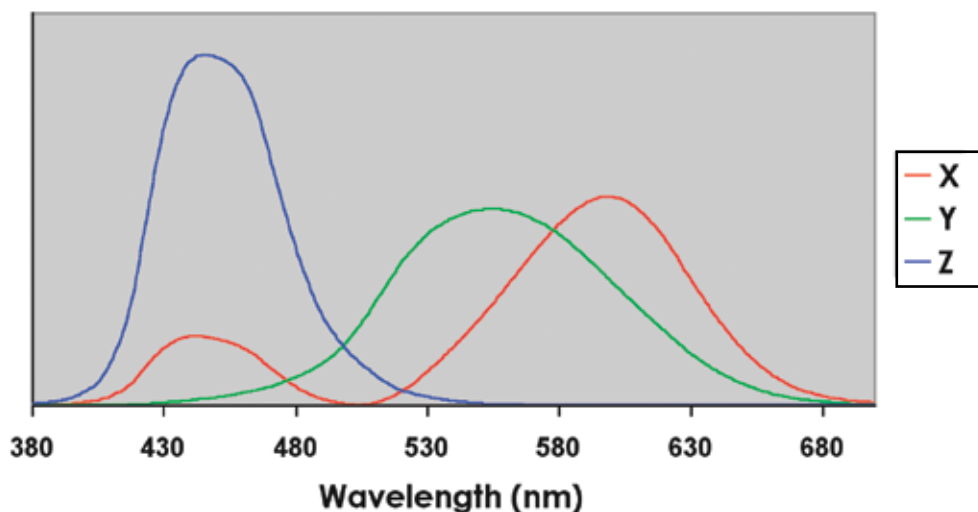
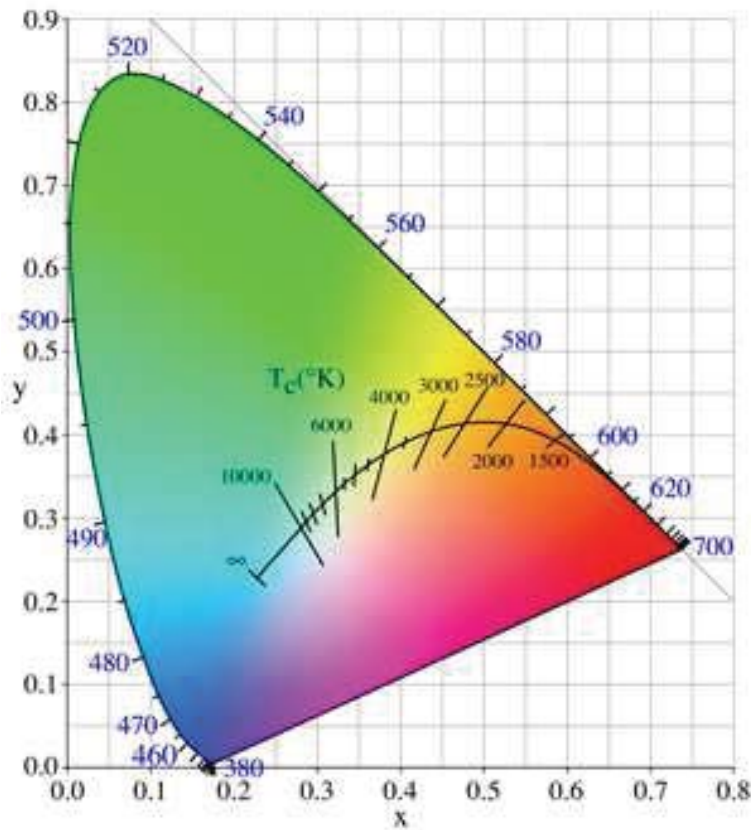


Figure 10 – CIE 1931 Colour Functions



Resultant data from colour measurements is 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.



### CIE 1931 x, y Chromaticity Chart

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

Figure 11 – CIE 1931 x,y Chromaticity Chart

**Refer to IALA publication:**

*IALA Recommendation E-200-3 on Marine Signal Lights - Part 3 - Measurement.*

### 3.2.4 Rhythms / Character

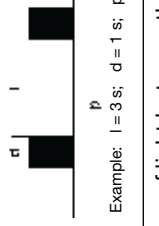
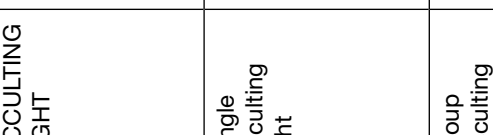
IALA has produced a recommendation on the characters for light on aids to navigation. The tables of classifications and specifications of aid to navigation characters are provided in Table 7 – Classification Of The Rhythmic Characters Of Lights

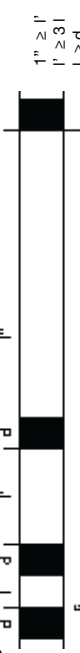



**Refer to IALA publication:**

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


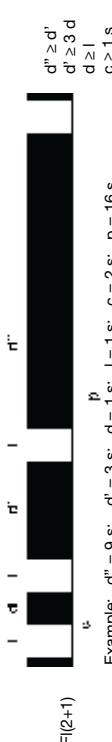
The Rhythmic Characters of Lights are provided in Table 8 – Rhythmic Characters of the Lights in the IALA Maritime Buoyage System.

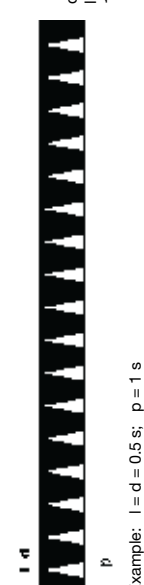
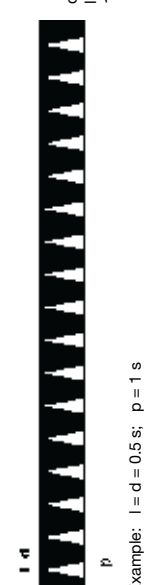
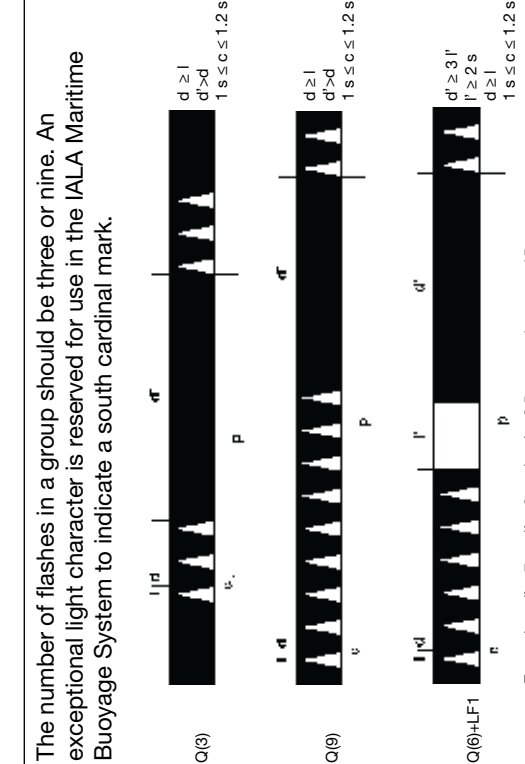
Table 7 – Classification Of The Rhythmic Characters Of Lights

	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 	A single occulting <i>White</i> 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 <i>Yellow</i> light indicates a special mark.



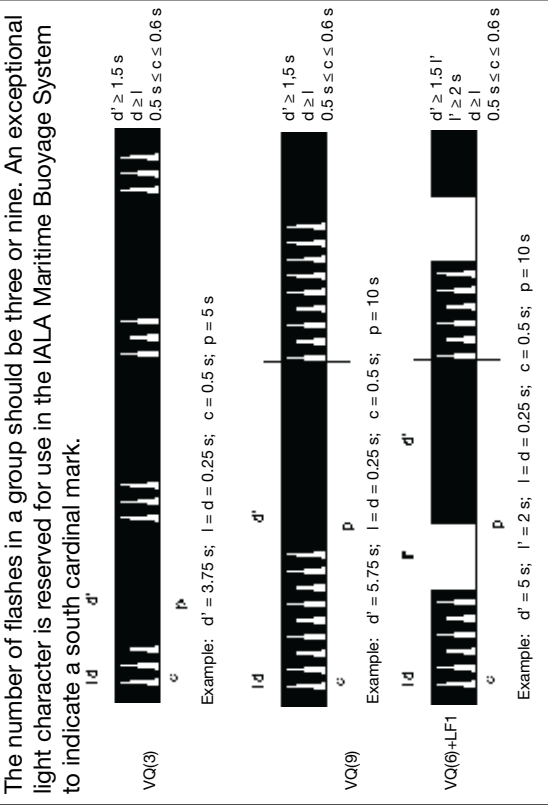
	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
2.3	Composite group occulting light	Oc(# + #) eg. Oc(2 + 1)	A light similar to a group occulting light except that successive groups in a period have different numbers of eclipses.	<p>This class of light character is not recommended because it is difficult to recognize.</p>  <p>Example: <math>l'' = 9</math> s; <math>l' = 3</math> s; <math>l = 1</math> s; <math>d = 1</math> s; <math>c = 2</math> s; <math>p = 16</math> s</p> <p><math>l'' \geq l'</math> <math>l' \geq 3l</math> <math>l \geq d</math> <math>c \geq 1</math> s</p> <p>Oc(2+1)</p>	
3	ISOPHASE LIGHT	Iso	A light in which all the durations of light and darkness are clearly equal.	<p>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.</p>  <p>Example: <math>l = d = 2</math> s; <math>p = 4</math> s</p> <p><math>l = d</math> <math>p \geq 2</math> s</p>	An isophase <i>White</i> 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.	<p>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.</p>	
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).	<p>The duration of the interval of darkness (eclipse) between two successive flashes should not be less than three times the duration of a flash.</p> <p>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).</p>  <p>Example: <math>d = 3</math> s; <math>l = 1</math> s; <math>p = 4</math> s</p> <p><math>d \geq 3l</math> <math>p \geq 2</math> s</p>	A single flashing <i>Yellow</i> light indicates a special mark.
4.2	Long flashing light	LFl	A single flashing light in which an appearance of light of not less than 2 s duration (long flash) <sup>17</sup> is regularly repeated.	 <p>Example: <math>d = 8</math> s; <math>l = 2</math> s; <math>p = 10</math> s</p> <p><math>d \geq 3l</math> <math>l \geq 2</math> s</p>	A long flashing <i>White</i> light with a period of 10 s indicates a safe water mark.

<sup>17</sup>The term "long flash", which is used in the descriptions of the long-flashing light and of the light characters reserved for south cardinal marks, means an appearance of light of not less than 2 seconds duration. The term "short flash" is not commonly used and does not appear in the Classification. If an Authority requires discrimination between two flashing lights that only differ in having flashes of different durations, then the longer flash should be described as "long flash" and be of not less than 2 seconds duration, and the shorter flash may be described as "short flash", and should be of not more rhythmic character of such a light is than one third of the duration of the longer flash.

	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
4.3	Group flashing light	Fl(#) eg. Fl(2)	A flashing light in which a group of flashes, specified in number, is regularly repeated.	<p>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.</p> <p>The number of flashes in a group should not be greater than five in general, and should be six only as an exception.</p> <p>The duration of an eclipse within a group should not be less than the duration of a flash.</p> <p>The duration of an eclipse between groups should not be less than three times the duration of an eclipse within a group.</p> <p>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.</p> <p>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).</p> 	<p>A group flashing <i>White</i> light with a group of two flashes, in a period of 5 s or 10 s, indicates an isolated danger mark.</p> <p>A group flashing <i>Yellow</i> light with a group of four, five or (exceptionally) six flashes indicates a special mark</p>
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.	<p>Light characters should be restricted to (2 + 1) flashes in general, and should be (3 + 1) flashes only as an exception.</p> 	<p>A composite group flashing <i>Red</i> or <i>Green</i> light with a group of (2 + 1) flashes indicates a modified lateral (preferred channel) mark.</p> <p>A composite group flashing <i>Yellow</i> light indicates a special mark.</p>

	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
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.	<p>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.</p> 	
5.1	Continuous quick light	Q	A quick light in which a flash is regularly repeated.		A continuous quick <i>White</i> light indicates a north cardinal mark.
5.2	Group quick light	Q(#) eg Q(3) eg Q(9) eg Q(6) +LFI	A quick light in which a specified group of flashes is regularly repeated.	<p>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.</p> 	<p>A group quick <i>White</i> light with a group of three flashes, in a period of 10 s, indicates an east cardinal mark.</p> <p>A group quick <i>White</i> light with a group of nine flashes, in a period of 15 s, indicates a west cardinal mark.</p> <p>A group quick <i>White</i> 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.</p>



	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
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.		A continuous very quick <i>White</i> light indicates a north cardinal mark.
c	Group very quick light	VQ(#) eg VQ(3) eg VQ(9) eg VQ(6)+LFI	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. 	A group very quick <i>White</i> light with a group of three flashes, in a period of 5 s, indicates an east cardinal mark. A group very quick <i>White</i> light with a group of nine flashes, in a period of 10 s, indicates a west cardinal mark. A group very quick <i>White</i> 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.

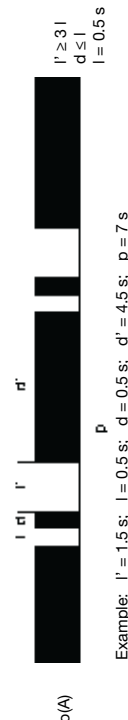


	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
7	ULTRA QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 160 flashes per minute.	A light in which flashes are repeated at a rate of not less than 240 flashes per minute 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".  Example: $l' = 1.5 \text{ s}$ ; $l = 0.5 \text{ s}$ ; $d = 0.5 \text{ s}$ ; $d' = 4.5 \text{ s}$ ; $p = 7 \text{ s}$	A Morse Code <i>White</i> light with the single character "A" indicates a safe water mark. A Morse Code <i>Yellow</i> light, but not with either of the single characters "A" or "U", indicates a special mark.
9	FIXED AND FLASHING LIGHT	FFI	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. 	
10	ALTERNATING LIGHT	AI## 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.  Example: $l = d = 2 \text{ s}$ ; $p = 4 \text{ s}$	

Table 8 – Rhythmic Characters of the Lights in the IALA Maritime Buoyage System

Mark	Rhythmic character of the light	Remarks and further recommendations
LATERAL	All recommended classes of rhythmic character <sup>18</sup> , 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" <sup>19</sup> .	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	1 s of blue light and 1 s of yellow light with 0.5 s of darkness between	Yellow/blue alternating

<sup>18</sup>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.

<sup>19</sup>A Morse Code white light with the single character "U" is assigned to offshore structures.



## Maximum Periods for Light Characters

**Refer to IALA publications:**

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

Table 9 is an extract of the recommended maximum periods for rhythmic characters of lights.

**Table 9 – Maximum period for rhythmic characters of aids to navigation lights**

Character Class	Maximum period (seconds)
Isophase light	12
Single-occluding light	15
Single-flashing light	15
Group very quick light	15
Interrupted very quick light	15
Interrupted ultra quick light	15
Group-occluding light	20
Long-flashing light	20
Group-flashing lights of two flashes	20
Group-quick light	20
Interrupted quick light	20
Group-occluding 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

## Timing of Astronomical Events

The description of a lighted Aid to Navigation emphasises the night time operations but daytime role is often as important. The astronomical events that define the transitions from day to night are shown in Table 10<sup>20</sup>.

<sup>20</sup>The timing of astronomical events can also be applied to calculations (computer programs) for sizing solar power supplies.

Table 10 – Timing of Astronomical Events

Event	Condition	Typical Illumination Lux	Comment (Assuming the absence of moonlight, artificial lighting or adverse atmospheric conditions)
Sunset/Sunrise	Upper edge of the sun's disc is coincident with the horizon.	600	
Civil Twilight (beginning / ending)	Centre of the sun is at a depression angle of six (6) degrees below the horizon.	6	Illumination is sufficient for large objects to be seen but no detail is discernible. The brightest stars and planets can be seen. For navigation at sea, the sea horizon is clearly defined.
Nautical Twilight (beginning / ending)	Centre of the sun is at a depression angle of twelve (12) degrees below the horizon.	0.06	It is dark for normal practical purposes. For navigation at sea, the sea horizon is not normally visible.
Astronomical Twilight (beginning / ending)	Centre of the sun is at a depression angle of eighteen (18) degrees below the horizon.	0.0006	Illumination due to scattered light from the sun is less than that from starlight and other natural light sources in the sky.

### 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 publication:**

*IALA Guideline 1038 on Ambient Light Levels at which Aids to Navigation should switch on and off.*

### Night Operations

#### Nominal Range and Luminous Intensity

Table 11 provides a conversion between nominal range and luminous intensity.

**Refer to IALA publication:**

*Recommendation E200-2 On Marine Signal Lights - Calculation, definition and notation of luminous range.*



**Table 11 – IALA conversion table for Luminous Intensity and Nominal Range for night observations**

**Note** - This assumes an atmospheric transmissivity of  $T=0.74$  and a threshold of illumination of 0.2 microlux.

Nominal Range (nautical miles)	Luminous Intensity (candela)	Nominal Range (nautical miles)	Luminous Intensity (candela)
1	0.9	12	3600
1.5	2.4	13	5700
2	5	14	8900
2.5	9	15	14000
3	15	16	21000
3.5	24	17	32000
4	36	18	49000
4.5	53	19	73000
5	77	20	110000
6	150	21	160000
7	270	22	240000
8	480	23	360000
9	820	24	520000
10	1400	25	770000
11	2200	26	1100000

### 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.

The light can be made more conspicuous by increasing its intensity, changing its colour or by varying its rhythm.

### 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; and
- should be reduced to 0.01 lux if the background is very dark.

**Refer to IALA publications:**

*Recommendation E-112 for leading lights (including Microsoft 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.
- Reduce the intensity of the light by:
  - Reducing the illuminance of the light source.
  - 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.

**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.

**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), and;
- progressive deterioration of the light source over the service interval.

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



## 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 publication:**

*Recommendation E200-2 on Marine Signal Lights - Part 2 - Calculation, definition and notation of luminous range.*

*Recommendation E-111 on Port Traffic Signals.*

Table 12 and Figure 12 provide a conversion between nominal daytime range and luminous intensity.

**Table 12 – IALA conversion table for Luminous Intensity and Nominal Daytime Range**

Luminous intensity kilocandelas (103 cd)	Nominal range (rounded) nautical miles (M)	Luminous intensity Megacandelas (106 cd)	Nominal range (rounded) 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



### Luminous Range Diagram for Daytime use

The Luminous Range Diagram, shown in Figure 12 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 13).

**Table 13 Required Illuminance in varying meteorological conditions**

Meteorological condition	Luminance in $\text{cd}/\text{m}^2$	Required illuminance $E_i$ in $10^{-3} \text{ lx}$
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

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

#### Example:

Suppose that it is required to calculate the luminous range of a light of  $2\,000\,000 \text{ cd}$  for a meteorological visibility of 2 nautical miles under an ordinary overcast sky (luminance  $1\,000 \text{ cd}/\text{m}^2$ ).

Measure the distance A separating graduations  $10\,000 \text{ cd}$  and  $1\,000 \text{ cd}$  on the auxiliary scale.

Transfer this distance to the scale of abscissae from the graduation corresponding to  $2\,000\,000 \text{ cd}$  ( $2 \times 10^6 \text{ cd}$ ) 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.

### Daymarks (Dayboards)

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).

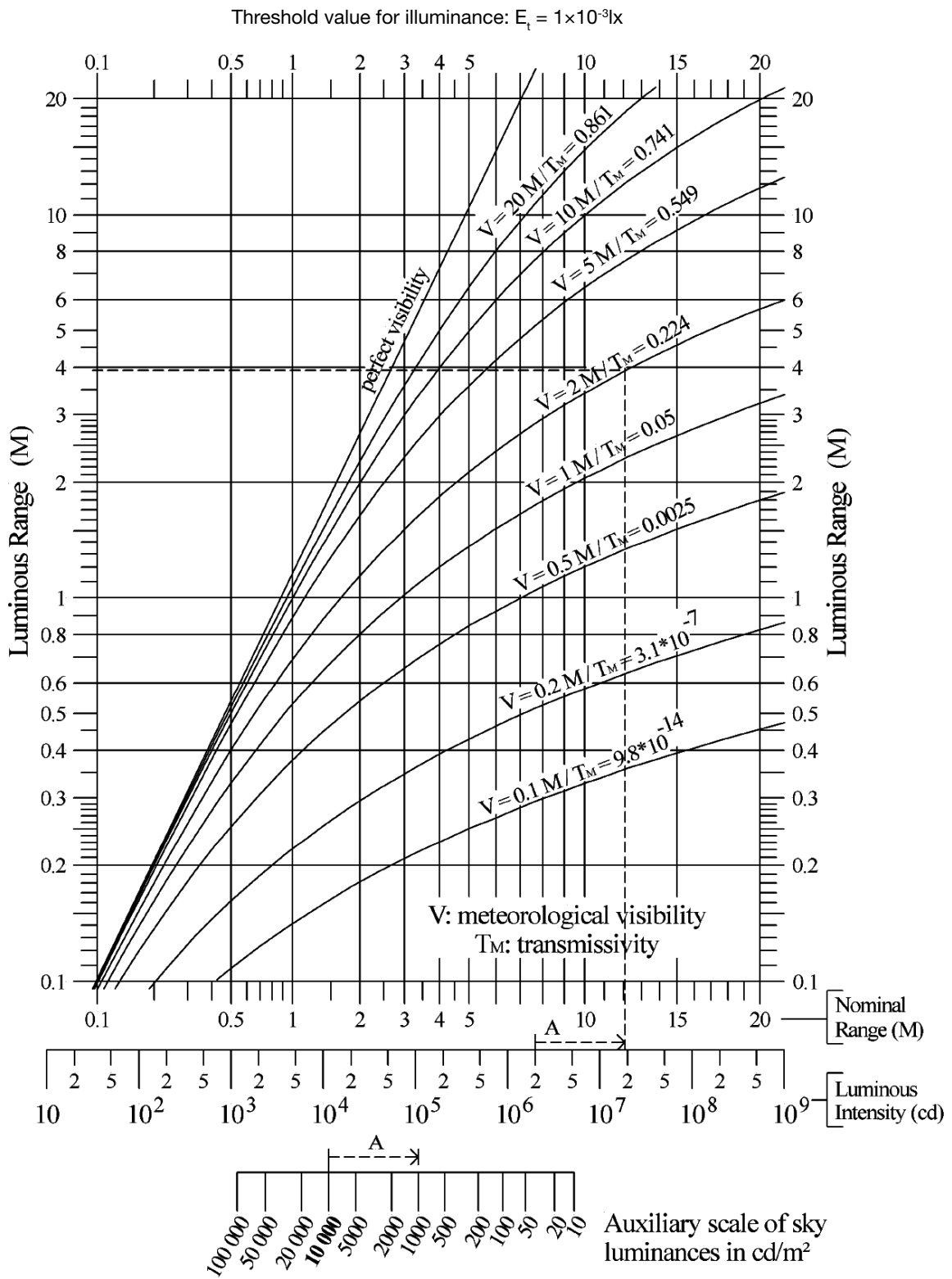


Figure 12 – Daytime Luminous Range Diagram

The typical operational range of daymarks under different visibility conditions is shown in Table 14.

**Table 14 – Typical operational range of daymarks**

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

Table 15 provides guidance on the impact of background lighting and meteorological conditions on light intensity required to achieve a particular range.

### 3.2.5 Fixed Aids to Navigation

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

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

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

Other aids to navigation such as audible signals and radio aids to navigation may be located on or near the lighthouse.

A lighthouse may be a staffed or automated facility, although the staffing of lighthouses is becoming less common.

An automated lighthouse will often be remotely monitored and in some cases remotely controlled.

Table 15 (Night and day with background) For Guidance Only – not to be used for Nominal Range Publication

Nominal Range	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)	Intensity (cd)
Background Lighting or Meteorological Condition (see 1.3.3)	None	Minor	Substantial	Day VDO	Day DO	Day OO	Day BO	Day BC	Day VBC			
Luminance (cd/m <sup>2</sup> )	2.00E-07	2.00E-06	2.00E-05	100	200	1000	5000	10000	20000			
Illuminance (lx)	0.74	0.74	0.74	1.30E-06	2.39E-06	1.07E-04	5.09E-04	9.99E-04	1.99E-03			
Transmissivity (per M)	10	10	10	0.74	0.74	0.74	0.78	0.79	0.81			
Visibility (M)	10	10	10	10	10	10	12	13	14			
Range (M)												
0.2	0.03	0.3	3	2	3	16	73	144	284			
0.5	0.20	2	20	13	24	107	492	961	1,880			
0.7	0.41	4	41	27	50	222	1,010	1,970	3,870			
1	1	9	93	60	111	465	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	966	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	4,960	9,170	41,000	151,000	271,000	456,000			
6	149	1,490	14,900	9,660	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	238,000	818,000	1,360,000	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	8,660,000			
12	3,600	36,000	360,000	234,000	460,000	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	1,660,000	7,360,000						
16	21,200	212,000	2,120,000	1,360,000	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										
21	163,000	1,630,000										
22	242,000	2,420,000										
23	367,000	3,670,000										
24	524,000	5,240,000										
25	767,000	7,670,000										
26	1,120,000											
27	1,630,000											
28	2,360,000											
29	3,420,000											
30	4,940,000											

Abbreviation	Meteorological Condition	Luminance (cd/m <sup>2</sup> )
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

**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.<sup>21</sup>

#### **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.
- Base for 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.

#### **3.2.6 Floating Aids to Navigation**

A floating aid to navigation serves a similar purpose to a beacon or 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.

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<sup>21</sup>In these situations the beacon will generally show a colour scheme and topmarks in accordance with the IALA Maritime Buoyage System.



## 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 in range of 1 to 3 m diameter. Buoys may be fitted with sound signals.

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

- where lights are exhibited they are usually solar or single cycle battery powered, however gas powered buoys are still in operation;
- where lights are exhibited, due to power limitations, light ranges are restricted to typically 2 to 5 nautical miles, although much higher ranges are used in some applications;
- additional services are restricted due to limited power on a buoy but racon and AIS units are sometimes deployed in addition to a light;
- electric fog signals are used on buoys in some countries.

## Lightvessels, Lightfloats and Large Navigational Buoys (LANBYS)

Lightvessels, lightfloats and lanbys (or LNB) are defined as **major floating aids** and may carry one or more of a racon, AIS AtoN, sound signal, and in some cases, a radio beacon in addition to the aid to navigation light. A lightvessel may also display a white riding light to signify a vessel at anchor.

These types of aids to navigation:

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

Some lightvessels continue to be manned, but the trend is towards automation, often with remote monitoring and control.

### Refer to IALA publication:

*IALA Recommendation O-104 for 'Off Station' signals for major floating aids to navigation.*

## IALA Maritime Buoyage System (MBS)

The Maritime Buoyage System 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 world wide 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.

The IALA Maritime Buoyage System uses 5 types of marks, which may be used in combination. The mariner can distinguish between these marks by identifiable characteristics. The system includes Cardinal and Lateral marks. The Lateral marks differ between Buoyage Regions A and B.



Synthetic buoy (Emergency Wreck Mark)  
Photo courtesy of China Maritime Safety Administration



Steel buoy (Cardinal Mark)  
Photo courtesy of Australian Maritime Safety Authority



Lanby  
Photo courtesy of Commissioner for Irish Lights



Lateral Mark  
Photo courtesy of Mobilis

Figure 13 – Some examples of floating aids



During the period 2006-2009 the IALA Maritime Buoyage System was revised by IALA. Key changes made to the MBS with effect from 2010 include introduction of an emergency wreck marking buoy in response to concerns from members over the marking of new, dangerous wrecks, the incorporation of lighthouses and digital aids to navigation.

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

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.

**Refer to IALA publications:**

*IALA Maritime Buoyage System (with supporting guidelines).*

*IALA Guideline 1046 on a Response Plan for the Marking of New Wrecks.*

*IALA Recommendation O-133 on the Emergency Wreck Marking Buoy.*

**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.<sup>22</sup>

The availability of a floating aid is the principal measure of performance determined by IALA. The recommended availability targets are indicated in Table 16.

**Table 16 – Availability Targets**

Type of Aid (examples only)	Availability Target	
Floating aids to navigation that are considered to be of primary navigational significance.	Category 1	at least 99.8%
Floating aids to navigation that are considered to be of navigational significance.	Category 2	at least 99%
Floating aids to navigation that are considered to be of less navigational significance than Category 1 or 2.	Category 3	at least 97%

**Note:** The availability objective assigned to floating aids to navigation conforming to the IALA Maritime Buoyage System should also apply to the topmark.

**Refer to IALA publications:**

*IALA Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation.*

*IALA Guideline 1035 on Availability and Reliability of Aids to Navigation.*

<sup>22</sup>As adapted from the IALA Guideline 1035 on Availability and Reliability of Aids to Navigation, Theory and Examples.



### Technical Considerations for Floating Aids to Navigation

There are various technical considerations that should be taken into account, including: cost; design factors; positioning 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:

*IALA 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:

*IALA Guideline 1006 on Plastic Buoys.*

*IALA Guideline 1011 on a standard method for defining and calculating the load profile of aids to navigation.*

*IALA Guideline 1036 on Environmental Considerations in Aids to Navigation Engineering.*

*IALA Guideline 1037 on Data Collection for Aids to Navigation Performance Calculation.*

*IALA Guideline 1040 on the Maintenance of Buoys and Small Aids to Navigation Structures.*

*IALA Guideline 1067-0 on Selection of Power Systems for Aids to Navigation and Associated Equipment.*

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

*IALA Guideline 1067-2 on Power Sources.*

*IALA Guideline 1067-3 on Electrical Energy Storage for Aids to Navigation.*

*IALA Guideline 1043 on Light Sources used in Visual Aids to Navigation.*

*IALA Recommendation E-106 on the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System.*



## Mooring Design and Swing Radius

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 and current on the floating aid and drag on the mooring line. The basic assumptions made for determining the forces are that the:

- mooring system is tangential to the sea bed under all conditions of current and wind at the site;
- 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.

## Swing Radius

The following formula can be used for determining the maximum swing radius.

Where the recommended minimum length of mooring line is:

- $L_{\min} = 3H$  for depths less than 50 metres;
- $L_{\min} = 2H$  for depths greater than 50 metres;
- $L_{\min} = 7H$  for shallow moorings where breaking waves occur

$L$  = Length of mooring line (m)

$H$  = Depth of water (m)

(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.)

### Refer to IALA publications:

*IALA Recommendation E-107 on Moorings for Floating Aids to Navigation..*

*IALA Guideline 1066 on the Design of Floating Aid 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 for positional errors to occur while laying the anchors/sinkers.

Anchors/sinkers have traditionally been laid while taking cross bearings and/or horizontal sextant angles from fixed visual marks. When out of sight of land the process may have relied on radionavigation or radio-positioning aids. While some authorities may still use these procedures, the use of DGPS position fixing is increasingly seen as the preferred method. The benefits of DGPS position fixing are: convenience, accuracy and repeatability. A buoy tender using DGPS 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 descent 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.

Topmarks can be conical, cylindrical, spherical or a cross which can be either diagonal or vertical/perpendicular.

#### Conical topmarks (for lateral and cardinal marks):

- The vertical height of a cone from base to apex should be about 90% of the base diameter.
- For cardinal marks, the separation distance between cones should be about 50% of the base diameter of the cone.
- The vertical clear space between the lowest point of the topmark and all other parts of the mark should be at least 35% of the base diameter of the cone.
- In the case of a buoy, the base diameter should be 25%-30% of the diameter of the buoy at the waterline.

#### Cylindrical (can) topmarks (for lateral marks):

- The vertical height of a cylinder should be 1 to 1.5 times the base diameter.
- The vertical clear space between the lowest part of the cylinder and all other parts of the mark should be at least 35% of the diameter of the cylinder.
- In the case of a buoy, the base diameter of the cylinder should be 25%-30% of the diameter of the buoy at the waterline.

#### Spherical topmarks (for isolated danger and safe water marks):

- In the case of a buoy, the diameter of the sphere(s) should be at least 20% of the diameter of the buoy at the waterline.
- For isolated danger marks the separation distance between spheres should be about 50% of their diameter.
- The vertical space between the lowest part of the sphere(s) and all other parts of the mark should be at least 35% of the diameter of the sphere(s).

#### 'X' (Diagonal Cross) topmarks (for special marks):

- In the case of a buoy, the arms of the 'X' should be diagonally contained within a square with length of side of about 33% of the buoy diameter at the waterline. The width of the arms of the 'X' should be about 15% of the length of side of the square.

#### '+' (Vertical/Perpendicular Cross) topmark (for Emergency Wreck Marking Buoy):

For a pillar-shaped buoy, the arms of the '+' should be contained within a square with length of side of about 33% of the buoy diameter at the waterline. The width of the arms of the '+' should be about 15% of the length of side of the square. For a Spar buoy, the arms of the '+' should be contained within a square with length of side 1 to 1.5 times the diameter of the spar.



### 3.2.7 Sector Lights and Leading (Range) Lines

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.

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

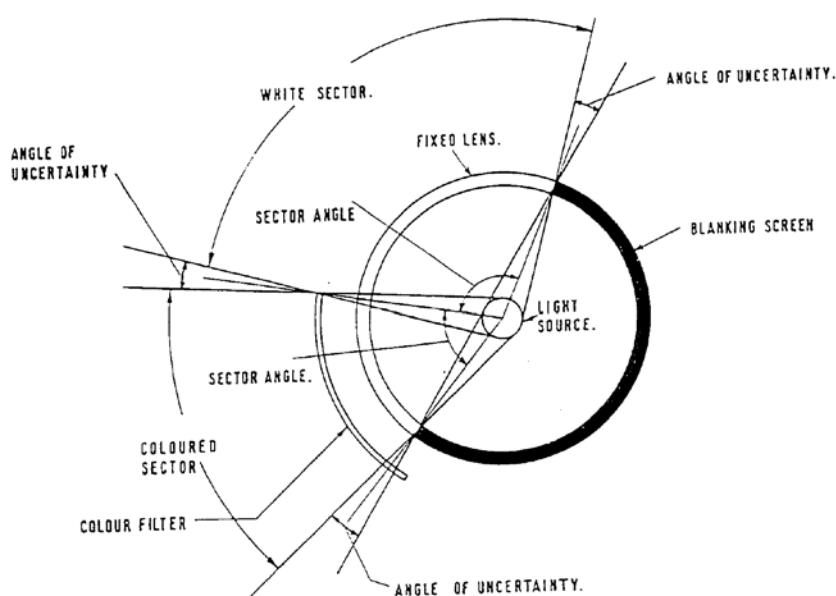


Figure 14 – Angle of Uncertainty

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  $0.25^\circ$  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)**<sup>23</sup>.

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.



*PDL light -  
Photo courtesy of Vega Industries*

### Applications

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.



*VLS-46 LED Sector light  
Photo courtesy of Vega Industries*

<sup>23</sup>Also known by the trade name of PEL Light.

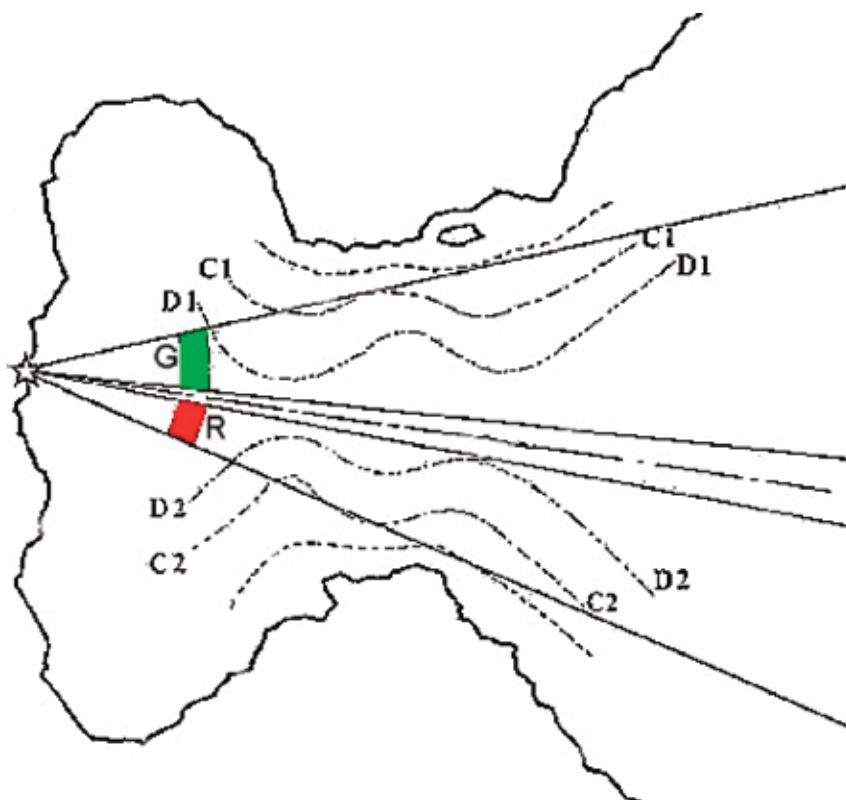


A **Precision Direction Light (PDL)** allows for further applications that include the ability to:

- 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.



*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.

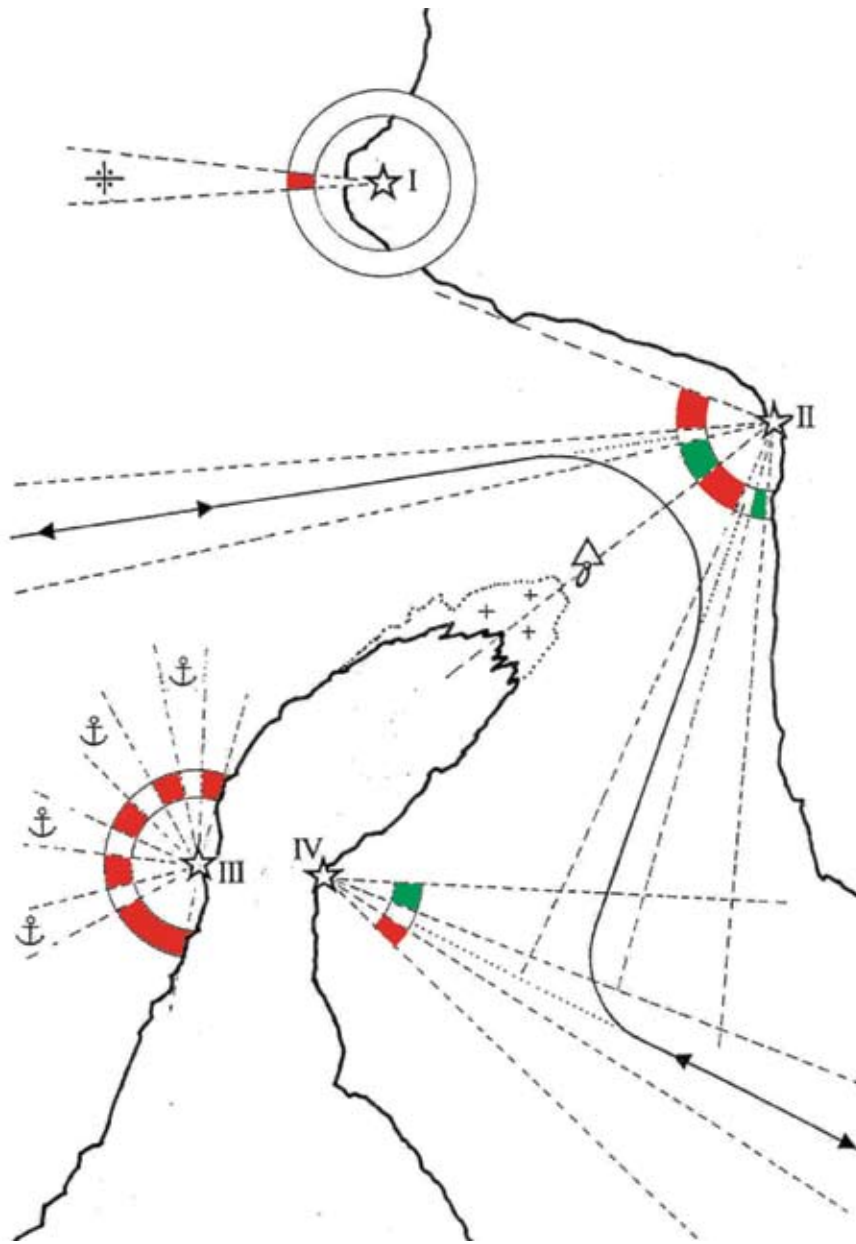


Figure 16 – Shows several applications for sector lights.

The function of each light 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 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<sup>24</sup> ;
- **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;
- **Multiple sectors:** Multiple sectors can be used to provide a better indication of a vessel's lateral position within the channel but at the expense of complexity for both the system designer and navigators.
- **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:

*IALA Guideline 1041 on sector lights.*

<sup>24</sup> See also IALA Recommendation E 110, The Rhythmic Character of Lights on Aids to Navigation.



### Transits / Leading Lines (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.

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.

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.



*Leading (Range) light – Photo courtesy of Vega Industries*

### 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<sup>25</sup> or do not satisfy the accuracy requirements for safe navigation.
- Define a safe approach bearing to a harbour or river entrance, particularly where there are cross currents.
- Separate two-way traffic (i.e. when passing a bridge).

<sup>25</sup>See also IALA Recommendation E 110, The Rhythmic Character of Lights on Aids to Navigation.



*Leading Line - Photo courtesy of Canadian Coast Guard*

### **Design Considerations for Leading Lines**

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

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

The characters of rhythmic leading lights should be selected so that the front and rear lights, in their free running states, can generally be observed together. In some situations it may be preferable to provide additional equipment to synchronise the light characters.

If lights are to be used both day and night, the light intensities should be adapted for each situation to avoid glare at night.

Radar transponders (RACONs) may be used as leading line markers.

#### **Refer to IALA publications:**

*IALA Recommendation E-112 for leading lights (including excel program).*

*IALA Guideline 1023 for the design of leading lines.*



### 3.2.8 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 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 and communication modules.

**Refer to IALA publications:**

*IALA Guideline 1064 on Integrated Power Systems Lantern.*



# 4

## e-NAVIGATION

### 4.1 Introduction

e-Navigation is an IMO-led broad strategic vision for the harmonisation of marine navigation systems and supporting shore services, underpinned by user needs.

The concept involves the utilization and integration of all available navigational tools to secure a greater level of safety and accident prevention. Implementation of e-Navigation will, at the same time, deliver substantial operating efficiencies with resulting commercial benefits.

e-Navigation will incorporate the use of new technologies in a structured way and ensure that their use is compliant with the various electronic navigational and communication technologies and services that are already available.

It should be noted that without e-Navigation, the multiplicity of systems and equipment will continue to evolve, with varying degrees of effectiveness. e-Navigation is an opportunity to optimise these developments and ensure the focus of future developments is based on a holistic approach to safe berth-to-berth navigation.

Rising trends of marine accidents both in terms of numbers and costs are mainly associated with collisions and groundings. There are numerous examples of collisions and groundings that might have been avoided had there been suitable input to the navigation decision-making process.

Research indicates that around 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, due to a general reduction in manning.

In human reliability analysis terms, the presence of someone checking the decision-making process improves reliability by a factor of 10. If e-navigation could assist in improving this aspect, both by well-designed onboard systems and closer cooperation with vessel traffic management (VTM) instruments and systems, risk of collisions and grounding and their inherent liabilities could be dramatically reduced.

However, although e-navigation may be able to improve the situations described above, there is also a need to recognize the role of the practice of good seamanship, the provision of suitable training and the use of procedures.

In 2006, seven IMO Member States made a joint submission to the Maritime Safety Committee to *“develop a strategic vision for the utilization of existing and new navigational tools, in particular electronic tools, in a holistic and systematic manner.”*

## 4.2 Definition of e-Navigation

The definition of e-Navigation adopted by IMO is:

*“e-Navigation is 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”.*

### 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 proposed by 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”, but this would unnecessarily limit what can be done within e-Navigation. It must be noted that generic electronic marine navigation already exists in many forms and should not be confused with this specific IMO initiative.

## 4.3 A vision for e-Navigation

A vision of e-Navigation is embedded in the following general expectations for the onboard, ashore and communications elements:

### On board

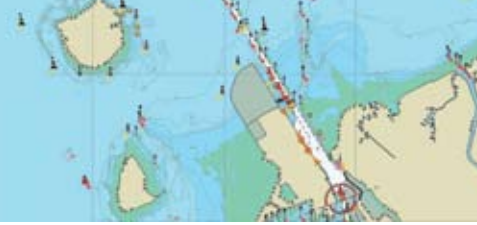
Navigation systems that benefit from the integration of own ship sensors, supporting information, a standard user interface, and a comprehensive system for managing guard zones and alerts. Core elements of such a system will include, actively engaging the mariner in the process of navigation to carry out his/her duties in a 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.

### Communications

An infrastructure providing authorised seamless information transfer onboard ship, between ships, between ship and shore and between shore authorities and other parties with many related benefits.



## 4.4 Strategy and Implementation

In 2008, IMO approved the development of an e-Navigation Strategy Implementation Plan. This includes the development of a technical architecture, gap analysis, cost benefit analysis and the creation of a detailed implementation plan. A structured and phased approach is required to capture evolving user needs, making use of the existing agreed methodology.

The Strategy Implementation Plan includes priorities for deliverables, a schedule for implementation and provision for the continual assessment of user needs. Implementation will be a phased, iterative process. The architecture for e-Navigation will encompass hardware, data, information, communications technology and software. It will be based on a modular and scalable concept and will cater for continued development and enhancements. The initial architecture is to be completed by 2010.

The deployment of new technologies is to be based on a systematic assessment of how the technology can best meet defined and evolving user needs within the e-Navigation concept.

The initial gap analyses are to be focused on technical, regulatory, operational and training aspects and are to be completed by 2010.

Cost-benefit and risk analyses will be used to support strategic decisions, as to when certain functions need to be enabled. The analyses will address financial and economic aspects, as well as assess the impact on safety, security and the environment. The aim is to complete this by the year 2011.

Implementation of the e-Navigation plan is due to begin in 2012 and will include: identification of responsibilities of the appropriate organizations/parties; transition planning; and a phased implementation schedule, along with possible roadmaps to clarify common understanding necessary for implementation.

### High Level User Needs

The IALA methodology was used to capture evolving user needs. It was based on the elements contained within the accepted definition of e-Navigation and applied templates to define specific user needs based on the harmonized collection, integration, exchange, presentation, analysis and human element aspects for all users. Following extensive feedback from Member States, other maritime organizations, and interested parties, an analysis was conducted resulting in the identification of high-level generic user needs for both ship and shore users. Thus the needs of a typical SOLAS ship and a generic shore authority have been used as the basis for the identification of the high-level user needs described below. A more detailed user needs may have to be identified as a part of the implementation plan.

### 1) Common Maritime Information / Data Structure

Mariners require information pertaining to the planning and execution of voyages, the assessment of navigation risk and compliance with regulation. This information should be accessible from a single integrated system. Shore users require information pertaining to their maritime domain, including static and dynamic information on vessels and their voyages. This information should be provided in an internationally agreed common data structure. Such a data structure is essential for the sharing of information amongst shore authorities on a regional and international basis.

### 2) Automated and Standardized Reporting Functions

e-Navigation should provide automated and standardized reporting functions for optimal communication of ship and voyage information. This includes safety-related information that is transmitted ashore, sent from shore to ship borne users and information pertaining to security and environmental protection to be communicated amongst all users. Reporting requirements should be automated or pre-prepared to the extent possible both in terms of content and communications technology. Information exchange should be harmonized and simplified to reduce reporting requirements. It is recognized that security, legal and commercial issues will have to be considered in addressing communications needs.

### 3) Effective and Robust Communications

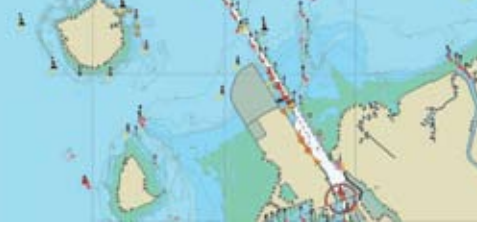
A clear need was expressed for there to be an effective and robust means of communications for ship and shore users. Shore-based users require an effective means of communicating with vessels to facilitate safety, security and environmental protection and to provide operational information. To be effective, communication with and between vessels should make best use of audio/visual aids and standard phrases to minimize linguistic challenges and distractions to operators.

### 4) Human Centred Presentation Needs

Navigation displays should be designed to clearly indicate risk and to optimize support for decision making. There is a need for an integrated “alert management system” as contained in the revised recommendation on performance standards for Integrated Navigation Systems (INS) (resolution MSC.252(83)).

Consideration should be given to the use of decision support systems that offer suggested responses to certain alerts, and the integration of navigation alerts on board ships within a whole ship alert management system. Users require uniform and consistent presentations and operation functionality to enhance the effectiveness of internationally standardized training, certification and familiarization.

The concept of S-Mode has been widely supported as an application on board ship during the work of the Correspondence Group. Shore users require displays that are fully flexible supporting both a Common Operating Picture (COP) and a User Defined Operating Picture



(UDOP) with layered and/or tabulated displays. All displays should be designed to limit the possibility of confusion and misinterpretation when sharing safety-related information. e-Navigation systems should be designed to engage and motivate the user while managing workload.

### **5) Human Machine Interface**

As electronic systems take on a greater role, facilities need to be developed for the capture and presentation of information from visual observations, as well as user knowledge and experience. The presentation of information for all users should be designed to reduce “single person errors” and enhance team operations. There is a clear need for the application of ergonomic principles, both in the physical layout of equipment and in the use of light, colours, symbology and language.

### **6) Data and System Integrity**

e-Navigation systems should be resilient and take into account issues of data validity, plausibility and integrity for the systems to be robust, reliable and dependable. Requirements for redundancy, particularly in relation to position fixing systems, should be considered.

### **7) Analysis**

e-Navigation systems should support good decision making, improve performance and prevent single person error. To do so, shipboard systems should include analysis functions that support the user in complying with regulations, voyage planning, risk assessment, and avoiding collisions and groundings including the calculation of Under Keel Clearance (UKC) and air draughts. Shore-based systems should support environmental impact analysis, forward planning of vessel movements, hazard/risk assessment, reporting indicators and incident prevention.

Consideration should also be given to the use of analysis for incident response and recovery, risk assessment and response planning, environment protection measures, incident detection and prevention, risk mitigation, preparedness, resource (e.g., asset) management and communication.

### **8) Implementation Issues**

Best practices, training and familiarization relating to aspects of e-Navigation for all users should be effective and established in advance of technical implementation. The use of simulation to establish training needs and assess its effectiveness is endorsed. e-Navigation should as far as practical be compatible forwards and backwards and support integration with equipment and systems made mandatory under international and national carriage requirements and performance standards. The highest level of interoperability between e-Navigation and external systems should be sought where practicable.

#### **Refer to IALA publications:**

*IALA Guideline 1072 on Aid to Navigation Information Exchange and Presentation.*



## 4.5 IALA's Role

IALA's e-Navigation Committee has contributed substantially to the formulation of the IMO Strategy for the implementation of e-Navigation and to the Strategy Implementation Plan. The working groups of the e-NAV Committee are developing shore user requirements, information systems and data structures, a World Wide Radio Navigation Plan, a Radio Communications Plan, a future second generation AIS and a shore-side architecture, together with a documentation structure to encompass the whole of e-Navigation.

## 4.6 Architecture

A representation of the ship to shore portion of the proposed e-Navigation architecture being developed by IALA, under the IMO e-Navigation agenda, is shown in Figure 17. It includes the shipboard entities, the physical link(s) and the shore-based entities.

From an e-Navigation perspective, the relevant devices within the ship environment are the transceiver station, the data sources and the data sinks connected to the transceiver station, the Integrated Navigation System (INS) and the Integrated Bridge System (IBS). Only one transceiver station is shown for simplicity, although there may be several.

The shipboard transceiver station interfaces with the physical link(s) to the appropriate technical e-Navigation services ashore.

The shore-based technical e-Navigation services provide the interfaces of the shore-based user applications to the physical link(s). The data transfer network(s) depend on the application, for example, a shore-based radar service would require different data transfer network capabilities to a shore-based AIS service.

Figure 17 shows the IMO World Wide Radio Navigation System (WWRNS) as a system "external" to the e-Navigation architecture, providing position and time information. The WWRNS includes GNSS, GNSS augmentation and terrestrial backup radio navigation systems.

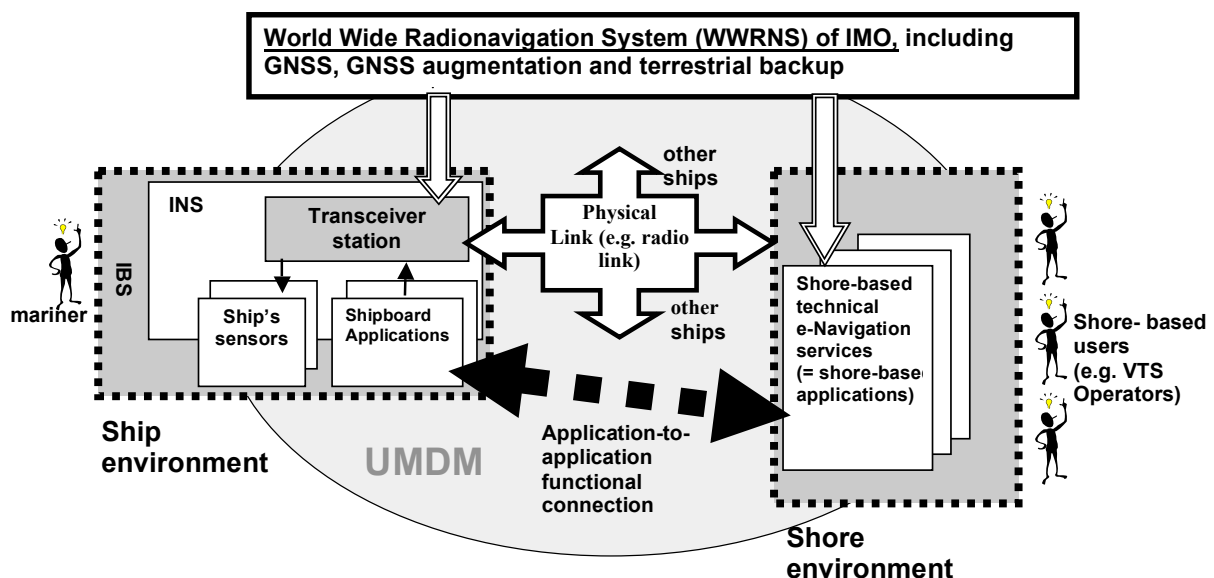
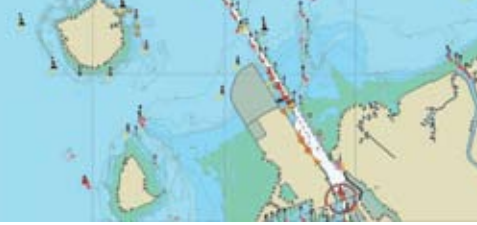


Figure 17 - Ship to shore portion of the proposed e-Navigation architecture



## 4.7 Technology for e-Navigation

Many sub-systems or components will have to be developed, enhanced or provided to realise the full integrated concept of e-Navigation. Crucial among these are Positioning, Navigation and Timing (PNT), communications and information systems. It should be noted that not all of the following technologies or systems will be needed within the e-Navigation concept.

## 4.8 IALA Plan

IALA has developed a World Wide Radio Navigation Plan (WWRNP) aimed at providing the WWRNS to support e-Navigation. One key concept in this plan is the separation of the generation of correction data from the means of transmission, to facilitate broadcasting by a variety of methods. This could lead to the integration of terrestrial systems (DGNS beacons, e-Loran, AIS) to provide shared data channels and common correction sources, as well as additional ranging signals, contributing to a redundant position-fixing solution, complementary to, but independent of GNSS.

Future standards for position-fixing systems should be considered in the context of position-fixing requirements for e-Navigation. This WWRNP could be the basis for a submission to IMO as a contribution to the WWRNS. The plan provides guidance to IALA members regarding potential future developments, which will enable members to identify areas requiring resource allocation and research activity.

**Refer to IALA publications:**

*IALA Recommendation e-Nav-140 on e-Navigation Architecture.*

*IALA Guideline 1072 on Aid to Navigation Information Exchange and Presentation.*

## ELECTRONIC POSITION FIXING SYSTEMS

### 4.9 Global Navigation Satellite Systems (GNSS)

Global Navigation Satellite System (GNSS) is a generic term for a satellite system that provides a world-wide position determination, 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 their position and velocity in real time, based on ranging measurements.

If a GNSS conforms to IMO Resolution A.953(23) for a World-Wide Radionavigation System (WWRNS), the receivers of that GNSS will satisfy the IMO carriage requirements for position fixing equipment referred to in Chapter V of the SOLAS Convention.

Several Global Navigation Satellite Systems (GNSS) have been deployed, fully or partially, or are under development.

Since 1996, the US "Navstar" Global Positioning System (GPS) and the Russian Global Orbiting Navigation Satellite System (GLONASS) have been recognised as components of the WWRNS. In the future, GNSS will include other systems such as the "GALILEO", a system currently under construction by the European Union, and "COMPASS", currently under construction by China. Furthermore, regional GNSS components like "QZSS" from Japan and IRNSS from India are planned to become operational in the next few years.

### 4.9.1 GPS

The Global Positioning System, Standard Positioning Service<sup>26</sup> (GPS SPS) is a three-dimensional positioning, three-dimensional 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.

The 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) orbits at an inclination angle of 55 degrees and with a 12-hour period.

The GPS SPS is available on a non-discriminatory basis and 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)<sup>27</sup>.

GPS receivers, in combination with other equipment, are able to provide:

- absolute positioning;
- relative positioning (this can be further processed to derive speed over ground (SOG) , course over ground (COG), etc.); and
- timing.

This information may refer to a stationary observer (static positioning) or to a moving observer (kinematic positioning).

There are 31 usable satellites in the constellation at present. A modernization 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 called M-Code. Full Operational Capability of the L2C code is not expected before 2014 and for L5 before 2016.

The next generation of satellites, GPS III, is in its definition phase (timeframe to 2021).

Further information on GPS can be found on the USCG NAVCEN website: [www.navcen.uscg.gov](http://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.

### 4.9.2 GLONASS


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.

GLONASS has a similar potential user community to GPS SPS. It is available on a non-discriminatory basis and free of direct user fees to all users with an appropriate receiver. With

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<sup>26</sup>The Standard Positioning Service is the one available to civilian and commercial users. A Precise Positioning Service (PPS) is also provided for the US Military Services.

<sup>27</sup>GPS SPS Performance Standard, 2008.



a full complement of 24 satellites, the service would satisfy the requirements for general navigation and give a horizontal position accuracy of 45 metres (95% probability). Further satellite launches planned for 2009-10 would be expected to restore the full complement of satellites.

Recent launches have included the improved GLONASS M satellites with a second civil signal. The new GLONASS-K with a third civil signal on L3, was due to start launching in 2009. It will also carry differential corrections, integrity information and search and rescue functions. Present satellites use Frequency Division Multiple Access, but the future GLONASS K-M system, which is at the requirement definition stage, is planned to include a code division multiple access (CDMA) signal, inter-operable with GPS.

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

### **4.9.3 Galileo**

Galileo, the future European satellite navigation system, will be under civilian control.

Galileo is expected to have a constellation of 30 satellites, of which 27 will be operational, with three active spares. These will be positioned in a Medium Earth Orbit (MEO) with an inclination of 56° to the equator. These satellites will provide dual frequencies as standard, enabling users to calculate their positions with metre level accuracy.

Galileo will provide five levels of service, each with their own performance standards: Open Service (OS), Safety-of-Life Service (SoL), Commercial Service (CS), Public Regulated Service (PRS) and Search and Rescue Service (SAR). Galileo is expected to provide timely warnings of integrity failure, within a few seconds. Among its novel features will be a system to relay distress messages to COSPAS-SARSAT service centres, while keeping the user informed.

Two test-bed satellites, GIOVE A and GIOVE B are in orbit, providing signals for test purposes, including navigation signals. The first launch of an operational Galileo satellite is scheduled for 2010 and full operational capacity is planned for 2013. Agreement has been reached with the U.S. on interoperability and cooperation with GPS.

Further information on Galileo can be found on the Internet at: [europa.eu.int/comm/dgs/energy\\_transport/galileo](http://europa.eu.int/comm/dgs/energy_transport/galileo)

### **4.9.4 Beidou/Compass**

China is currently engaged in the development of a global system, complemented by a regional component. The first four COMPASS satellites were GEOs (Geo-stationary Orbit). Then, in April 2007, the first MEO (Medium Earth Orbit) was launched.

The system currently uses two GEOs, with a third as a backup, to provide 100 m horizontal accuracy. Beidou 2 may be a full 30 MEO constellation, or 4 GEOs and 12 MEOs, or some other combination of MEOs, GEOs and inclined geo-stationary orbit satellites (IGSO), with a proposed operational date of 2015.

#### 4.9.5 QZSS

Japan is developing a Quasi-Zenith Satellite System (QZSS). QZSS is based on 3 satellites in highly elliptical, inclined orbits guaranteeing one satellite always in visibility of Japan with a minimum elevation angle of 60 degrees. Each satellite will transmit 6 signals in the L-band: 3 in L1, one in E6, one in L2 and one in L5.

One of the signals aims to provide sub-metre accuracy and integrity while maintaining compatibility with SBAS. The signal in E6 aims to support a commercial service with high data rate (2 kbps). The other signals are GPS-like signals, including L2C and L1C standards.

#### 4.9.6 IRNSS

The Indian Regional Navigational Satellite System (IRNSS) 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. It is planned to launch the first IRNSS satellite in 2009, with system completion by 2011.

Three IRNSS services are anticipated:

- Open Service using signals in the L5 and S bands.
- Precise Positioning Service using signals in the L5 and S bands.
- 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 IRNSS 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.

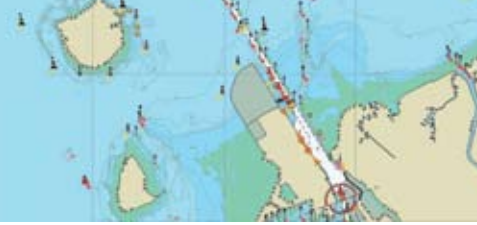
### 4.10 Differential GNSS

Differential GNSS is an augmentation system for providing integrity and reducing the errors in the GNSS signals within a given area. The process involves comparing the accurately surveyed position of the DGNSS Reference Station with positions determined from the GNSS satellites in view. Messages containing positional errors and satellite integrity (health) information are broadcast for users equipped with appropriate receivers. The result for the user is:

- enhanced positional accuracy within the service area, and;
- almost immediate notification of faulty satellites (compared with up to two hours for GPS).

In addition to GPS and GLONASS, the DGNSS augmentation system will be able to provide similar advantages to future GNSS signals (e.g. Galileo OS signals).

DGNSS services can be provided from Ground based augmentation systems (GBAS) using terrestrial transmitters such as the IALA beacon system and AIS or from Satellite Based Augmentation Systems (SBAS).



### 4.10.1 IALA Beacon DGNSS

The internationally accepted method of providing DGNSS corrections to maritime users is by local broadcast stations transmitting non-encrypted corrections on frequencies within the maritime radionavigation band (283.5 to 325 kHz)<sup>28</sup>.

The radio link of this system is internationally defined at ITU (Recommendation ITU-R M.823-3). Type-approved DGNSS radiobeacon receivers meeting IEC 61108-4 test and performance standards are available. The IALA system provides DGNSS correction transmissions as well as a data channel for text messages (ASCII) and is available in most coastal waters, especially in areas of high traffic density.

IALA has recommended that members operating the beacon DGNSS service should consider modernization, to ensure that levels of service can be maintained and future requirements can be met (IALA Recommendation R-135). This recommendation takes into account the potential alternatives, in particular Satellite Based Augmentation Services (SBAS) and the Automatic Identification System (AIS). The simplest option may be replacement of existing hardware with similar dedicated Reference Stations and Integrity Monitors (RSIM), but this would limit the potential for development. There are other possibilities, including software RSIM, Virtual Reference Station Networks and integration with SBAS.

The full list of about 400 maritime radiobeacon based DGNSS stations (as notified to IALA by authorities) can be accessed via the IALA website: [www.iala-aism.org](http://www.iala-aism.org)

Further information on DGPS can be found on the USCG Navigation Centre website: [www.navcen.uscg.gov](http://www.navcen.uscg.gov)

### DGNSS using AIS Message No. 17

Automatic Identification System (AIS) is a ship to ship and ship to shore data broadcast system, operating in the VHF maritime band. It is described in more detail in section 4.19.

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

The use of AIS Message No 17 increases the number of vessels, which benefit from DGNSS transmissions with respect to better accuracy and integrity.

#### **Refer to IALA publications:**

*IALA Guideline 1060 on Recapitalisation of DGNSS*

### 4.10.2 SBAS

Satellite Based Augmentation Systems (SBAS) support wide-area or regional augmentation through the use of additional satellite-broadcast messages. Such systems are commonly composed of multiple ground stations, located at accurately-surveyed points. The ground stations take measurements of the GNSS satellite signals and environmental factors which may impact the signal received by the users. Using these measurements, information messages are created and sent to one or more GEO satellites for broadcast to the end users.

<sup>28</sup>A 1kW transmitter will generally allow position fixing to better than 10 metres over a radius of about 200 nautical miles.

### WAAS

The Wide Area Augmentation System (WAAS) has been implemented by the U.S. 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](http://www.navcen.uscg.gov)

### EGNOS

The European Geo-stationary Navigation Overlay Service (EGNOS) is a joint project of the European Space Agency (ESA), the European Commission (EC) and Eurocontrol. It consists of three GEOs and a network of ground stations and transmits correction and integrity information for GPS and potentially other GNSS, designed for safety-of-life applications (i.e. civil aviation). EGNOS is currently in its initial operational phase with discussions on-going to secure the long-term operation of the system. The system currently provides an SBAS service in the L1 band through two GEO transponders on INMARSAT satellites. A third GEO transponder on ARTEMIS is used to support system upgrades. EGNOS is presently fully interoperable with the current generation of WAAS and MSAS. However, these systems are already planning an evolution towards a dual-frequency capability in the L1/L5 bands.

Further information on EGNOS can be found via website: [www.egnos-pro.esa.int](http://www.egnos-pro.esa.int)

### MSAS

In Japan, the Multi-Satellite Augmentation System (MSAS) is an 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.

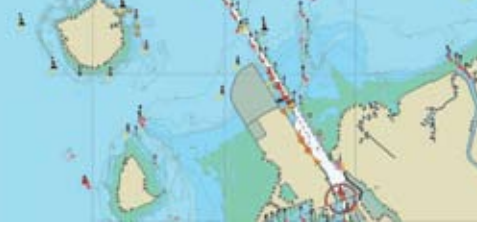
Further information on MSAS can be found via the website: [www.kasc.go.jp/\\_english/msas\\_01.htm](http://www.kasc.go.jp/_english/msas_01.htm)

### GAGAN

India is developing a GPS-Aided Geo Augmented Navigation system (GAGAN), which is an SBAS similar to WAAS and EGNOS. It is currently at the end of its technology demonstration phase. 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. Full operational capability has been announced for 2010, when the system would have been extended with an additional master control centre, an additional up-link station, 2 additional GEO links (L1/L5) plus one in-orbit spare and more reference stations.

### SDCM

Russia is also considering an augmentation to GLONASS called SDCM (System for Differential Corrections and Monitoring), which appears to be in a preliminary phase. The concept originally diverged substantially from SBAS standards but it seems that there is an interest in converging towards a more interoperable system.



## 4.11 Receiver Autonomous Integrity Monitoring (RAIM)

RAIM is a technology developed to assess the integrity of GNSS signals in a receiver. It is of special importance in safety-critical applications, such as aviation and marine.

RAIM uses redundant measurements in a navigation receiver to confirm the integrity of the derived position solution. Usually RAIM uses only “Fault Detection” (FD), but newer receivers incorporate “Fault Detection and Exclusion” (FDE) which enables them to continue to operate in the presence of a single GNSS satellite failure.

Because RAIM operates autonomously it requires a number of redundant pseudo range measurements. To detect a faulty satellite, at least five measurements are required, and to isolate and exclude a faulty space vehicle, at least six measurements are required.

The need for redundant measurements reduces RAIM availability and continuity, especially in shadowed areas. Depending on the satellite geometry more measurements may be needed to perform the RAIM process with an appropriate confidence level.

## 4.12 Terrestrial – eLoran

### 4.12.1 Introduction

Enhanced Loran (eLoran) is a development from the long-standing, low-frequency, Loran-C (LONg-RANGE Navigation) system. It is intended to be an internationally-standardised Positioning, Navigation, and Timing (PNT) service for use by land, sea and air navigation as well as other applications, including timing. eLoran is an independent, dissimilar, complement to Global Navigation Satellite Systems like GPS and Galileo. It will allow GNSS users to retain the safety, security, and economic benefits of GNSS, even when their satellite services are disrupted.

### 4.12.2 Background

The present Loran-C is a hyperbolic radionavigation system developed during the 1960s to meet U.S. Department of Defense requirements. The Russian Federation operates a similar radionavigation system called CHAYKA. There are currently about 24 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, noting that the USA and Canada shut down their chains in February 2010.

Present 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 brief radio pulses on a carrier wave frequency centred on 100kHz. 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 pulses is a characteristic unique to each chain and is referred to as the Group Repetition Interval (GRI).

The carrier wave frequency favours the propagation of a stable ground wave over long distances. Loran receivers are designed 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.

#### 4.12.3 eLoran Performance

eLoran will meet the accuracy, availability, integrity and continuity performance requirements for aviation non-precision instrument approaches, maritime harbour entrance and approach manoeuvres, land-mobile vehicle navigation, and location-based services. It is also a precise source of time and frequency for applications such as telecommunications. eLoran is predicted to provide accuracy (8 - 20 metres) and timing (stratum-1) performance equivalent to current GPS, as shown in Table 17.

**Table 17 eLoran Predicted Performance**

Accuracy	Availability	Integrity	Continuity
8 – 20 Metres	99.9% - 99.99%	1 X 10 <sup>-7</sup> Per Hour	99.9% To 99.99% over 150 seconds

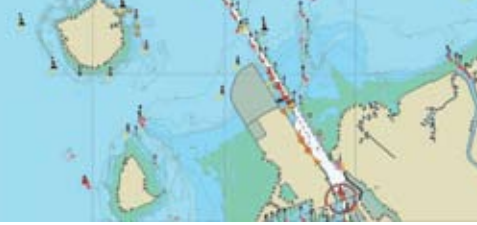
#### 4.12.4 Core eLoran Elements

eLoran comprises a core system (modernised control centres, transmitting stations and monitoring sites) and application-specific augmentations (e.g. differential reference stations) that will use a data channel on the eLoran signal to communicate with users. eLoran transmissions are synchronised to an identifiable, publicly-certified, source of Coordinated Universal Time (UTC) by a method wholly independent of GNSS. This allows the eLoran Service Provider to operate on a time scale that is synchronised with, but operates independently of, GNSS time scales. Synchronising to a common time source also allows receivers to employ a mixture of eLoran and satellite signals.

eLoran transmitters use modern solid-state components which are efficient, reliable and stable. This produces a highly stable eLoran signal. The lower power usage of these modern transmitters allows Uninterruptible Power Supplies (UPS) to be installed to overcome short periods of utility power outage, again ensuring a more stable and reliable signal. The use of reliable modern components increases the Mean Time between Failures and with in-built redundancy, allows eLoran stations to be un-manned. This ensures the system is a cost effective solution as backup to GNSS.

Absolute position offsets are caused by ASF (Additional Secondary Factors). These result from differing speeds of signal propagation over different terrains as well as the interfaces between those terrains e.g. land/sea path, mountains/wetlands. These terrains delay signal reception from that expected of a perfect sea path and is the main component of ASF. However, seasonal (summer/winter) and diurnal (day/night) changes to the ASF value will also occur. Modern eLoran receivers will include a built-in ASF table to remove the main ASF offset.

One of the inherent features of eLoran is the inclusion of the data channel which will be used to transmit, amongst other messages, differential eLoran data to negate the varying ASF value. This differential eLoran data will be optimised for areas of importance such as ports and harbour approaches.



#### 4.12.5 Compatibility between eLoran and Loran-C

Legacy receivers will be able to use both eLoran and Loran-C signals at present as they are compatible, with eLoran stations forming part of the presently organised chains. eLoran retains the basic signal format. However, future eLoran stations may be independent of chains. The concept of hyperbolic position fixing from chains will be replaced with an all-in-view concept of operation. Therefore any eLoran station within reception can be used in the position solution.

#### 4.12.6 eLoran as a viable backup to GNSS

The need for a robust PNT system has been identified as a key component of the emerging e-Navigation concept. eLoran is a dissimilar system to GNSS in terms of frequency, signal power, infrastructure and signal penetration and with performance comparable to GNSS is considered to be the only contender as a viable back-up to GNSS. This has been recognised in the U.S. where eLoran has been adopted as the national PNT system that complements the Global Positioning System (GPS) in the event of an outage or disruption in service.

It needs to be recognised that any future eLoran systems are likely to be regional, although Loran systems presently cover a large percentage of the major shipping ports. eLoran is likely to be a component of the future World Wide Radio Navigation System.

### 4.13 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 to carry a 9 GHz radar, and;
- all ships of 3,000 gross tonnage and upwards 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 06 December 2004 states that 9 GHz radars should be capable of detecting radar beacons and should be capable of detecting SARTs and radar target enhancers.

9 GHz radars are also extensively carried by vessels not covered by SOLAS or local regulation. Because of this high rate of carriage, radar aids to navigation in the 9 GHz band are especially useful.

#### 4.13.1 New Technology Radars

Previous to IMO Resolution MSC 192(79) IMO radar performance standards stated that 3 GHz radars should be capable of detecting radar beacons. Resolution MSC 192(79) removed this requirement. A number of factors were considered in this decision. Among them were:

- Pressure from ITU and other organizations to reduce the bandwidth needed for 3 GHz radars and to reduce the amount of spurious out of band emissions.

- Demand by the mariner for higher performance radars, especially with small object detection and reduction of sea clutter. Higher performance 3 GHz radars have been available for many years. But, because of the techniques used by these radars, they would not detect racons, could not be used to satisfy carriage requirements and were rarely installed.
- Reduction of cost for sophisticated radars because of technology improvements in signal processing and solid-state transmitters.

With the removal of the racon detection requirement, ship-owners are free to use higher performing radars, often referred to as New Technology (NT) radars.

#### 4.13.2 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 the 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 of its use 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.

The range at which a radar reflector target can be detected is dependent on the heights of the radar antenna and the reflector and the output power of the radar. There are analogies to the geographical range of visual marks. The radar performance of corner cluster reflectors may vary considerably from one make to another, despite being of similar physical size. This arises from differing design philosophies; some that favour the fabrication process and others that try to optimise the polar distribution of radar reflections.

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 are also usable with 3 GHz radars; however, the effective radar cross section is about an order of magnitude less.

#### 4.13.3 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. A paper on RTE trials presented at the 1998 IALA Conference noted that the RTE tested had an effective radar cross section (RCS) of about 100 square metres, compared with an RCS of 20 to 30 square metres for passive radar reflectors typically fitted to buoys.

To date, commercially available RTEs only operate in the 9 GHz band.

RTE use is subject to multipath fading effects. Please refer to IALA Guideline No. 1010 on racon range performance for a discussion on multipath fading.

#### 4.13.4 Radar Beacon (Racon)

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.

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 18) 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 and uses a Morse character for identification.



Figure 18 – Example of a racon and a radar display 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:

- ranging and identification of positions in ice conditions or on inconspicuous coastlines;
- identification of aids to navigation, both seaborne and land based;
- landfall identification;
- indicating centre and turning point in precautionary areas or Traffic Separation Scheme (TSS);
- marking hazards;
- indicating navigable spans under bridges; and
- identifying leading lines.

#### 4.13.5 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.

However, to avoid masking other features on the radar screen, the racon response is usually switched on and off on a preset cycle.

#### Signal Characteristics

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

**Table 18 – Preferred terminology for the description of racon operating frequencies**

Preferred Terminology	Alternatives		
9 GHz	9300 9500 MHz	X - Band	3 cm
3 GHz	2900 3100 MHz	S - Band	10 cm

#### 4.13.6 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 99.6%.

##### Refer to IALA publications:

*IALA Guideline 1010 on racon range performance.*

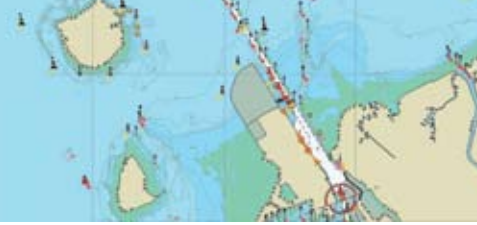
*IALA Recommendation R-101 on maritime radar beacons (Racons).*

*IALA Recommendation O-113 for the marking of fixed bridges over navigable waters.*

#### 4.13.7 Technical Considerations

There are a number of technical considerations in the use of racons to assist the navigation of a ship:

- 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.
- When the ship is very close to the 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.

#### **4.13.8 Use with New Technology Radars**

All currently available and installed racons are designed for use with high power pulse radars. In comparison, NT radars use low power transmissions with long pulses. Because of the low received signal strength and long pulse at the racon, current racons may not detect NT radars and may not transmit a response usable by NT radars.

Currently installed 3 GHz high power pulse radars are not expected to be replaced by NT radars in the near future and racons with 3 GHz capability will continue to be useful. At some point there may be a requirement to replace all high power pulse radars, at which time present racons with 3 GHz pulse capability may need replacement.

#### **4.13.9 Non-radio positioning (Inertial)**

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

There are different grades of IMU, ranging from the very expensive navigation grade, costing many tens of thousands of dollars; through tactical grade to low cost units based on MEMS (Micro Electro Mechanics System) technology. They give different rates of drift and are therefore capable of covering various lengths of GNSS outage.

None of the systems available at present 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 1 hour and 15 minutes respectively). For coastal areas, 15 minutes of good accuracy would be maintained using a navigation-grade IMU. For the harbour approach phase, accuracy to 10 metres could be obtained for 3.5 minutes with a navigation-grade IMU-based system. For docking and where sub-10 metre accuracy is required, coupling inertial systems with GNSS does not appear to offer any benefit in the event of a GNSS failure. In the future low cost MEMS based IMUs could be a useful addition to a ship's navigation system.

MEMS is an enabling technology with a global market. The major growth opportunities will come from automotive and consumer applications. The idea of an IMU on a chip with unit cost as low as a GPS module is anticipated in the near future.

Nearly all MEMS accelerometers work by measuring the motion of a proof mass against a fixed frame. The main sensing approaches are capacitive or piezoresistive. The power requirement of such sensors is in the range 1-10 mW.

The navigation performance of a MEMS based inertial system depends mostly on the gyro error behaviour, the position error can grow up to more than 80 m during a GNSS outage of 60 sec. Nevertheless MEMS based INS could make a useful contribution by providing a stable heading output during GNSS outages and could help to stabilise position even when GNSS is available, therefore the development of MEMS based IMUs should be kept under observation.

## COMMUNICATIONS

### 4.14 Maritime Radio Communications Plan

IALA has prepared a Maritime Radio Communications Plan (MRCP) for the communications required to support e-Navigation. The MRCP is intended to meet the key strategy element of identifying communications technology and information systems to meet user needs. This may involve the enhancement of existing systems or the development of new systems. The IALA work starts by identifying existing and future systems, then drawing on the user requirements already identified to assess the information flows and the data channels needed.

## LONG RANGE IDENTIFICATION AND TRACKING

### 4.15 Introduction

Competent authorities with responsibility for aids to navigation, port security and other shoreside activities are often faced with the requirement to maintain surveillance of maritime approaches to their ports and port facilities for safety, security, and environmental protection.

These authorities are pursuing vessel tracking technologies to assist in the detection, classification, identification, and tracking of vessels. Among these technologies, Long Range Identification and Tracking (LRIT) is being implemented internationally for tracking ships globally.

### 4.16 LRIT Concept

Long range identification and tracking (LRIT) is a cooperative surveillance capability. In the simplified LRIT concept (Figure 19), a ship carries radio communications equipment that reports identification, position and time to authorities tracking that ship. However, the final implementation of LRIT is more complicated as explained below.

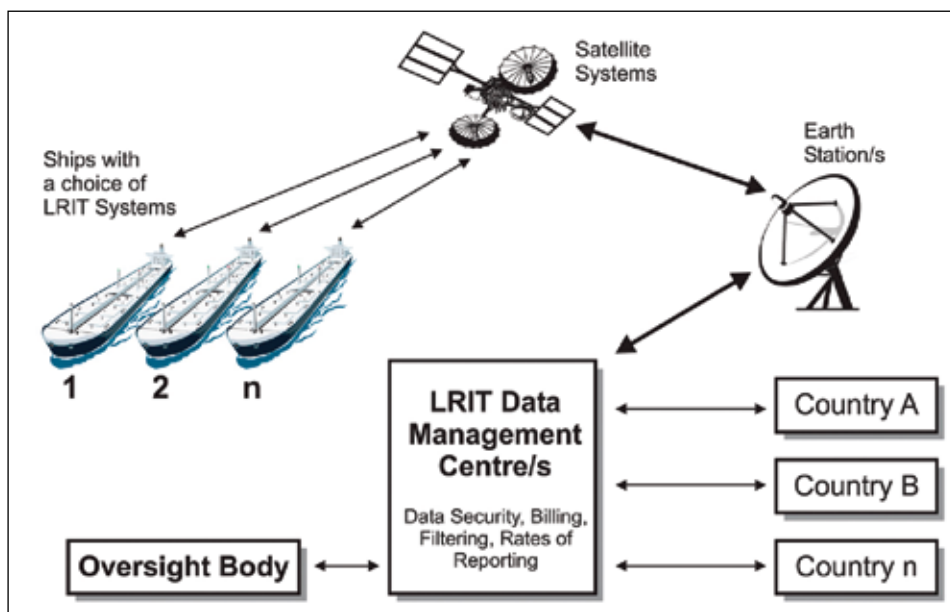


Figure 19 – Simplified LRIT Concept (courtesy of INMARSAT)

## 4.17 LRIT Performance Standards and Functional Requirements

The approved performance standards and functional requirements for long-range identification and tracking lay out the LRIT system architecture (Figure 20) and describe how the long-range identification and tracking system works.

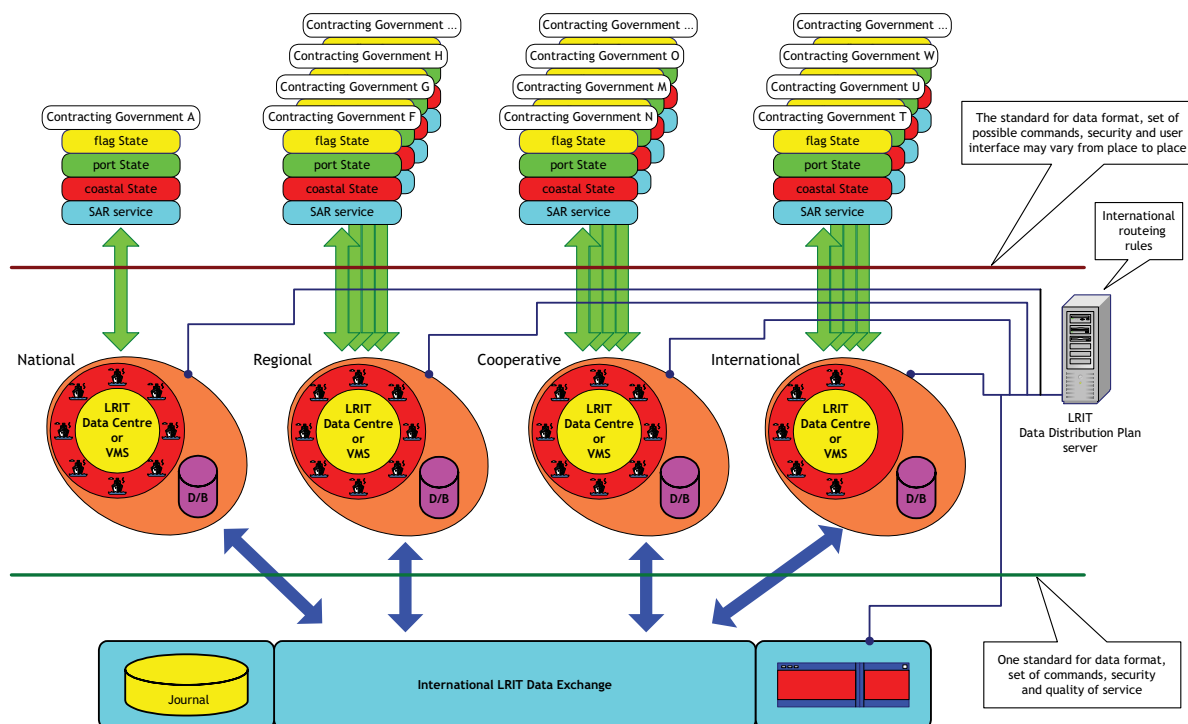


Figure 20 - LRIT system architecture

In this architecture, the Administration determines whether its ships will report to a national, regional/cooperative, or the international LRIT data centre. Each of these types of centres may use multiple communications service providers. The architecture is also designed to accommodate multiple application service providers. Building on the basic concept noted above, a ship carries radio communications equipment that reports identification, position and time to the national, regional/cooperative, or international LRIT data centre tracking that ship. The Administration of the ship can access the LRIT information directly from the data centre. Other Contracting Governments that are entitled to that information (i.e., port and coastal states) can request the information through their data centre and thence through the international LRIT Data Exchange. The LRIT information is routed to the requesting data centre through the data exchange.



## AUTOMATIC IDENTIFICATION SYSTEM

### 4.18 Overview

Automatic Identification System (AIS) is a ship and shore-based data broadcast and interrogation technology, operating in the VHF maritime band, that makes it possible to monitor and track ships from suitably equipped ships, and shore stations.

AIS characteristics and capability make it a powerful tool for enhancing situational awareness, thereby contributing to the safety of navigation and efficiency of shipping traffic management. Shipboard AIS enables the provision of fast, automatic and accurate information regarding risk of collision allowing the Closest Point of Approach (CPA) & Time to Closest Point of Approach (TCPA) to be calculated from the positional information transmitted by target vessels. AIS increases the possibility of detecting other ships, even if they are behind a bend in a channel or river or behind an island in an archipelago. AIS also solves the problem inherent with radars, by detecting smaller craft, fitted with AIS, in sea and rain clutter.

An AIS unit is a VHF radio transceiver capable of exchanging information such as station identity, position, course over ground, speed, length, ship type and cargo information etc., with other ships and suitable receivers ashore within VHF range. Figure 21 gives an overview of the system.

Once set up correctly, information from an operational shipboard AIS unit is transmitted continuously and automatically, without any intervention by the ship's staff. AIS transmissions consist of bursts of digital data 'packets' from individual stations, according to a pre-determined time sequence.

Therefore, AIS is an important supplement to existing systems, including radar. In general, data received via AIS will enhance the information available to the Officer of the Watch and the Vessel Traffic Service Operator (VTSO).

The International Maritime Organization (IMO) has established carriage requirements for merchant ships. The International Telecommunication Union (ITU) has defined the technical characteristics and ratified the global frequencies. In addition, the International Electrotechnical Commission (IEC) has developed methods for testing AIS for global interoperability.

*Note: This section aims to provide a broad overview of AIS. The reference list at the end of this section assists the reader seeking amplifying information on various aspects of AIS.*

### 4.19 Purpose and Function

The purpose of AIS is to positively identify vessels, provide additional information in order to assist in collision avoidance and assist in vessel tracking. It also aims to simplify and promote the exchange of information automatically, thereby reducing the need for doing so verbally (e.g. mandatory ship reporting by radiotelephony).

AIS satisfies the following functional requirements, as laid down by IMO<sup>29</sup>:

- in a ship-to-ship mode for collision avoidance;
- as a means for littoral States to obtain information about a ship and its cargo; and
- as a VTS tool, i.e. ship-to-shore (traffic management).

AIS automatically exchanges shipboard information (provided by shipboard sensors), between vessels and between a vessel and a shore station(s).

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<sup>29</sup>IMO Resolution MSC.74 (69) Annex 3 refers.

## 4.20 System Characteristics

### Frequencies and Capacity

AIS operates on two dedicated VHF FM radio frequencies AIS1 (channel 87B – 161.975 MHz) and AIS2 (channel 88B– 162.025 MHz) in the maritime mobile band.

Transmissions consist of bursts of 'data packets' from individual stations, according to an automatically determined time-ordered sequence. Stations organize themselves on the common frequencies (AIS 1 and AIS 2) based on the knowledge of their own transmissions and that of other stations. This method of operation is known as Self Organizing Time Division Multiple Access (SOTDMA). The time slots for AIS transmissions are all precisely aligned to Coordinated Universal Time (UTC), provided for by a Global Navigation Satellite System (GNSS) receiver. This avoids the possibility of two stations transmitting at the same time, in the same slot.

There are 2250 time slots available on each frequency per minute, making the total number of slots equal to 4500.

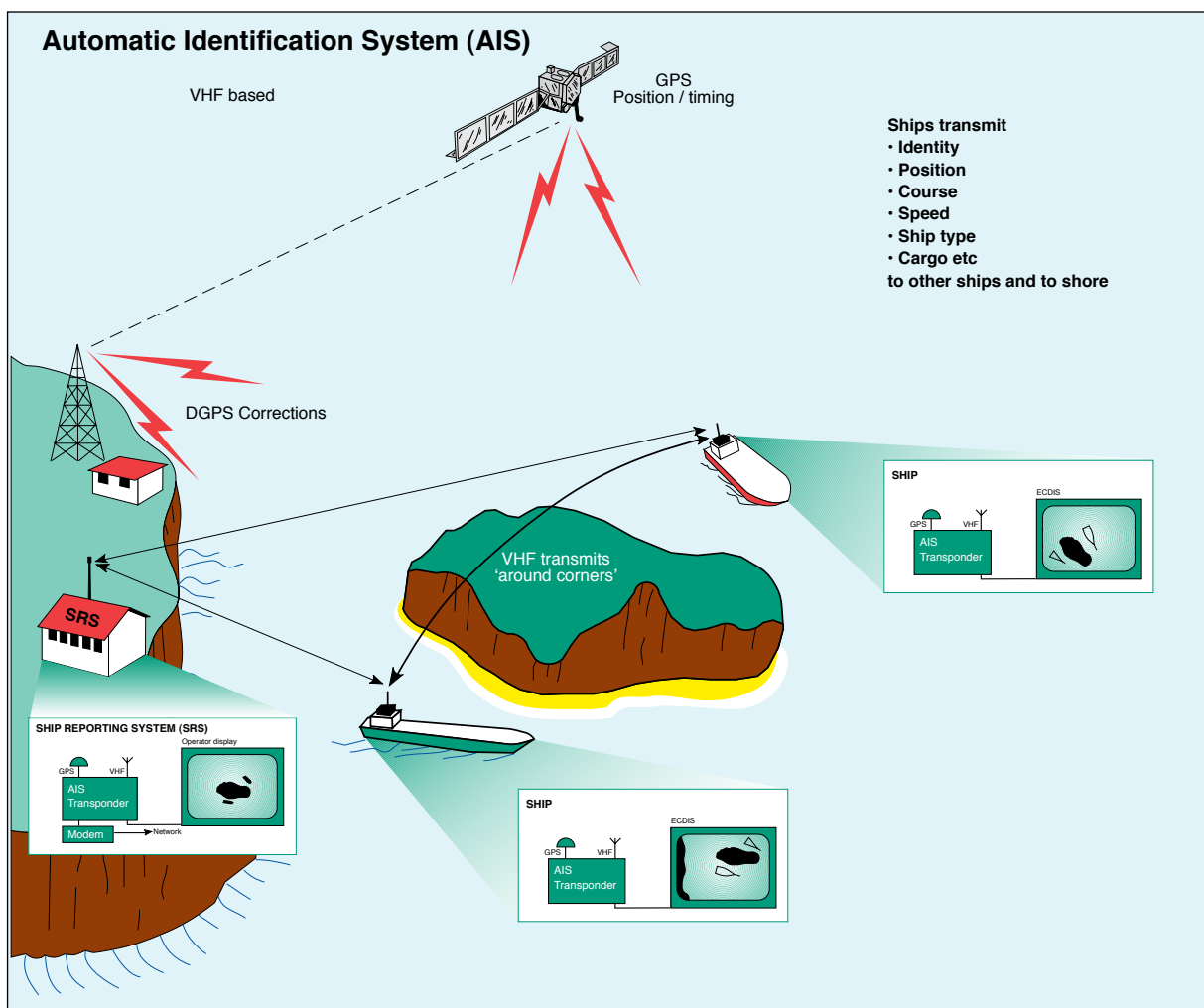


Figure 21 – Overview of the AIS System

## 4.21 Shipboard AIS

A shipboard AIS unit transmits its own data to other vessels and to AIS equipped stations continuously and autonomously. It also receives AIS data of other stations (ship and shore) and can display this data textually and graphically, as required.

Each AIS station consists of a VHF transmitter, two VHF SOTDMA receivers, a VHF DSC receiver, a GNSS receiver (to provide timing for slot synchronisation), and a marine electronic communications link to shipboard display and sensor systems.

Positional information can be derived from the internal GNSS or an external electronic position fixing system.

The display panel with the unit is often the only means of showing received AIS data. Together with a keypad, this basic configuration is known as a Minimum Keyboard and Display (MKD).

The display part of a MKD, as a minimum, consists of three lines of data, each showing bearing, range and identity of the target. In practice, most MKDs display more lines of data and may also have a simple graphical display, showing the relative location of targets, rather like the Plan Position Indicator of a radar.

Ideally, AIS information should to be displayed graphically on a radar, ECDIS or on its own dedicated display.

### Information available

The AIS information transmitted by a ship station includes four different data sets:

- **Fixed or static information** is entered into the AIS unit on installation and need only be changed if the ship changes its name, call sign etc. This information is broadcast every six minutes or on request by a shore authority.
- **Voyage related information** (destination, ETA etc) is manually entered and updated during the voyage. This information is also broadcast every six minutes. In order that correct AIS information is broadcast to other vessels and shore authorities, mariners are reminded to enter current voyage related data such as draught, type of hazardous cargo, destination and ETA properly at the beginning of each voyage and whenever changes occur.
- **Dynamic information** is automatically updated from the ship sensors connected to the AIS. This includes COG, SOG, position (with accuracy and integrity flag), time and navigation status (e.g., underway).
- Broadcast or addressed **short safety related messages**, as required.

#### Refer to IALA publications:

*IALA Guideline 1028 on the Universal Automatic Identification (AIS) – Volume 1, Part 1 – Operational Issues.*

*IALA Guideline 1029 on the Universal Automatic Identification System (AIS) – Volume 1, Part 2 – Technical Issues.*



## 4.22 Shore based AIS

SOLAS Chapter V, Regulation 19, 2.4 refers to the carriage requirements for AIS. The regulation states that AIS shall provide and receive information from appropriately equipped shore stations. The provision of shore based AIS will be necessary to attain the full benefit of the 1974 SOLAS Convention (as amended).

Competent authorities should therefore consider the provision of an AIS shore infrastructure so that the full benefit of the system can be realised in terms of navigation safety and protection of the environment.

As AIS can be seen as a tool related to Vessel Traffic Services (VTS), Competent Authorities should consider implementing AIS into existing VTS Centres. Information on the use of AIS in VTS operations is contained in Sections 1015-1027 of the IALA VTS Manual.

### Refer to IALA publications:

*IALA Recommendation A-123 on the provision of shore based automatic identification systems.*

*IALA Recommendation A-124 on the Automatic Identification System (AIS) Shore Station and Networking Aspects relating to the AIS Service.*

## 4.23 AIS as an aid to navigation

A special type of AIS station fitted to an aid to navigation provides positive identification of the aid without the need for a special ship-borne display. In addition, AIS as an AtoN can provide information and data that will:

- complement or replace an existing aid to navigation, providing identity, state of 'health' and other information such as real time tidal height and local weather to surrounding ships or back to a shore authority;
- provide the position of floating aids (mainly buoys) by transmitting an accurate position (corrected by DGNS) to monitor if they are on station;
- provide real-time information for performance monitoring, with the connecting data link serving to remotely control changes in AtoN parameters or switching on back-up equipment;
- provide local hydrological (hydrographical) and meteorological information;
- possibly replace radar beacons (racons) in the future, providing longer range detection and identification in all weather conditions; and
- gather shipping traffic data on AIS fitted ships for future aid to navigation planning purposes.

For practical or economic reasons it may not be appropriate to fit an AIS to an AtoN. In this case, the 'Synthetic' or Virtual AIS approach may be taken. There are two types of synthetic AIS AtoN, 'Monitored' and 'Predicted'.

- A 'Monitored Synthetic AIS AtoN' is transmitted from an AIS Station that is located remotely. The AtoN physically exists and there is a communication link between the AIS Station and the AtoN. The communication between the AtoN and AIS shall confirm the location and status of the AtoN.
- A 'Predicted Synthetic AIS AtoN' is transmitted from an AIS Station that is located remotely. The AtoN physically exists but the AtoN is not monitored to confirm its location or status. It should not be used for floating aids to navigation.

A Virtual AIS toN is transmitted from an AIS station to establish an aid to navigation that does not physically exist. In this case, a digital information object will appear on the navigational system for

a specified location, even though there is no physical AtoN. A nearby base station or AtoN station could broadcast this message. The AIS message will clearly identify this as a Virtual AIS AtoN.

A new Recommendation and Guideline on the use of Virtual AtoN is expected to be available from April 2010.

**Refer to IALA publications:**

*IALA Recommendation A-126 on the use of the automatic identification system (AIS) in marine aids to navigation.*

*IALA Guideline 1050 on the Management and Monitoring of AIS Information.*

## 4.24 Carriage Requirements

There are two 'types' of AIS units for ship stations. These are termed Class A and Class B units.

Class A ship-borne mobile units must comply with ITU-R M. 1371-1, and are required to be carried on board those vessels to which Regulation 19 of SOLAS Chapter V applies and meet the IMO performance standard. All these ships were to have AIS fitted by 31 December 2004.

Class B ship-borne mobile equipment, while also complying with ITU-R M.1371-1, is designed for vessels such as pleasure craft and fishing vessels. These units are provided with less functionality than Class A units, and do not necessarily meet all the IMO performance requirements. They are designed to operate co-operatively with Class A units.

Administrations can require the carriage of Class B units as part of their domestic requirements.

## 4.25 Cautions when using AIS

The Officer of the Watch (OOV) should always be aware that other ships, in particular pleasure craft, fishing vessels, warships and some shore stations including VTS centres, may not be fitted with AIS.

The OOV should always be aware that AIS fitted on other ships as a mandatory carriage requirement, might, under certain circumstances, be switched off, particularly where international agreements, rules or standards provide for the protection of navigational information. AIS<sup>30</sup> can also provide incorrect information if the input data is wrong.

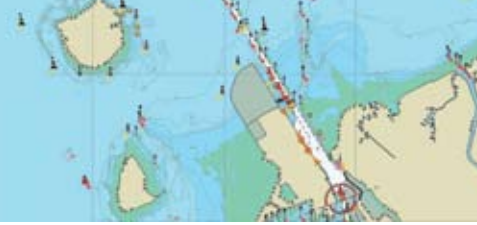
Navigators should be aware of the limitations of AIS. In particular, government agencies and owners should ensure that watch-keeping officers are trained in the use of AIS. Because of these limitations navigators are advised that AIS should not be used as the primary means of collision avoidance.

## 4.26 Strategic Applications of AIS

From a number of maritime perspectives (such as VTS and regulatory compliance), the availability of comprehensive ship information, offers a mechanism for:

- better monitoring of compliance with national and international regulations for mandatory routing and reporting systems, Particularly Sensitive Sea Areas, discharging of oil, garbage disposal etc;
- maritime logistics applications such as fleet management, cargo tracking and port facilities management (movement of pilot boats, tugs etc);

<sup>30</sup>Section 12 of the IALA Guideline 1028 on AIS Volume 1 Part 1 – Operational Issues.



- better control, co-ordination and response in the event of marine incidents, such as SAR and pollution;
- shore-based navigational assistance;
- shipping information gathered from AIS can be channelled into a central repository of a local, national or regional network serving maritime administrations, port authorities, shipping agents, freight handlers, customs, immigration, etc.

Further information on AIS can be found within IMO, IALA, ITU and IEC documentation.

**Refer to IALA Publications:**

*IALA Guideline 1026 on AIS as a VTS Tool*

*IALA Guideline 1028 on AIS - Volume 1, Part I – Operational Issues,*

*IALA Guideline 1029 on AIS - Volume 1 Part II – Technical Issues, Edition 1.1*

*IALA Technical Clarifications on ITU Recommendation ITU-R M.1371-1 Edition 2.4*

**Refer to IMO Publications:**

*Recommendation on Performance Standards for an Universal Shipborne Automatic Identification System (AIS) (MSC 74(69) Annex 3).*

*Guidelines for the onboard operational use of shipborne Automatic Identification Systems (AIS) (Resolution A.917 (22), as amended by Resolution A.956 (23)).*

*Performance Standards for the presentation of navigation-related information on shipborne navigational displays (Resolution MSC. 191(79)).*

*SN/Circ. 227 Guidelines for the installation of a shipborne Automatic Identification System (amended by SN/Circ 245).*

*SN/Circ. 236 Guidance on the application of AIS Binary Messages.*

*SN/Circ. 243 Guidelines for the presentation of navigation-related symbols, terms and abbreviations.*

*SN/Circ. 244 Guidance on the use of UN/LOCODE in the destination field of AIS messages.*

**Refer to ITU Publications:**

*ITU-R M.1371-1 Recommendation on the Technical Characteristics for a Ship-borne Universal Automatic Identification System (AIS) Using Time Division Multiple Access in the Maritime Mobile Band.*

*Radio Regulations, Appendix S18, Table of Transmitting Frequencies in the VHF Maritime Mobile Band.*

*ITU-R M.823-2 Recommendation on the technical characteristics of differential transmissions for global navigation satellite systems from maritime radio beacons in the frequency band 283.5-315 kHz in region 1 and 285-325 kHz in regions 2 and 3.*

**Refer to IEC Standards:**

*61993 Part 2: Class A Ship-borne equipment of the Automatic Identification System (AIS) - Operational and Performance requirements, methods of testing and required test results.*

*61108-1 (2nd edition): navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS).*

*61162-1 (2nd edition) Maritime navigation and radiocommunication equipment and systems – Digital interfaces – Part 1: Single talker and multiple listeners.*

*62320-1: Maritime Navigation and Radiocommunication equipment and systems – Automatic Identification System. AIS base stations - Minimum operational and performance requirements - methods of test and required test results.*

*62320-2 Maritime Navigation and Radiocommunication equipment and systems – Automatic Identification System. AIS aids to navigation - Minimum operational and performance requirements - methods of test and required test result.*

*62287-2 (Part A and B) Class B AIS (Part A – CSTDMA; Part B – SOTDMA)*

*61097-14 (pending) Global Maritime Distress and Safety System (GMDSS). AIS search and rescue transmitter (AIS-SART) – Operational and performance requirements: methods of testing and required test results.*

## 4.27 IALA-NET

IALA-NET is a global government to government maritime data network being established by IALA. The network is multi-lateral, with freely shared data, and facilitates the exchange of maritime information between Competent Authorities. The content and capability of IALA-NET is envisaged to expand from the present AIS data up to and including e-Navigation data. It is the intent that IALA-NET facilitate the growth of value added services, such as global vessel tracking, risk analysis, marine incident analysis and near miss analysis, based upon the data it exchanges.

### Refer to IALA Publications:

*IALA Recommendation E-142 on Maritime Data Sharing 'IALA-NET'*

## 4.28 Electronic Chart Display and Information System (ECDIS)

Although ECDIS, as ship borne equipment, is not an “aid to navigation” as defined by IALA, it deserves to be mentioned because it brings major changes to the manner in which vessels are navigated. ECDIS uses digital vector data in a way that replaces the traditional paper charts with a more versatile electronic product that can draw on a variety of positioning and data inputs, such as GNSS, DGNS, AIS, radar, echo sounder, compass, an electronic chart, navigational publications, the chart amendments and tidal and meteorological information.

### Performance Standards

The performance standards for ECDIS have been defined by the International Maritime Organization (IMO), in conjunction with the International Hydrographic Organization (IHO).

IMO Resolution A.817(19) as amended by Resolution MSC.64(67) and by Resolution MSC.86(70) enables marine administrations to accept ECDIS as a legal equivalent to paper charts that are required to be carried for compliance with SOLAS Chapter V.

### Performance Elements

There are two key performance elements to ECDIS:

- an approved processing system (or ‘box’): and
- Electronic Navigational Charts (ENCs) that have been prescribed by a national hydrographic office and meet the standards set down in the 3rd Edition of the IHO Special publication No.57 (S 57).

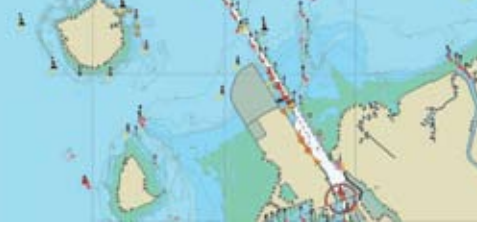
While an ECDIS ‘box’ may be capable of reading other forms of electronic charts, it ceases to be a compliant system without the official ENCs.

Non-S57 electronic charts include:

- Raster Navigation Charts (RNC) that are effectively electronic copies of paper charts; and
- electronic charts that are not issued by a national hydrographic authority or differ from the S57 standard.

When the relevant chart information is not available in the appropriate form (issued by a national hydrographic office and meeting the S57 standards) some ECDIS equipment may operate in the Raster Chart Display System mode, but in that case the ECDIS equipment should be used together with an appropriate portfolio of up-to-date paper charts. Additional information on ECDIS is available on the IMO and IHO websites.

The IHO is developing the S-100 IHO Universal Hydrographic Data Model standard. S-100 can support a wide variety of hydrographic-related digital data sources, and is fully aligned with mainstream



international geospatial standards, thereby enabling the easier integration of hydrographic data and applications into geospatial solutions. S-100 will eventually replace S-57. S-100 enables the development of new applications that go beyond the scope of traditional hydrography - for example, high-density bathymetry, seafloor classification, marine GIS, etc. The S-100 development and maintenance process is specifically aimed at allowing direct input from non-IHO stakeholders, thereby increasing the likelihood that these potential users will maximise their use of hydrographic data for their particular purposes. This approach will potentially enable S-100 to become an important tool in the development and implementation of e-Navigation.

## 4.29 Maritime Information

The timely provision and display of maritime information will be an essential component of e-Navigation. Generically called Marine Information Overlays (MIOs), this includes both static and dynamic information capable of being used ashore (e.g., at a VTS Centre) and onboard ships at sea. Static information could pertain to marine protected areas, sea ice coverage, emergency management/response areas, and seafloor bathymetry. Dynamic operational information would be broadcast via AIS binary messages as time-critical information regarding ship/voyage data, marine traffic signals, area notices, dangerous cargo, environmental, meteorological, hydrographic, and status of AtoN. In particular, mariners require this type information pertaining to the planning and execution of voyages, the assessment of navigation risk and compliance with regulation. The provision and use of MIOs will depend on the current situation and task-at-hand.

At the 54th session of the IMO Safety of Navigation Subcommittee (July 2008) it was recommended that there be Common Maritime Information/Data Structure that would be accessible from a single integrated system. Shore users require information pertaining to their maritime domain, including static and dynamic information on vessels and their voyages. Ideally, this information should be provided in “an internationally agreed common data structure. Such a data structure is essential for the sharing of information amongst shore authorities on a regional and international basis.”

At present, there is no specific guidance or standards related to the presentation/display of MIOs on shore-based equipment or systems. However, there are a number of general and equipment-specific international standards that have been adopted by IMO, IHO, and IEC that contain “guidance” related to the presentation/display of various types of shipborne navigation-related information. This is something that will need to be part of e-Navigation development and implementation.

## 4.30 AtoN Attribute Information

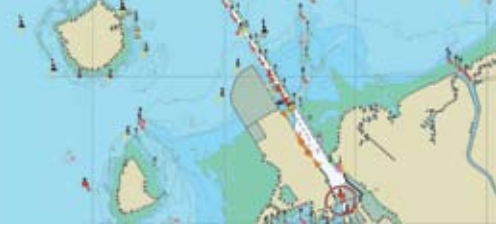
The exchange of information about AtoN between any parties in a digital environment will require an internationally agreed standard so that information can be automatically compiled for sending and automatically understood by systems that receive it.

Such a standard will enable harmonisation of the management of information about AtoN, and in particular information that is relevant to mariners: “situation normal” data (position, colour, shapes, light etc) and also “situation abnormal” (lost top mark, light on reduced range, unlit etc). In GIS terms this sort of information can be described as attribute data (information particular to a GIS object, such as an AtoN) and metadata (data about the attribute data).

### **Refer to IALA Publications:**

*IALA Guideline No. 1072 On AtoN Information Exchange & Presentation .’*





### 4.31 Meteorological and Hydrological Information

IMO is responsible for the AIS Binary Broadcast Messages (AIS Message 8) and a message structure has been defined for meteorological and hydrological information.

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. 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. Providing real-time information of this type, for example dynamic under-keel clearance, wave heights or sea state can be seen as applications of e-Navigation, requiring integration between shore-side and ship-borne systems.

### 4.32 Intergovernmental Oceanographic Commission

The Intergovernmental Oceanographic Commission (IOC) is responsible for co-ordinating the Global Sea Level Observing System (GLOSS) program to establish global and regional networks of sea level stations for providing essential information for international oceanographic research programmes, including those dedicated to the study of aspects of climate change, and operational oceanography. The main component of GLOSS is a network of 287 sea level stations worldwide (referred to as the 'Global Core Network').

IALA supports and encourages participation in the GLOSS program.

Authorities that are procuring or upgrading Sea Level Measurement devices are encouraged to consider using equipment that can support the requirements of the GLOSS program. 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.pol.ac.uk/psmsl/programmes/gloss.info.html](http://www.pol.ac.uk/psmsl/programmes/gloss.info.html)

# 5

## VESSEL TRAFFIC SERVICES (VTS)



### 5.1 Definition

A VTS, as defined by IMO Resolution A.857(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”.**

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.

### 5.2 Services

Participation in a VTS may be mandatory or voluntary, depending on local regulations. In either case, vessels operating in a VTS area may avail themselves of the following services:

- **Information Service:** is a service to ensure that essential information becomes available in a timely manner to support on-board navigational decision making. This may include information on the position, identity, intentions and destination of other vessels; meteorological and hydrological conditions, notices to mariners, status of aids to navigation, or any other condition or situation on the waterway that could affect a vessel's transit.
- **Traffic Organisation Service:** 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. Traffic Organisation concerns the forward planning of movements to maintain vessel safety and to achieve efficiency. This service may include the allocation of water space, establishing and operating a system of traffic clearances, managing traffic around certain vessels with limited manoeuvrability, establishing routes to be followed and speed limits to be observed, or any other measures that may be considered necessary and appropriate by the VTS. All or certain classes of vessels may be required to participate in this service.
- **Navigational Assistance Service:** is a service to assist in the on-board navigation decision making and to monitor its effect. This may include bearing and range to a nearby danger or landmark, a course to make good, or assistance in determining a vessel's position. Navigational assistance may be provided at the request of a vessel or when deemed necessary by the VTS.
- **Support of Allied Services:** VTS are often closely aligned with SAR services, government agencies or commercial port services and may be of assistance in aiding vessels to contact or communicate with these allied services. These services may benefit from correct and timely information about vessel positions, movements, destinations and times of arrival. This enables those allied services to enhance their own efficiency, whilst at the same time to better plan and utilise their resources.



### 5.3 VTS System

To respond to developing traffic situations and to decide upon appropriate actions, a VTS should be capable of generating a comprehensive overview of the traffic in its service area combined with all traffic influencing factors. Examples of data that should be collected to compile the traffic image include:

- data on the fairway situation, such as meteorological and hydrological conditions and the operational status of aids to navigation;
- data on the traffic situation, such as vessel positions, movements, identities and intentions with respect to manoeuvres, destination and routing;
- data on vessels in accordance with the requirements of ship reporting and any additional data required for the effective operation of the VTS.

The traffic image provides situational awareness and facilitates the VTS operator to evaluate conditions and make decisions accordingly. The information presented in the traffic image is communicated to participating vessels through the VTS capability to interact with traffic.

#### Refer to IALA Publications:

##### **Recommendations**

- V-102 Application of "User pays" principle to Vessel Traffic Services.*
- V-103 Standards for Training and Certification of VTS personnel.*
- V-119 Implementation of Vessel Traffic Services.*
- V-120 Vessel Traffic Services in Inland Waters.*
- V-125 Integration and Display of AIS and other information at a VTS Centre.*
- V-127 Operational Procedures for Vessel traffic services.*
- V-128 Operational and Technical Performance Requirements for VTS equipment.*
- A-123 The Provision of Shore Based AIS.*
- A-124 AIS Shore Station and networking aspects relating to AIS service.*
- A-126 Use of AIS in Marine Aids to Navigation.*

##### **Guidelines**

- 1014 - Accreditation of VTS Training.*
- 1017 - Assessment of training requirements for existing VTS Personnel, candidate Operators and the revalidation of VTS Operator Certificates.*
- 1018 - Risk management.*
- 1026 - AIS as a VTS Tool.*
- 1027 - Designing and implementing simulation in VTS training.*
- 1032 - Aspects of Training of VTS Personnel relevant to the introduction of AIS.*
- 1045 - Staffing Levels at VTS Centres.*
- 1046 - Response plan for marking new wrecks.*
- 1055 - Preparing for a voluntary IMO Audit on VTS Delivery.*
- 1056 - Establishment of VTS Radar Services.*
- 1071 - Establishment of a VTS beyond Territorial Seas.*

##### **IALA Manuals**

- VTS Manual (2008).*

# 6

## OTHER SERVICES AND FACILITIES

### 6.1 Pilotage

#### 6.1.1 Pilotage as a Service to Navigation

Pilotage is a specialised, and usually, licensed service that may be applied to navigation in restricted waters. The skill draws on local knowledge such as the relative positions of geographic points or aids to navigation, submerged features, traffic pattern, tides, currents, climatic conditions, as well as special ship handling competence.

Pilotage may be required in coastal waters, estuarial waters, rivers, channels, ports, harbours, lakes, canals, or 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 and English Channel, the Baltic Sea and the entrances to the Baltic Sea.

When a pilot embarks a vessel, it is customary for the pilot to be given the “conduct of the vessel”, but not the “command”. The role of the pilot is to act as an adviser to the master, which often includes:

- giving instructions to the bridge personnel operating the navigational and manoeuvring equipment;
- assisting or performing the communication with VTS centres, port controls and other vessels;
- employing special knowledge of:
  - current conditions
  - traffic conditions;
  - operational status of aids to navigation;
  - sailing directions;
  - fairway restrictions applicable to the piloted vessel;
  - other local conditions.

In addition the pilot needs to be able to adapt quickly to the operational culture on board; the handling characteristics of the vessel; and the state of the navigation equipment aboard.

A Portable Pilot Unit (PPU) can be generally described as a portable, advanced computer based system which a pilot brings on board a vessel as a supporting tool for the decision-making when navigating in confined waters or waters with dense traffic. Interfaced to a positioning sensor such as GPS/DGPS and using updated ENCs approved by hydrographic offices, the PPU will show the position and movement of the vessel in real-time. In addition, the PPU provides information about the locations and movements of other vessels via an AIS interface.

Increasingly, PPU's are being used to display other types of navigation-related information such as soundings and depth contours from recent hydrographical surveys, dynamic water levels, current flow, ice coverage, and security zones.

### 6.1.2 Compulsory or Recommended Pilotage

Pilotage may be applied within declared ports, but also in coastal areas, lakes, inland waterways or even deep seas. 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 service provider 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: Vessels of given characteristics and/or carrying specific types of cargo must take a pilot when entering a declared area.
- A country may seek IMO approval for an area to be declared a Particularly Sensitive Sea Area (PSSA). If approved, the declaration allows Additional Protective Measures to be applied to shipping. This could include compulsory pilotage arrangements.
- Recommended pilotage: A Competent Pilotage Authority or IMO can promulgate notices recommending that masters of applicable vessels should engage a licensed pilot.

### 6.1.3 Other Pilotage Considerations

Pilot Services can be provided by public or private operators or service providers depending on national legislation. However, generally the pilot licensing authority should be a government-regulated Competent Pilotage Authority.

The IMO has issued minimum standards for training and certification of pilots other than deep sea pilots. However individual countries may impose more stringent standards.

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

### 6.1.4 IMO documents relating to pilotage or pilot training and certification

In 2003 the IMO Assembly 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:

- Resolution A.480(IX) (adopted in 1975) recommends the use of qualified deep-sea pilots in the Baltic and 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); IMO Resolution MEPC.133(53), which 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.889(21) on Pilot Transfer Arrangements gives recommendations on the construction of pilot ladders.
- Resolution A.960(23) gives recommendations on training and certification and operational procedures for Maritime Pilots other than Deep Sea pilots.





*Photo courtesy of Wasser und Schifffahrtsdirektion (Germany)*

## 6.2 Ships Routing

The General Provisions on Ships' Routing are established by SOLAS Chapter V, Regulation 10<sup>31</sup> and adopted by IMO Resolution A.572(14).

### 6.2.1 Objectives

The purpose of ships' routing 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' routing 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 routing system will depend upon the particular hazardous circumstances which it is intended to alleviate, but may include some or all of the following:

- the separation of opposing streams of traffic so as to reduce the incidence of head-on encounters;
- the reduction of dangers of collision between crossing traffic and shipping in established traffic lanes;
- the simplification of the patterns of traffic flow in converging areas;

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<sup>31</sup> Refer to IMO Publication 'Ships; Routing', IMO, London, 9th Edition.



- the organization of safe traffic flow in areas of concentrated offshore exploration or exploitation;
- the organization of traffic flow in or around areas where navigation by all ships or by certain classes of ship is dangerous or undesirable;
- the organization of safe traffic flow in or around or at a safe distance from environmentally sensitive areas;
- the reduction of risk of grounding by providing special guidance to vessels in areas where water depths are uncertain or critical; and
- the 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' routing:

**Approach Channel:** An approach channel is defined as any stretch of waterway linking the berths of a port and the open sea. There are two main types; the seaway or outer channel, and the main approach or inner channel which lies in relatively sheltered waters.

**Area to be avoided:** A routing measure comprising an area within defined limits in which either navigation is particularly hazardous or it is exceptionally important to avoid casualties and which should be avoided by all ships, or certain classes of ship.

**Deep-water route:** A route within defined limits which have been accurately surveyed for clearance of sea bottom and submerged obstacles as indicated on the 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<sup>32</sup>:** A routing 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 routing system:** A routing 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 routing 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 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 routing 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.

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<sup>32</sup>This term is used in the 1972 COLREGs



**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<sup>33</sup>:** A routing 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.

**Routing system:** Any system of one or more routes or routing 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<sup>34</sup>:** 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<sup>35</sup>:** 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<sup>36</sup>:** A routing 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 Manoeuvring

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 22. These comprise:

- turning;
- recovery, and;
- track keeping.

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

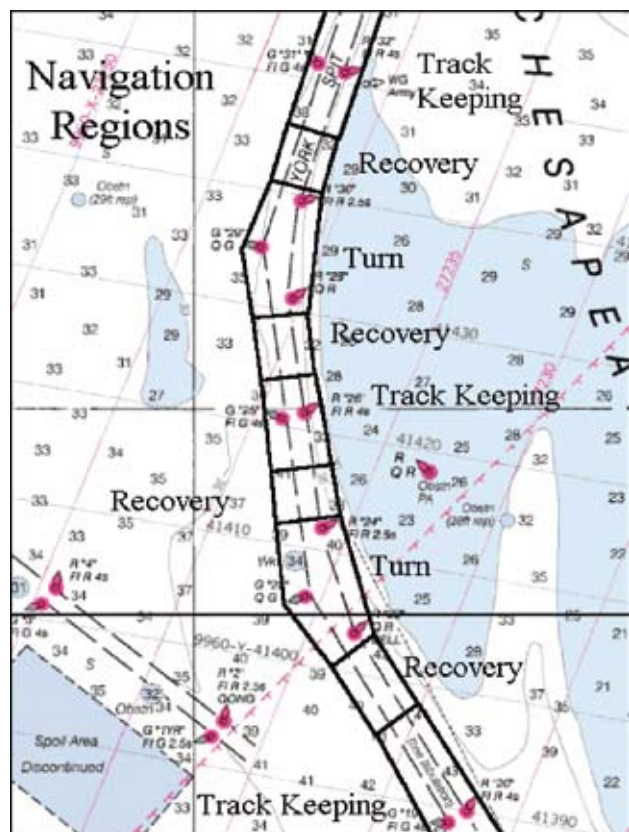


Figure 22 – Vessel manoeuvring phases

<sup>33</sup>This term is used in the 1972 COLREGs

<sup>34</sup>This term is used in the 1972 COLREGs

<sup>35</sup>This term is used in the 1972 COLREGs

<sup>36</sup>This term is used in the 1972 COLREGs



## 6.3 Achieving a 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. The responsible provision of AtoN systems requires that systems be designed to meet the essential minimum requirements for safe and expeditious navigation through specific waters in accordance with the type and volume of traffic.

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

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 reduces 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 regions of the waterway must be considered, the overall aids to navigation system must support a smooth transit of the waterway as a whole. The toolbox for the design consists of the IALA MBS (Annex A of this document) and the technical tools referred to in Chapter 3 (Aids to Navigation) and Chapter 4 (e-Navigation), and also described in many IALA Recommendations and Guidelines.

The specific aids to navigation system that is 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 the waterway users, a system of aids to navigation must:

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

As indicated in “Step 1” of the LOS/OPS statement (refer 8.2), AtoN systems may be provided for the safety of navigation in various areas:

- Fairways, dredged channels and canals.
- Waters adjacent to the coast.
- Archipelagic waters, in pristine and/or improved condition.
- Estuarine rivers.
- River systems.
- Straits.
- Narrow stretches of land.
- Open sea with Ships’ Routeing Systems.

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 lies 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" June 1997. This Guide is currently under review by PIANC's Marcom Working Group 49 and the report is expected to be available in 2010.

### 6.3.1 Design Elements

During the design phase the required level of different design parameters should be considered. In this phase the functional requirements have to be translated into technical 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 this 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 mitigations. However, the planner must also consider the higher availability objectives that may be required. Competent Authorities should refer to IALA Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation for additional information related to the categorization of individual aids to navigation, the calculation of availability targets, and recommended availability objectives.

AtoN systems should be designed to assist mariners under various weather, sea and ice conditions found during the local navigation season for the various types of vessel.

Short Range AtoN, especially buoys, should be designed regarding their visual information, radar information (active or passive) and other modes of information (Radionavigation, AIS as an AtoN). Design elements must take into account the visibility and radar availability implications. Designing for worst case visibility is not practical. Reduced visibility due to haze and fog must be considered.



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

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

**Refer to IALA publication:**

*IALA Recommendation O-130 on Categorisation and Availability Objectives for Short Range AtoN.*

### **6.3.2 Dredging Considerations**

Port and waterways authorities should consider the significant contribution that proper use of aids to navigation in improving positioning accuracy and navigational accuracy can make to the efficiency of major dredging projects and waterways maintenance.

In some cases the required channel width could be reduced as can the costs for major and maintenance dredging. The PIANC Guide 'Approach Channels', June 1997, which is currently under review, contains further information on this issue.

### **6.3.3 Hydrographic Considerations**

Usually, the uncertainty of positioning an AtoN should not be bigger than the uncertainty in survey and charting.

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 soundings, dangers, other significant submerged features, AtoN features significant to navigation, the coastline and topographical features should be determined such that the horizontal uncertainty meets the requirements specified. This includes all uncertainty sources not just those associated with positioning equipment.

### **6.3.4 Economic Considerations**

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

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

### 6.3.5 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 to 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).



*Full Mission Simulator – Photo courtesy of Force Technology*



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 lay-out, 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 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.

A number of different simulation tools are available for design studies and have different usability and applications. The following simulation tools are the most common:

- Fast time simulation.
- Desktop simulation.
- Part task simulation.
- Full mission simulation.
- Traffic flow simulation.

**Refer to IALA publications:**

*IALA Recommendation O-138 on the Use of GIS and Simulation by Aids to Navigation Authorities.*

*IALA Guideline 1058 on the Use of Simulation as a Tool for Waterway Design and AtoN Planning.*

*IALA Guideline No. 1069 on Synchronisation of Lights.*

## 6.4 The Marking of Man-Made Offshore Structures

New uses of ocean and coastal waters, subsoil and seabed, are constantly emerging with consequent increases in the number and types of man-made structures being built in the maritime environment.

Effective and consistent marking of these diverse structures, during their construction phase and when established, can be a significant challenge for Aids to Navigation Authorities. IALA Recommendation O-139 The Marking of Man-made Offshore Structures provides comprehensive information on the required marking. This replaces previous recommendations O-114, O-116, O-117 and O-131 which are now consolidated in this single document.

This section outlines the general requirements but reference should be made to O-139 for detailed information. In O-139 the various structures are set out in four groups:

- Offshore Structures in General (those not included in other groups).
- Aquaculture Farms.
- Wind farms.
- Wave and Tidal Energy Devices.

### 6.4.1 Offshore Structures in General (those not included in other groups)

Early consultation between all relevant parties is important to avoid prejudicing the safe use of Traffic Separation Schemes, Inshore Traffic Zones, recognised sea lanes and safe access to anchorages, harbours and places of refuge. On a case-by-case basis consideration may be given to establishing exclusion or Safety Zones.

The Offshore Structures mentioned in this section should be marked as a single unit or as a block or field as follows:

- At night by one or more white lights (Morse letter « U » • • –), operated in unison, so that at least one light is visible upon approaching the structure from any direction.
- The horizontal and vertical extremities of the structure shall be adequately marked.
- Each structure shall, where practicable, display identification panels with black letters or numbers 1 m high on a yellow background visible in all directions in daylight as well as at night.
- Each structure may carry one or more sound signals (Morse letter « U » • • – every 30 seconds) audible upon approaching the structure from any direction with a range of at least 2 nautical miles.
- A radar beacon may be fitted (on a temporary uncharted structure this shall be coded « D » – • • ).
- Where necessary buoys or beacons shall be placed to mark the perimeter of a group of structures, or to mark channels through a group of structures, or to mark any fixed structure while being erected or dismantled.
- Additional marking and Maritime Safety Information may be required during construction / decommissioning.

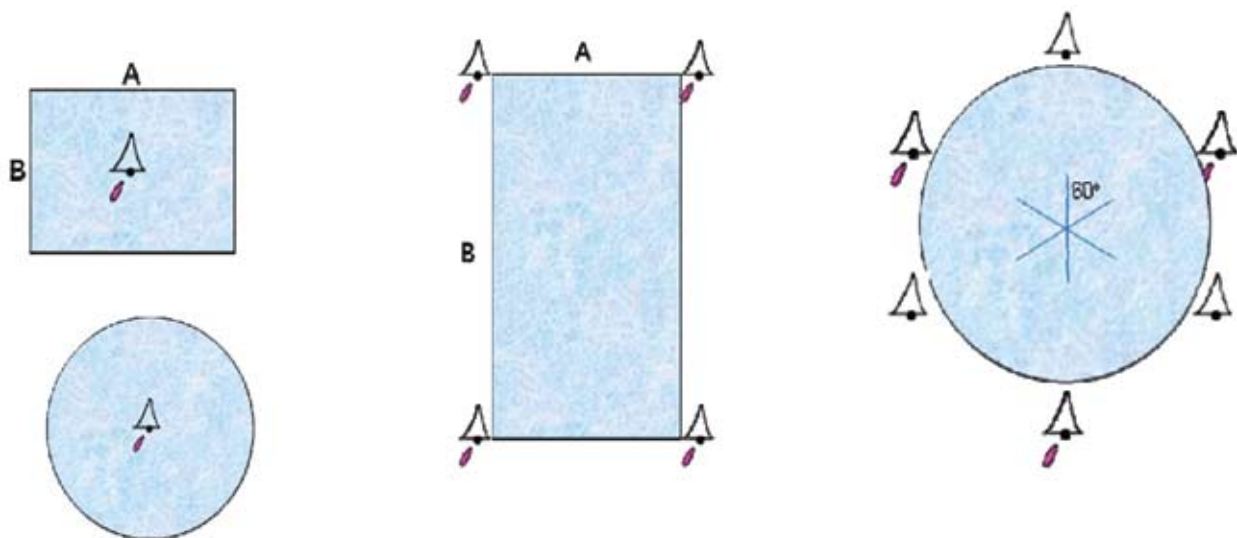


## 6.4.2 Offshore Aquaculture Farms

Aquaculture farms should be marked in accordance with the IALA Maritime Buoyage System:

- Farms are normally marked by special marks, lateral or cardinal marks and the use of Racons or AIS may also be considered.
- Channels between aquaculture farms should normally be marked with lateral marks.
- Radar reflectors and reflective material should be considered.

Depending on the size and shape of the farm the minimum marking arrangement may range from a light in the middle of the aquaculture farm for small farms (sides or diameter  $\leq 500$ ) to lights and daymarks on corners or sectors on farms where sides are greater than 900 / 2,500 metres or radius greater than 2,000 metres, as shown in Figure 23.



Small - Sides/ Diameter < 500 metres

Larger - Sides between 900 and 2,500 metres or radius > 2,000 metres

Figure 23 – Sample marking system for offshore aquaculture farms

## 6.4.3 Offshore Wind Farms

This group includes Meteorological Masts, Wind Generators and Wind Farms. These AtoN have an availability of not less than 99.0% (IALA Category 2).

Early consultation between all relevant parties is important. In general, these developments should not prejudice the safe use of Traffic Separation Schemes, Inshore Traffic Zones, recognised sea lanes and safe access to anchorages, harbours and places of refuge. On a case-by-case basis consideration may be given to establishing exclusion or safety zones.

There is evidence to show that wind farms can interfere with shipborne and shore based radar systems.



A Significant Peripheral Structure (SPS) is the 'corner' or other significant point on the periphery of the wind farm. The distance between SPSs should not normally exceed three (3) nautical miles.

There are different requirements for isolated structures which, because of the increased danger they pose, should be lighted with a white light flashing Morse code « U » (• • –).

The overall marking requirements are:

- Turbine tower painted yellow (or yellow bands) all round from the level of Highest Astronomical Tide (HAT) to 15 metres or the height of the Aid to Navigation.
- AtoN should be mounted below the lowest point of the arc of the rotor blades and at least 6 metres above HAT.
- Each SPS should be fitted with lights visible from all directions in the horizontal plane. These lights should be synchronized to display flashing yellow, with a range of not less than five (5) nautical miles.
- Selected intermediate (I) structures on the periphery of a wind farm other than the SPSs, should be marked with flashing yellow lights which are visible to the mariner from all directions in the horizontal plane. The flash character of these lights should be distinctly different from those displayed on the SPSs, with a range of not less than two (2) nautical miles. The lateral distance between such lit structures or the nearest SPS should not exceed two (2) nautical miles.
- In addition to the above further consideration should be given to lighting all peripheral structures or lighting all structures within the wind farm and to the use of Racons, Radar Reflectors, Radar Target Enhancers and/or AIS as an Aid to Navigation.
- Consideration may be given to the provision of sound signals, taking into account the prevailing visibility, topography and vessel traffic conditions. The typical range of such a sound signal should not be less than two (2) nautical miles.
- Additional marking of individual structures may also be considered. This may include lighting of each structure, unlighted structures with retro-reflective areas, structures illuminated with down-lights on, flashing yellow lights or identifying numbers (either lit or unlit).
- Consideration should be given to use of synchronised lights to mitigate the effect of the proliferation of lights in high density developments.

An electrical transformer station or a meteorological or wind measuring mast, if considered to be a composite part of the wind farm, should be included as part of the overall wind farm marking. If not considered to be within the wind farm block it should be marked as an offshore structure (i.e. a white light flashing Morse code « U » (• • –)).

As far as practicable, aeronautical obstruction warning lights fitted to the tops of wind generators should not be visible below the horizontal plane of these lights. Aviation Authorities should be consulted regarding the specification of such lights. Additional marking and Maritime Safety Information may be required during construction / decommissioning. An example is provide in Figure 24.

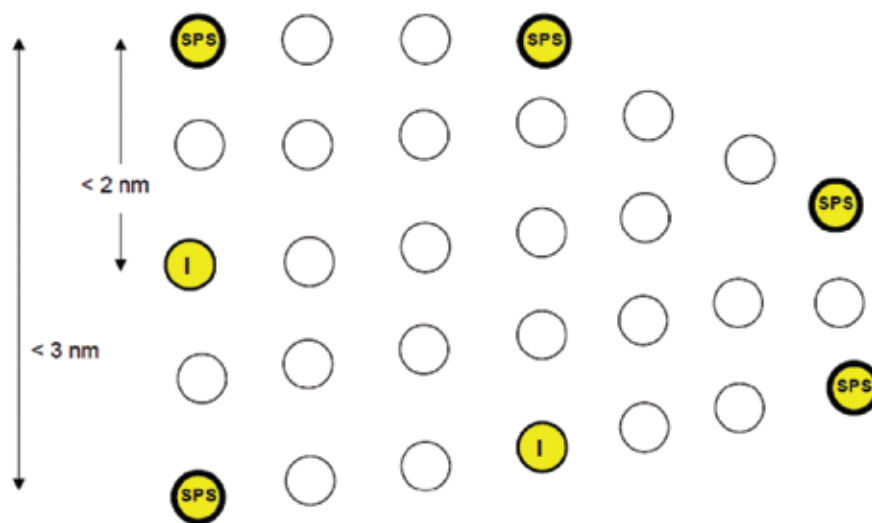


Figure 24 - Sample marking of a Wind Farm

#### 6.4.4 Offshore Wave and Tidal Energy Devices

A diverse range of Wave and Tidal Energy Devices are being trialled and established.

Many of these devices are low freeboard floating structures that are moored to the seabed. They may be moored in deep or shallow water and some may be located on the seabed or just below the surface or with subsurface or surface piercing elements. There may also be subsurface moving blades to be considered.

Early consultation between all relevant parties is important. In general, these developments should not prejudice the safe use of Traffic Separation Schemes, Inshore Traffic Zones, recognised sea lanes and safe access to anchorages, harbours and places of refuge. On a case-by-case basis consideration may be given to establishing exclusion or safety zones.

Aids to Navigation for these devices should normally have an availability of not less than 99.0% (IALA Category 2).

Offshore Wave and Tidal Energy Devices should be marked as follows:

- When structures are fixed to the seabed and extend above the surface, they should be marked in accordance with the recommendations set out for the marking of Offshore Wind farms (see above).
- Areas containing surface or sub-surface devices should be marked by lighted navigation buoys in accordance with the IALA MBS.
- In addition to buoys active or passive radar reflectors, retro reflecting material, Racons and/or AIS transponders should be fitted as the level of traffic and degree of risk requires.
- Site boundary markings should be visible to the Mariner from all relevant directions in the horizontal plane, by day and by night.
- Lights should have a nominal range of at least 5 (five) nautical miles.

- The Northerly, Easterly, Southerly and Westerly boundaries should normally be marked with the appropriate IALA Cardinal mark. However, depending on the shape and size of the field, there may be a need to deploy lateral or special marks.
- In the case of a large or extended energy extraction field, the distance between navigation buoys that mark the boundary should not normally exceed 3 (three) nautical miles.
- Individual devices within a field which extend above the surface should be painted yellow above the waterline.
- Depending on the boundary marking, individual devices within the field need not be marked. However, if marked, they should have flashing yellow lights with a minimum range of 2 nautical miles so as to be visible to the mariner from all relevant directions.
- Consideration should be given to the provision of AIS as an Aid to Navigation on selected peripheral devices.
- A single structure, standing alone, that extends above should be marked as an Isolated Danger as described in the IALA MBS.
- In the case of a single device which is not visible above the surface, but is considered to be a hazard to surface navigation, it should be marked by a Lighted Special Mark buoy with a range of not less than 5 nautical miles.
- Additional marking of individual structures may also be considered. This may include lighting of each structure, unlighted structures with retro-reflective areas, structures illuminated with down-lights on, flashing yellow lights or identifying numbers (either lit or unlit).
- Consideration should be given to use of synchronised lights to mitigate the effect of the proliferation of lights in high density developments.

An electrical transformer station or other structure, if considered to be a composite part of the energy extraction field, should be included as part of the overall marking. If not considered to be within the boundaries of the field, it should be marked as an Isolated Danger as described in the IALA MBS.

Contingency plans should be established to provide an appropriate response in the event of a device breaking loose and becoming a hazard.

Additional marking and Maritime Safety Information may be required during construction / decommissioning.

## 6.5 Sound Signals

Although sound signals still exist, it has been IALA policy since 1985 that these devices should only be used as a hazard warning.

The Competent Authority shall determine whether a hazard requires a sound signal and the level of reduced visibility per year that justifies its installation (e.g. 10 days of visibility under 1nm/year). Certain man-made structures such as offshore structures, bridges, breakwaters and isolated AtoN may be considered a hazard requiring a sound signal.

### Refer to IALA publications:

*IALA Recommendation E-109 for the Calculation of the Range of a Sound Signal.*

*IALA Recommendation O-113 for the Marking of Fixed Bridges over Navigable Waters.*

*IALA Recommendation O-139 for the Marking of Man-Made Offshore Structures.*



### 6.5.1 Considerations on Sound Signals and their use

Consideration may be given to providing one or more sound signals on offshore structures and wind farms. Where provided the sound signals should have a range of at least 2 nautical miles. There are a number of considerations to be taken into account with regards to sound signals and their use:

- Sound propagates in the atmosphere in a variable manner, making the perception of direction and distance to the emitter difficult. It may be very difficult to estimate the location of a danger.
- A linear increase in the perception of a sound corresponds to an exponential power increase in the sound source.
- Background noise level on board vessels may prevent recognition of a sound signal.
- Occasionally, sound propagation is such that a signal may be almost inaudible close to the source, but of the expected level further away from the source.
- The identification of the sound signal characteristics may not be reliable as a result of fluctuations in propagation causing interruption of reception.
- A sound signal may be considered a nuisance by the local community.
- In some situations, there is the need to combine two or more sound sources or to install a baffle device to avoid the propagation of sound in a certain direction. In both cases, care must be taken to avoid the sound of one source being cancelled by the sound of the other or by the reflected sound.
- Sound signals are normally operated automatically using a fog detector.

### 6.5.2 Considerations on Fog Detectors

Until approximately thirty years ago, sound signals were operated by lighthouse keepers observing local visibility and turning on the signal as required. At present, automatic fog detectors that emit an infrared beam, measure the reflection from the water particles in the air, and activate the sound signal at certain visibility thresholds.

Reliable remote visibility meters, developed for use at remote meteorological stations, are used as fog detectors. These may be activated by heavy rain or snow, as well as fog.

### 6.5.3 Sound Signals in the World

Some countries, including Finland, Iceland, Australia and Norway have abolished the use of sound signals.

Other countries continue to use fog signals, usually 2 mile range electric signals, on offshore lighthouses and light vessels. In countries with high incidence of fog, some large compressed air powered signals are still in use.

### 6.5.4 Range of a sound signal

Nominal Range: the distance at which, in fog, a lookout positioned in the wing of the bridge has a probability of 90% of hearing the signal when subjected to a noise as defined by IALA as being equal to or in excess of that found in 84% of large merchant vessels, the propagation between the sound signal emitter and the listener occurring during relatively calm weather and with no intervening obstacles (refer Table 19).

Table 19 – Nominal Range

Pn(NM) f(Hz)	Sound Pressure Level			
	0.5	1	1,5	2
25	162	172	176	178
50	149	161	165	168
100	138	150	154	157
200	130	142	147	150
400	122	135	140	144
800	115	130	137	142
1000	113	129	137	144
1250	112	129	138	146
1600	110	130	140	150
2000	109	132	145	156
2500	108	136	151	166
3150	107	141	160	179
4000	109	150	177	199

Pn – Nominal Range in sea miles  
 f – Frequency of the sound in Hz  
 Nr – Sound Pressure Level, in decibels, of the sound emitted by the SOUND SIGNAL at the reference distance of 1 metre in the direction concerned.

Usual Range: the distance at which, in foggy weather, a lookout positioned in the wing of the bridge has a probability of 50% of hearing the signal when subjected to a noise as defined by IALA as being equal to or in excess of that found in 50% of large merchant vessels, the propagation between the sound signal emitter and the listener occurring during relatively calm weather and with no intervening obstacles (refer Table 18).

Table 20 – Usual Range

Pu(nm) f(Hz)	Sound Pressure Level			
	0.5	1	1,5	2
25	155	162	165	168
50	144	150	154	157
100	132	139	143	146
200	125	132	136	140
400	117	125	130	135
800	112	121	128	134
1000	110	121	128	135
1250	109	121	129	137
1600	109	122	132	141
2000	108	123	136	148
2500	109	127	142	157
3150	110	132	152	170
4000	112	142	168	193

Pu – Usual Range in sea miles  
 f – Frequency of the sound in Hz  
 Nr – Sound Pressure Level, in decibels, of the sound emitted by the SOUND SIGNAL at the reference distance of 1 metre in the direction concerned.



## 6.6 Nautical Publications

### 6.6.1 Navigational Warnings

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

“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.”

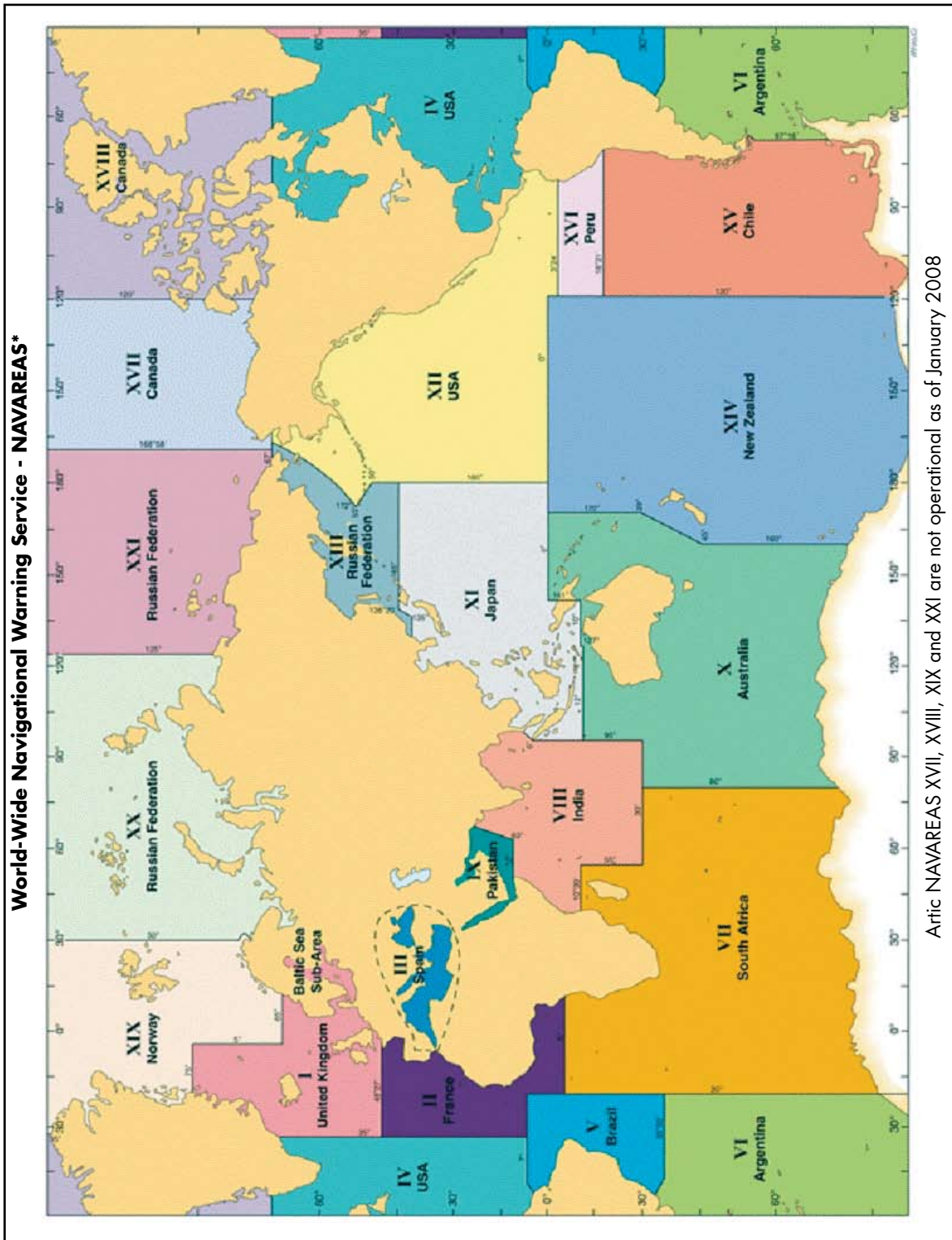
This information falls into three basic categories:

- information about planned changes, such as:
  - dredging, surveying, 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 un-planned events, such as:
  - the failure of 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 16 NAVAREAS (shown in Figure 25).** 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

#### List of Lights and List of Radio Signals

Lists of aids to navigation 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 will not always include buoys and unlit aids to navigation.

#### 6.6.4 Standard Descriptions

The Joint IMO/IHO/WMO Manual on Maritime Safety Information (IMO COMSAR/Circ 15), February 1998 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 21.

**Table 21 - Sample of the COMSAR/Circ15 standard terms**

Descriptors for Lighthouses, Beacons Buoys and Lightvessels	Comments
UNLIT	Incorrect Terms include: Out, Extinguished, Not Burning, Not Working
LIGHT UNRELIABLE	Incorrect Terms include: Weak, Dim, Low Power, Fixed, Flashing incorrectly, Out of Character
DAMAGED	Use only for major damage eg. loss of significant functionality
DESTROYED	Incorrect Terms include: Temporarily destroyed
ESTABLISHED (+ location)	New Light
OFF STATION	Buoy (lightvessel) not in the charted position
MISSING	Buoy (lightvessel) completely absent from position
RE-ESTABLISHED	Only appropriate for lights that have previously been Charted or Listed as Destroyed

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 22.



Table 22 – A suggested expanded list of terms and definitions for use in navigation warnings

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 (ie 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.



### 6.6.5 Positions

The Joint IMO/IHO/WMO Manual on Maritime Safety Information Edition 3 2009 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.

- Where an Authority has operational DGPS 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.
- 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:

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

### Bearings

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. 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<sup>37</sup> (used for the automatic broadcast of localised Maritime Safety Information (MSI) using radio telex);
- covers the specific NAVAREA and portions of adjacent areas;
- details of the broadcast schedules 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. These are:
  - transmitted from a national network of coastal radio stations;
  - broadcast at scheduled times;
  - use English and the national language.
- **Local Warnings:** that cover the area within the limits of a harbour or port authority:
  - to supplement Coastal Warnings, and;
  - may be limited to the national language.

Information concerning navigational warnings can be obtained from the Joint IMO/IHO/WMO Manual on Maritime Safety Information Edition 3 2009.

- **Off-Station Warnings for Major Floating Aids:**
  - When any lightvessel, lightfloat or Lanby (LNB) manned or unmanned is out of position such that it could be misleading to navigation, all its aids to navigation (lights, sound signals, racon, radio beacon) should be discontinued.
  - To avoid the risk of collision with passing vessels, warning lights should be continuously displayed as follows:
    - Two all-round red lights in a vertical line similar to those prescribed by Rule 27 of the COLREGS for a vessel “Not under command”.
    - If the appropriate Administration requires 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 a racon is deployed, it should be coded MORSE “D”.

**Refer to IALA publication:**

*IALA Recommendation O-104 on ‘Off Station’ Signals for Major Floating Aids to Navigation`.*

## 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<sup>38</sup>. 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.

<sup>37</sup>Also known as Narrow Band Direct Printing, or NBDP.

<sup>38</sup>IALA Recommendation V-128 – Operational and Technical Performance Requirements for VTS Equipment refers..



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/](http://www.gloss-sealevel.org/)

Technical recommendations on sea level observations can be found at: [www.pol.ac.uk/psmsl/manuals/](http://www.pol.ac.uk/psmsl/manuals/)

## 6.8 Under Keel Clearance Management Systems

There is an increasing use of real time Under Keel Clearance (UKC) management systems for port and coastal navigation. Proven tools exist to safely manage UKC without the need for a fixed draught limit. Real-time UKC systems have been adopted in many ports around the world. Vessel transits are pre-planned using predicted information and are refined with observed differences between predicted and actual information (e.g. tides) closer to the time of transit. Transits are 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. The pilot is able to fine-tune a ship's actual UKC by varying speed (affects squat/settlement) and rate of turn (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 increased in maximum draughts that may be accommodated through the use of real time UKC management systems.

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. Nautical charts can seldom, therefore, be absolutely 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.
  - The 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.

The difference in calculation of static and real time under keel clearance is shown in Figures 26 and 27 (courtesy of OMC International Pty Ltd).

Figure 26 –  
Traditional UKC  
measurement rules  
based on static data

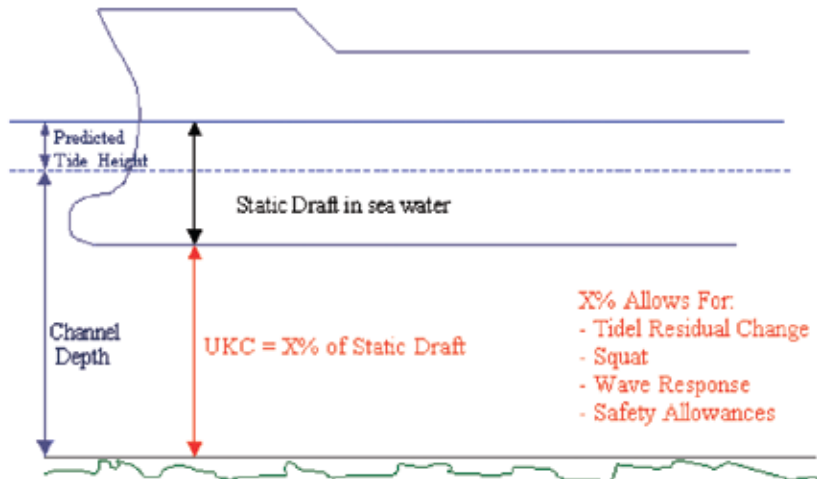
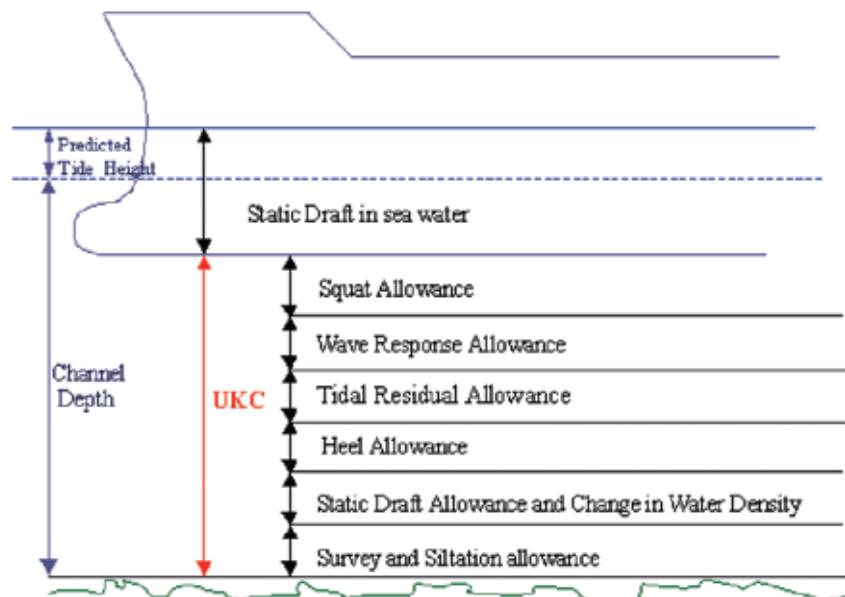


Figure 27 –  
UKC measurement  
based on real time  
data for each element



Typical port real-time UKC systems have two parts:

- A shore based system that enables UKC passage planning plus VTS-like passage monitoring/ assistance, and
- A portable UKC system which is taken onboard and used by pilots.

Portable UKC systems have data communication links to obtain real-time tide, current, wave and weather data. Portable UKC systems enable a pilot to fine tune a vessel's performance, typically speed (which affects squat and settlement) and rate of turn (which affects angle of heel), so as to manage and maintain UKC in accordance with predefined limits. Portable UKC systems contain electronic charts that, when combined with GNSS position inputs, complete the information required to enable safe navigation.

# 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 23.

Table 23 – Power sources for operating lighted aids to navigation

Electric Energy Sources	Non-Electric Energy Sources
Commercial power supply	Acetylene
Photovoltaic solar modules	Propane
Diesel and petrol engine driven generators	Butane
Primary cells	Kerosene
Wind generators	
Wave activated generators	
Fuel cells using alcohol or hydrogen	

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

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

**Refer to IALA publications:**

*IALA Guideline 1067-0 on Selection of Power Systems for Aids to Navigation and Associated Equipment.*

*IALA Guideline 1067-1 on the Total Electrical Loads of Aids to Navigation.*

*IALA Guideline 1067-2 on Power Sources.*

*IALA Guideline 1067-3 on Electrical Energy Storage for Aids to Navigation.*

Refer also to national standards for the safe handling of gases.

## 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;
- negligible deterioration in power output over its life; and
- low life-cycle costs.

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

*The potential difficulties associated with solar power are:*

- *finding ways to minimise bird fouling;*
- *mounting solar modules vertically is probably the best long-term solution for buoys;*
- *sizing arrays to operate at high latitudes;*
- *protecting solar modules from:*
  - *wave damage on buoys;*
  - *vandalism and theft; and*
  - *lightning.*

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

*Photo courtesy of  
Australian Maritime Safety Authority*



### Types

The three common technologies employed in the manufacture of silicon based, solar modules are listed in Table 24.

**Table 24 – Silicon solar cell technology**

Type (Technology)	Comments
Monocrystalline cells	<p>Are made from a thin slice cut from a single large crystal of silicon, usually produced as a circular section rod.</p> <p>Generally have the highest efficiency of the three technologies.</p> <p>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.</p>
Polycrystalline cells	<p>Are made from a thin slice cut from a large cast billet of silicon comprising many crystals.</p> <p>Are slightly less efficient than the mono crystalline cell but they can be shaped to completely fill the module.</p>
Amorphous module	<p>Are 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.</p> <p>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.</p>



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 12 volt battery charging applications, a voltage (charge) regulator is considered essential.

A **self-regulating solar module** was promoted as a means of eliminating the voltage regulator that had frequently been found to be the least reliable component in a solar power supply. The self-regulating module typically has 32 cells in series to give an open circuit voltage of around 18 volts (and a maximum on load voltage of around 15 volts). In a self-regulating solar module, the charging rate is determined by the interaction between the electrical characteristics of the battery and solar module.

Both concepts have worked well.

### **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, 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 aids to navigation. The most popular type were horizontal axis machines with a two bladed (propeller type) turbine. The maintenance requirements arising from the moving parts design of wind generators and susceptibility to storm damage has limited the 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 cable voltage drop;
- the size of wind generator likely to be considered for operating aids to navigation is at considerable risk of damage if there are populations of birds at the site.



### Wind Generator Types

A comparison of the typical performance of different types of wind generators is shown in Figure 28.

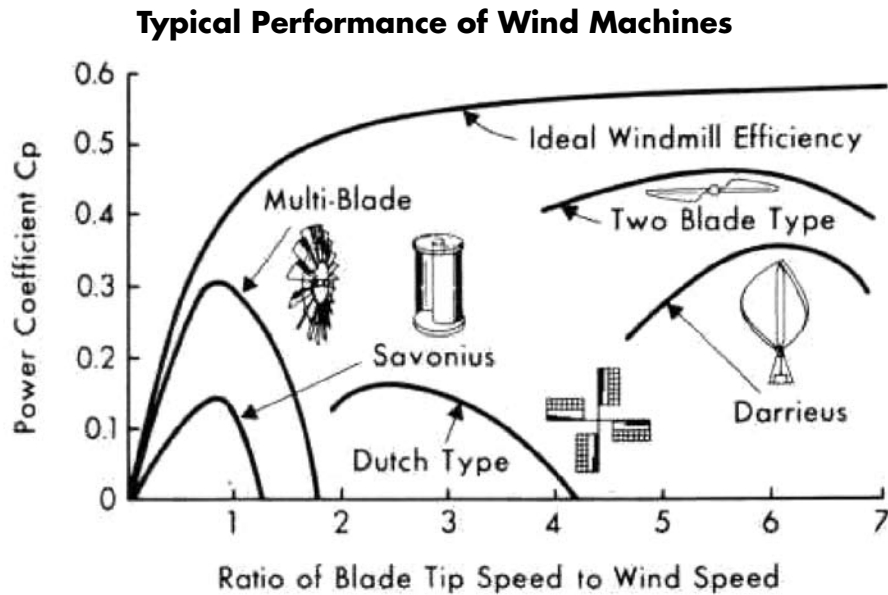


Figure 28 – Comparison of Performance of Wind Generator Types

### 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 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 is almost 100 watts. WAG's 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, and these aspects need to be taken into consideration when developing the maintenance regime for the WAG. WAG's can also be very susceptible to storm damage.

## 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 lithium batteries, nickel-metal-hydride (Ni-MH) batteries and lithium-iron phosphate (LiFePO<sub>4</sub>) batteries. The last offers lower weight and longer life span from more charge-discharge cycles.



## Lead Acid

The basic form of this battery uses a lead dioxide positive plate and a lead 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 gelified 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.

### 7.3.2 Primary Cells

Primary 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 change-out of primary cells have worked in favour of converting to renewable energy sources (e.g. solar, wind and wave generators).

#### Zinc-Air Cell

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

Is commonly used in some countries, and has the benefits of good low temperature performance

### Sea-Water Cells

The sea-water cell<sup>39</sup> developed for buoy applications in Norway is a primary cell that uses a magnesium anode and a largely inert copper cathode. The sea water acts both as an electrolyte and the provider of dissolved oxygen for the cathode.

A single cell is installed as part of the buoy tail tube. The motion of the buoy has a beneficial effect in agitating the water to provide an oxygen-rich flow through the cell and carry away the reaction products.

Copper was selected for the cathode material because of its inherent antifouling properties. A magnesium anode was considered environmentally acceptable because it is a naturally occurring element of sea water. The cell produces a voltage of 0.8 to 1 volt under load. Components of the cells under evaluated have been sized to provide around 35,000 watt hours of energy.

An AC-DC converter is used to raise the voltage to the level required by the load as it is impractical to use more than one cell due to the current leakage that would occur.

## 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 a mains electricity grid. 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 range of 10 to 30 kW. Diesel generators of this size are expected to consume around 0.4 litres/kWh.

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

- lighthouse automation (destaffing), and because;
- new beacon and lamp technology that enables a light with a nominal range 18 to 20 nautical miles to be operated from a renewable energy source.

### Petrol engine generators

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

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

### Thermo-electric generator

This is a solid-state generator in which a heat source, commonly from a propane burner, is directed onto a thermopile (i.e. an array of thermocouple type elements). Since each thermocouple only produces a voltage of around 0.5 volts, a number are connected in series.

This type of generator has a low thermal efficiency (around 5%) and is rarely used.

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<sup>39</sup>The chemistry of the sea-water cell and the prototype light buoys using this cell have been described in papers for the 1990 IALA Conference and IALABATT 2 and 3.



### **Stirling engine driven generator**

The Stirling engine is an external combustion engine that can be operated on gas or diesel fuel. Packaged generator sets are available that could operate a lighthouse. Typical generators produce 1kW electrical output and 5kW of heat. The heat output could be a useful by-product for maintaining a constant temperature in a lighthouse.

### **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. It can be thought of as a continuously fed battery.

The commercial fuel cell is still an emerging technology and at this stage is an expensive power source<sup>40</sup>. Aids to navigation applications are likely to be limited to situations where solar energy (photovoltaic) is impractical due to limited insulation or icing conditions.

There is some interest in the use of fuel cells in hybrid power systems with wind energy or solar energy. These systems are still in development.

## **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. This covers the loads for:

- lights;
- racons;
- AIS AtoN;
- electric sound signals;
- fog detectors;
- monitoring and telemetry systems;
- charge controllers; and
- signal control equipment

### **7.4.2 Lightning Protection**

To assist those engaged in the design of aids to navigation, 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:**

*IALA Guideline 1012 for the Protection of Lighthouses and Aids to Navigation Against Damage from Lightning.*

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<sup>40</sup>Refer to IALABatt 3 "Fuel cells for aids to navigation".



## 7.5 Non-Electric Energy Sources

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; and
- minimising leaks in pipe work and fittings.

### Propane

Propane gas ( $CH_3 CH_2 CH_3$ ) 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  $17^\circ C$ , and can be transported in quite light and low cost gas bottles;
- propane will maintain a positive pressure down to  $-40^\circ C$  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 IALA publication:

*'Practical Notes' for the safe handling of gases, October 1993.*

**Refer also to national standards for the safe handling of gases.**

# 8

## PROVISION, DESIGN AND MANAGEMENT OF AIDS TO NAVIGATION

### 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 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<sup>41</sup> are outlined in Table 25.

Table 25 – Contents of SOLAS Convention

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
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

<sup>41</sup>Reference SOLAS Consolidated edition 2009.

### SOLAS Chapter V

SOLAS Chapter V, and Regulations 12<sup>42</sup> and 13 in particular, defines 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 the mariner.

## 8.2 Level of Service (LOS)

In general, there are three levels of service components for aids to navigation services:

- **extent** which addresses whether a service will be provided by the contracting government or other agencies;
- **quantity** which addresses the type, size, number and mix of aids to navigation required; and
- **quality** which addresses the operational reliability of the service.

The SOLAS regulation is an excellent, general level of service statement in terms of the “extent” of service (where will Competent Authorities provide the service). The International Maritime Organization’s (IMO) Convention for Safety of Life At Sea (SOLAS), chapter 5, Regulation 13, states:

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

Each contracting government is expected to establish its own service level standards to determine where a service will be provided, based on a measure of benefits, costs, and risks.

<sup>42</sup> For VTS issues, please refer to Chapter 5 of the NAVGUIDE and the IALA VTS Manual.



The following addresses the levels of service provided in terms of “quantity” and “quality” of service wherever a contracting government has decided to provide an AtoN service.

### **8.2.1 Competent Authority Obligations**

To fulfil the obligations imposed by the requirements of the SOLAS Convention, it is recommended that Competent Authorities prepare Level of Service (LOS) statements as outlined below:

- Review both the quantity and quality of the service and the related LOS standards and Operational Performance Statements (OPS) on a regular basis and update them as necessary to reflect changing patterns of use and reassess risk factors, as well as changing technology and resource levels provided by contracting governments.
- Establish a formal mechanism for promulgating operational parameters and changes which can be accessed by all potential users. This should include a means of immediate notification, within practical limits, when the failure of an AtoN is identified.
- Where responsibility for the provision of an AtoN service is delegated, for example, to state, territory, or local government organizations, or to port, harbour, or waterway authorities, or to local private groups, responsibility to ensure and/or enforce national obligations shall remain with the Competent Authority concerned (some Authorities may not have sufficient resources to approve and monitor all private and other authorities’ AtoN, but will enforce national standards if users report a problem).

### **8.2.2 Level of Service Statement for Quantity**

The Level of Service (LOS) standards and Operational Performance Statements (OPS) for quantity will vary both from country to country and for individual areas depending on usage patterns, degree of risk and the mix of aids to navigation provided. The LOS/OPS statements represent a commitment from the Competent Authority to mariners in general who are navigating or operating in the area, and to the government and/or other client groups responsible for funding the provision of the AtoN service. It is important that the LOS/OPS statements are clearly understood and available to all concerned. The following outlines the stages that must be followed in the preparations of LOS/OPS statements:

#### **Level of Service / Operational Performance Statements**

It is recommended that LOS/OPS statements be prepared in three stages as follows:

**Step 1:** Determine the maritime usage patterns for the area concerned and identify risk factors for both vessels and the environment in general, taking into account at least the following:

- Nature and character of the area:
  - Depth;
  - Siltation;
  - Hazards;
  - Tides and currents;
  - Visibility, weather patterns, and sea-ice conditions;
  - Distinctive shoreline features for both visual and radar navigation;
  - Background lighting/background environment and relative position of the sun to the traffic routes.



- Traffic Analysis including:
  - Type of traffic and vessel characteristics by user group;
  - Routes and speed, including route marking requirements;
  - Volume of traffic by user group;
  - Type of cargo, particularly when hazardous.
- Risk assessment including:
  - Basic navigational risks, particularly in high traffic situations;
  - Risk to vessels caused by conflict between user groups;
  - Risk to the environment resulting from a maritime incident.

**Step 2:** Develop an overall Navigation Plan (NAVPLAN) for the area concerned indicating the mix of AtoN, both conventional and electronic in type, considered necessary to provide the required level of service in the most cost effective manner. This plan may also include appropriate vessel reporting and control requirements and separation schemes to further reduce the risk of an incident. As far as possible the NAVPLAN should ensure that failure of a single AtoN does not result in a major penalty to the overall AtoN service, or a substantial increase in risk.

In addition, the NAVPLAN should take into account the likely navigational aids carried by user vessels, including the probability that elements of these onboard navigational aids may themselves suffer failure. For this reason, the number, type and mix of AtoN types provided must be considered in terms of short-term, navigational aid failure during a critical manoeuvre, or extended period failure.

**Step 3:** For each proposed AtoN or system of AtoN, prepare an Operational Performance Statement (OPS). The format for the OPS will vary depending on the type of AtoN and mix of user groups.

For a light signal, the OPS should typically comprise information regarding the probability that the light can be seen at the required range when approached by a vessel at any random time while the AtoN is required for service. Inputs to this type of statement include the visibility in the area expressed as a cumulative probability by number of days and the AtoN equipment availability based on mean time between failures and meantime to repair; or

The statement may also be expressed in terms of the maximum operational capability of the light, or totality of lights in an area. Such an OPS would identify the minimum visibility level at which the light(s) can be seen at the required range when approached by a vessel at night. The statement would be similar for an unlighted system of aids - eg. AtoN system supports visual navigation until visibility is reduced below 1 nautical mile.

The type of OPS will depend on the method used to measure or establish the LOS standards for the quantity of service.

There are a number of analytical methods available for the establishment of LOS standards and OPS, including:

#### **Relative Risk**

- The level of service standard is based on a relative risk scale using quantified threats or risk factors to determine acceptable risk levels. Statistical probability ratios or percentages may be the basis for both the LOS and OPS.

#### **Visual Design**

- The level of service standard is based on a standard percentage of time that operational aids will be seen, using predetermined, acceptable risk levels based on professional judgment for



each individual, quantified threat or risk factor for each type and size of vessel. The OPS may be expressed in terms of percentage of time that the aids will be visible due to known, local atmospheric conditions, or as the minimum visibility level at which the AtoN system will support visual navigation and below which radar or other electronic systems will be required.

- For a radio AtoN such as a broadcast station providing differential GPS (DGPS) corrections, the LOS should take into account both the expected propagation conditions between the transmitting site and the user and the equipment availability of the AtoN itself.

### 8.2.3 Level of Service Statements for Quality

#### Equipment availability

The equipment availability of an AtoN is governed by the equipment operational reliability measured in terms of mean time-between-failure (MTBF) and the time to complete repairs in the event of a failure, measured in downtime or mean time-to-repair (MTTR). Where routine maintenance cannot be carried out during non-operational periods, an additional factor for planned downtime must be included.

Equipment with very high reliability may achieve required availability standards, even with a long MTTR. Competent Authorities should, therefore, consider including a maximum targeted downtime specified in the OPS, where usage and risk factors so dictate. MTTR depends not only on the ease with which a fault may be diagnosed and repaired on site, but also on access limitations (including weather and sea state conditions), availability of trained staff, and spare holdings, etc.

Key elements in achieving high equipment availability are:

- Choice of equipment which is inherently reliable.
- Inclusion of active or passive redundancy features wherever availability targets or maximum downtime targets are not achievable due to remoteness of the site or limited access due to weather or sea state conditions.
- Provision of performance measuring facilities, whenever availability or downtime targets are not achievable, will allow potential failures to be identified and corrected before actual failure occurs. For unwatched automatic AtoN this will normally require provision of a remote monitoring system.
- Availability of adequately trained staff and provision of suitable spares. In this context, Competent Authorities should address the option of contracting out maintenance and repair tasks with care. In particular:
  - Responsibility for meeting SOLAS Convention requirements cannot be delegated to the contracting organization.
  - When contracting out is contemplated, the Competent Authority concerned should retain sufficient design and performance assessment expertise to be able to audit the performance of the contracting organization in an efficient and effective manner.
  - The contracting organization should meet appropriate quality management criteria, including staff training requirements.

Level of service statements for quality of service should be expressed as one, or a combination of the following:

- An overall percentage availability statement reflecting the percentage of time that any AtoN can be expected to be operational.
- Percentage availability targets based on importance or type of AtoN.
- Maximum downtime targets for AtoN overall, or within a specific area.

#### 8.2.4 Consultation and Review of LOS

Development of the LOS targets, the NAVPLAN, and the OPS for each AtoN or AtoN area, should be an iterative process in consultation with all user groups and funding organizations. It is recommended that the consultation process include:

- Meetings with all user representatives conducted during the development of the LOS standards, OPS and NAVPLAN to review proposals and arrive at an equitable balance between service, risk and cost; and
- regular review meetings facilitated by the creation of an advisory board, where appropriate, and by feedback from both commercial and pleasure craft operators.

It is recommended that Competent Authorities put in place procedures to monitor the performance of individual AtoN and that regular reports of achieved equipment availability based on MTBF and MTTR are provided. As far as is practical, equipment performance monitoring is required in addition to reports of equipment failure received from mariners.

##### Refer to IALA publication:

*IALA Guideline 1004 on levels of service.*

*IALA Guideline 1079 on Establishing and Conducting User Consultancy by Aids to Navigation Authorities.*

#### 8.2.5 Mix of Aids to Navigation (Layers of Service)

Table 26 provides a summary of available aids to navigation systems and obtainable accuracies. It is assumed that radar and visual bearings have an accuracy of 0.5° and radio bearings 2° respectively.

**Table 26 – Indicative accuracies of aids to navigation systems**

Distance off shore in nautical miles	Obtainable accuracies		
	> 500 m	100 - 500 m	< 100 m
Unlimited	Astronomical Fix		GPS GLONASS
800 -150	Astronomical Fix	LORAN-C	GPS GLONASS
150 - 30	Astronomical Fix Radio Beacons		GPS GLONASS LORAN-C Precision Systems
30 - 6	Astronomical Fix Radio Beacons Visual Bearings Radio Bearings	Radar Bearings	GPS GLONASS LORAN-C Precision Systems
6 or less		Radio Beacons Visual Bearings Radar Bearings	GPS GLONASS LORAN-C Precision Systems



The various type of AtoN have advantages and disadvantages for the user as well as for the provider as indicated in Table 27.

**Table 27 – Comparison of the advantages and disadvantages of different types of aids to navigation**

System	Users		Providers	
	Advantages	Disadvantages	Advantages	Disadvantages
<b>Visual</b>	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
<b>Automatic Identification System (AIS)</b>	Can be used to provide virtual temporary replacement for failed visual aid Convey immediate information	Lack of integration with other onboard navigation systems in older vessels Coverage limited by VHF radio communications range	Can replace visual aids Low cost and maintenance compared to radar Can be used to broadcast warnings of dangers	Coverage limited by VHF radio communications range
<b>Radar</b>	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
<b>Radionavigation</b>	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 Lighthouse Authority control Monitoring requirement Training maintenance personnel Large investment

### 8.3 Risk Management

Dealing with “risk” is an intrinsic aspect of human existence. The establishment of the early lighthouses represent 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.

$$\text{Risk} = \text{Probability} * \text{Consequence}$$

Unwanted events include deprivation, 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, in fact the output of a risk management process, is dependant on the application of Human Factors disciplines. The concept of Human Factors and references to relevant models is therefore included in the IALA Guideline 1018 on Risk Management (December 2008). It is recommended that administrations, organisations and persons involved in a risk assessment process have suitable, updated and in-depth knowledge in the application of Human Factors disciplines.

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.

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, the lightkeepers);
- service **users** (mariners);
- **external groups** (politicians, local community, conservation groups).

**Refer to IALA publication:**

*IALA Guideline 1018 on risk management.*

A number of countries<sup>43</sup> also have national standards on risk assessment and risk management.

### 8.3.1 IALA Risk Management Tools

IALA is continuing to improve risk management tools that are capable of:

- Assessing the risk in ports or waterways, compared with the risk level considered by Competent 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.
- 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.

The 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 tools are based on the use of two models, Port And Waterway Safety Assessment tool (PAWSA) which conducts a **Qualitative** Risk Assessment and IALA Waterway Risk Assessment Programme (IWRAP Mk II) which conducts a **Quantitative** Risk Assessment. The two models can be used individually, sequentially or in parallel<sup>44</sup>.

Applications to use the IALA Risk Management Tool should be made by the Competent Authority concerned to the IALA Secretariat ensuring that registered users are provided with the latest versions of the PAWSA and IWRAP free of charge to the Authority.

<sup>43</sup>Example include Canada and Australia / New Zealand.

<sup>44</sup>When available, the Risk Model will be included in the IALA documents available at [www.iala-aism.org](http://www.iala-aism.org)



All the information necessary to prepare and conduct a PAWSA is contained on the PAWSA compact disk. However, if guidance is +required the IALA Secretariat is able to will arrange this.

Information on how to use the IWRAP tool is given through IALA IWRAP training seminars and on a dedicated IWRAP WIKI site on the internet (accessible through the IALA website). If further guidance or assistance is required the IALA Secretariat is able to arrange for experts to assist with conducting an IWRAP Risk Assessment.

Authorities are requested to provide copies of the results of risk assessments made by the IALA Risk Management Tool to the IALA Secretariat.

### 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; and
- e) Take action.

The diagram in Figure 28 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 chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property or the environment or other values.

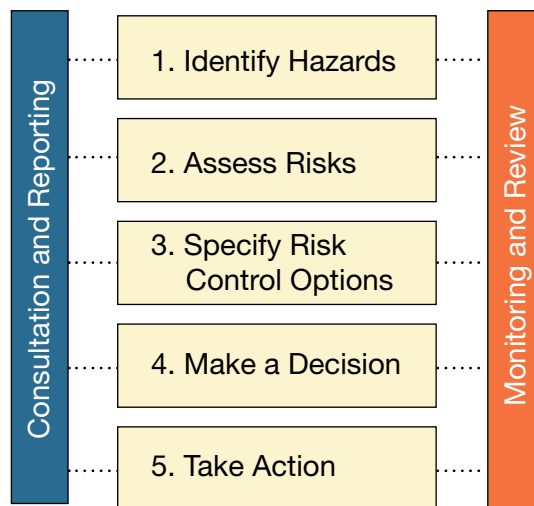


Figure 29 –  
The Risk Assessment and  
Risk Management process

The central part of the figure above 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.

Human Factors are one of the most important contributory aspects to the cause and avoidance of incidents. Human Factors issues should be systematically treated within the risk management framework, associating them directly with the occurrence of incidents, underlying causes or influences. Appropriate techniques for incorporating human factors should be used.

Some of the most common techniques used are listed below:

- Questionnaires.
- Observations.
- Interviews.
- Simulation studies.
- Hierarchical Task Analysis.
- Cognitive Walk-Through.
- Cognitive Task Analysis.
- Expert Judgment / Expert Evaluation.
- Human Reliability Assessment.

Without the application of Human Factors based techniques and taking Human Factors aspects into consideration in any of the five steps in the risk management there is a great risk that vital elements will be inadequately carried out.

If the human factor elements are missing, it is also likely that the result of a risk assessment related to any incident, accident, near miss or observations of undesired conditions, will fail as e.g. the root causes may be completely missed.

To understand the concept of human factors in a socio-technical system and what it includes reference can be made to the Septigon Model shown in Figure 30. The model describes seven basic areas to be considered as well as the interaction between any of the elements. The model can be used as a checklist in identifying hazards.

### 8.3.3 Levels of Risk

Once the risks have been identified it is generally useful to rank them in order of consequence. Resources can then be assigned to treating the most serious risks first. The matrix at Figure 31 provides a basis for prioritising risks.

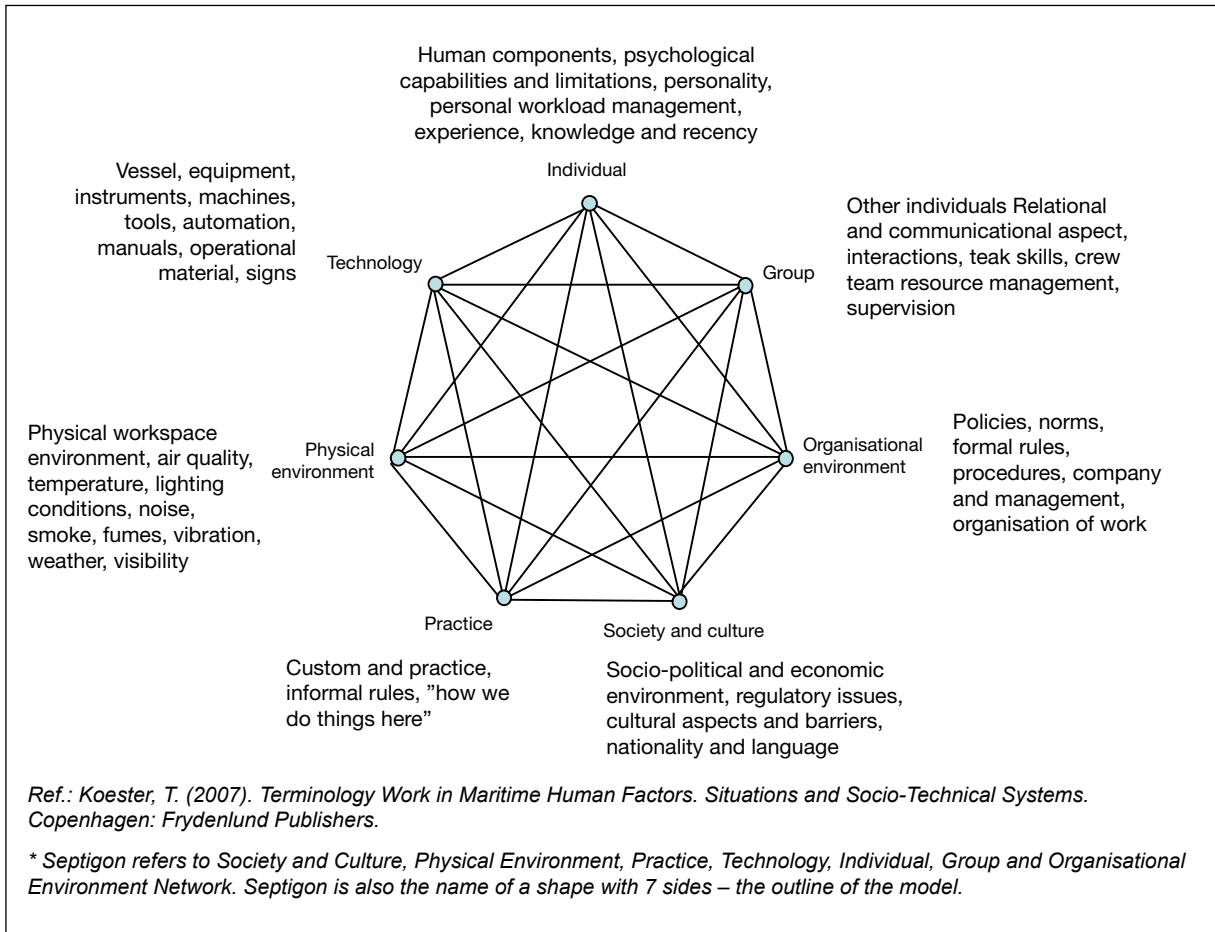


Figure 30 – The Septigon model illustrating relevant Human Factors elements to be considered in the risk management process.

Impact	High	Medium Level of Risk with Caution	High Level of Risk	High Level of Risk
	Medium	Low Level of Risk	Medium Level of Risk with Caution	High Level of Risk
	Low	Low Level of Risk	Low Level of Risk	Medium Level of Risk with Caution
		Low	Medium	High
		Likelihood		

- High Level of Risk
- Medium Level of Risk with Caution
- Low Level of Risk

Figure 31 – Risk matrix



## 8.4 Availability Objectives

Members of IALA became interested in the concept of availability around 1975 when significant numbers of lighthouses were being automated and destaffed. The measurement of 'Availability' provided a quantitative measure of performance (or service to the mariner) that was independent of whether an aid to navigation was manned or not.

'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;
- maintenance procedures;
- failure response;
- logistical arrangements.

In developing the concept of Availability, IALA considered it necessary to measure the long-term performance of an aid to navigation. To achieve this it was recommended that the calculations should use a time interval greater than 2 years. The original examples developed for the three availability categories of lights were based on a 1000 day time interval (most likely to simplify the conceptual calculations).

### 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:

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

### 8.4.2 Definition and Comments on Terms

#### Reliability

This is the probability that an aid to navigation<sup>45</sup>, 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:

- 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.

<sup>45</sup>Or any nominated system or component.



## Continuity

This is the probability that an aid to navigation or system will perform its specified function without interruption during a specified time:

- for example, if a DGPS station is functioning correctly when a vessel is about to make its approach into a port, the continuity factor is the probability that the DGPS service will not be interrupted in the time it takes the vessel to reach its berth;
- for GNSS systems, IALA has proposed that the time interval for continuity calculations be based on a three-hour time frame.

## 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<sup>46</sup>.

## 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;
- for a system such as a DGPS 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.  $=24 \times 365 \times 2 / 4$ ).

## Mean Time to Repair (MTTR)

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;
- 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.

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<sup>46</sup>IMO Resolution A.915(22).

### 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 28. IALA the method does not take into account 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 members to adopt.

**Table 28**  
**Category /**  
**Availability Table**

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

**Category 1:** An Aid to Navigation (AtoN) or system of AtoN that is considered by the Competent Authority to be of vital navigational significance. For example, lighted aids to navigation and racons that are considered essential for marking landfalls, primary routes, channels, waterways or new dangers or the protection of the marine environment.

**Category 2:** An AtoN or system of AtoN that is considered by the Competent Authority to be of important navigational significance. For example, it may include any lighted aids to navigation and racons that mark secondary routes and those used to supplement the marking of primary routes.

**Category 3:** An AtoN or system of AtoN that is considered by the Competent Authority to be of necessary navigational significance.

The absolute minimum level of availability of an individual aid to navigation should be set at 95%.

**Refer to IALA publication:**

*IALA Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation.*

*IALA Guideline 1035 on Availability and Reliability of Aids to Navigation.*

### 8.4.4 Availability and Continuity of Radionavigation Services

The availability objectives for DGNSS (DGPS) services have been handled somewhat differently from traditional aids to navigation. This reflects the broader policy formulation process that includes the IMO Resolution A.815(19) for a World Wide Radionavigation System.

**Refer to IALA publication:**

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

Recommendation R121 retains the original definition of availability, but adds a statement about “**non-availability**”:

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

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

Where: MTBO = Mean time between outages; based on a 2 year averaging period (30 days ocean phase)  
MTSR = Mean time to service restoration; based on a 2 year averaging period (30 days ocean phase)



### Example 1:

- assuming a scheduled maintenance cycle of 6 months;
- with a mean time between scheduled maintenance is 0.5 years; (i.e. 4 scheduled maintenance breaks in 2 years); and
- assuming a MTBF of 2 years.

The average number of failures over 2 years is expected to be approximately 1 giving a total of 5 outages over the two year period; mean time between outages is 2/5 years or approximately 3500 hours.

If the average out of service time for scheduled maintenance is 6 hours; the total out of service time for scheduled maintenance over the two year period is 24 hours.

Similarly, if the unscheduled maintenance period is 12 hours, and the total time out of service over the two year period is 36 hours. This covers 5 maintenance events.

The mean time to service restoration is 36/5 hours or approximately 7 hours.

The overall availability over the two year period is  $(3500 / (3500+7))$  or 99.8%.

### Example 2:

- assuming a scheduled maintenance cycle of 6 months;
- with a mean time between scheduled maintenance is 0.5 years; (i.e. 4 scheduled maintenance breaks in 2 years); and
- assuming a MTBF of 2000 hours.

The average number of failures over 2 years (17520 hours) is expected to be 8.76, rounded up to 9; giving a total of 13 outages over the two year period (4 scheduled + 9 unscheduled); mean time between outages is 17520 hours/13 or 1348 hours:

- If the average out of service time for scheduled maintenance is 6 hours; the total out of service time for scheduled maintenance over the two year period is 24 hours.

Similarly, if the unscheduled maintenance period is 67 hours, the total time out of service over the two year period is 91 hours. This covers 13 maintenance events.

The mean time to service restoration is 91/13 hours or approximately 7 hours.

The overall availability over the two year period is  $1348 / (1348+7)$  or 99.5%.

## 8.4.5 Over and Under Achievement Issues

The actual availability achieved by an individual aid to navigation is a reflection of the quality of the establishment process, the maintenance regime and the skills of personnel involved. (section 8.2 refers)

There is a cost penalty associated with prescribing a higher level of availability for a system such as an aid to navigation<sup>47</sup>. There is also a cost penalty 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 32.

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<sup>47</sup>Irrespective of whether or not the increased availability is required by the mariner.

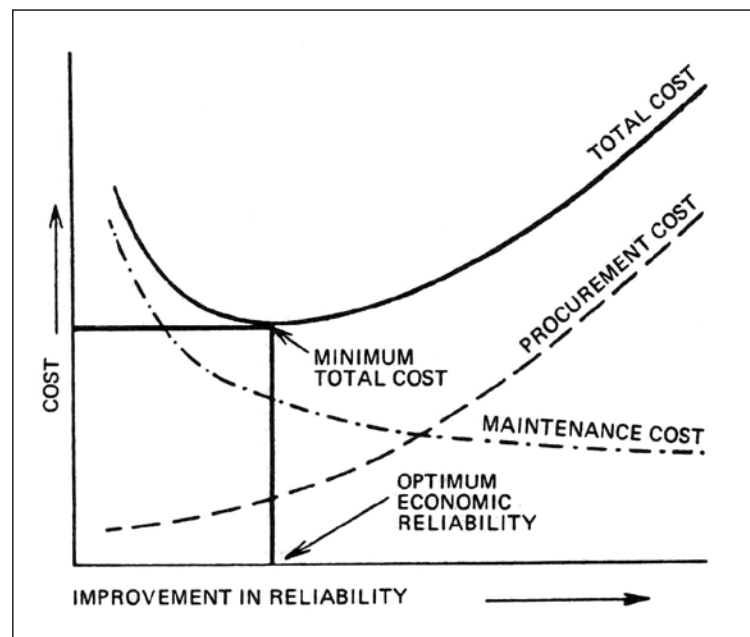


Figure 32 – The cost of reliability

### 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;
- issues relating to the consequential surplus maintenance capacity.

### 8.4.6 Continuity

IMO uses a more elaborate definition of Continuity than that given in Section 6.1.4.2. 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<sup>48</sup>.’



If the service is available at the beginning of the operation, then the probability that it is still available at a time 'T' later is:

$$P = \exp (-t/\text{MTBF})$$

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:

$$C = \exp (-\text{CTI}/\text{MTBF})$$

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

$$C = 1 - (\text{CTI}/\text{MTBF})$$

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

CTI = Continuity Time Interval – in the case of maritime AtoN calculations, Continuity Time Interval is equal to 3 hours.

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 three hour period is  $1-(3/17520)$ , or 99.98%.

#### **Example 2:**

Using the figures in the previous example for a system with a 2000 hour MTBF, the continuity over a three hour period is  $1-(3/2000)$ , or 99.85%.

## **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<sup>49</sup> 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 (Navigation Plan) with a suggested minimum 10 year outlook, and;
- 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 integrated with other electronic data, for example electronic nautical charts to display shipping patterns.

#### **User Consultancy**

The SOLAS Convention Chapter V Regulation 13 requires that contracting governments undertake to arrange (AtoN) as, in their opinion the volume of traffic justifies and the degree of risk requires, and

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<sup>48</sup>This is the same definition as "mission reliability".

<sup>49</sup>Some aids to navigation are in reality monuments to historical accidents and are of little value to modern shipping.

to arrange for information in relation to these AtoN to be made available to all concerned. Competent Authorities are guided by IALA to establish and conduct user consultation with stakeholders when planning all types of new AtoN or changes to their existing provision of AtoN. Consultation should also be a means to monitor these services.

Consultations, while often integral to many decision-making processes, can have various meanings for different practitioners and participants. In some cases, consultations are defined in legislation or agreements. Consultations can be ad hoc or regularised. Sometimes they are undertaken extensively, on broad issues with a wide-range of participants; other times, consultations are more intensive, with a narrower focus and specifically-targeted participants. A stakeholder is a person, group or agency that has a direct interest in an issue for which the Competent Authority has a mandate or legal responsibility, and may or may not be directly affected by the Authority's programs and activities, and also non-governmental organisations.

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

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

### 8.5.3 Operational Plans

The Operational Plan might cover:

- a) 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;

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<sup>50</sup>For example with national, state, territory, and local governmental bodies and international organisations.



- external relationships<sup>50</sup>;
  - information, communication and consultation management.
- b) 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 0); or
    - a level of service process, (see section 3.2); or
    - the authority's quality management procedures (see section 8.7);
    - the authority's technical and maintenance policies etc.
- c) **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 (GIS) 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 require to be marked. In addition, light pollution through coastal development, the advent of larger and faster ships and the continued growth in small craft usage means that designing suitable AtoN systems becomes ever more complex. Using GIS, accurate design and provision of AtoN systems as well as suitable simulation can prove very useful and may reduce the chance of costly mistakes being made.

AtoN are distinctly linked to physical locations and their use by mariners invariably involves the use of more than one AtoN at a time, that is, AtoN networks or systems. These single and interdependent linkages between AtoN and their physical locations mean that GIS technology can provide AtoN authorities with enhancements in many areas of their business, which may ultimately lead to benefits for mariners.

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

**Refer to IALA publications:**

*IALA Recommendation O-138 on the Use of Geographic Information Systems (GIS) and Simulation by Aids to Navigation Authorities.*

*IALA Guideline O-1057 on the Use of Geographic Information Systems (GIS) by Aids to Navigation Authorities.*

*IALA Guideline O-1058 on the Use of Simulation as a Tool for Waterway Design and AtoN Planning.*

*IALA Guideline No. 1079 on Establishing and Conducting User Consultancy by Aids to Navigation Authorities.*



## 8.6 Performance Measurement

Performance measurement is a management tool that can be used to measure, analyse and monitor the performance of a network of aids to navigation and/or specific systems and equipment. 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<sup>51</sup>;
- amend:
  - system designs;
  - procurement decisions;
  - equipment choices;
  - maintenance procedures and practices.
- increase or reduce maintenance effort;
- extend maintenance intervals.

## 8.7 Quality Management

Quality Management Systems have been developed and introduced by numerous businesses, but increasingly are being based on the ISO 9000 series of standards. These standards provide a broadly accepted framework for implementing a quality management system.

A generic quality management system is process focused and defines procedures for how things are to be done and what resources are necessary. It addresses:

- who does what?
- what skills and qualifications are necessary?
- what processes have to be followed to get consistent outcomes?
- what resources are necessary to do the work efficiently?

The equipment in aids to navigation systems can be divided into two aspects: the specific AtoN aspect, and the more generic aspect. Each aspect must comply with applicable standards and regulations.

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

### Refer to IALA publications:

*IALA Recommendation O-132 on Quality Management for Aids to Navigation Authorities.*

*IALA Guideline 1034 on product certification procedures.*

*IALA Guideline 1052 on Quality Management in Aids to Navigation Service Delivery.*

<sup>51</sup>Only where the opportunity arises and where both are engaged in substantially similar work.



## 8.7.1 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 - 2000

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 33.

### ISO 9004 - 2000

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.

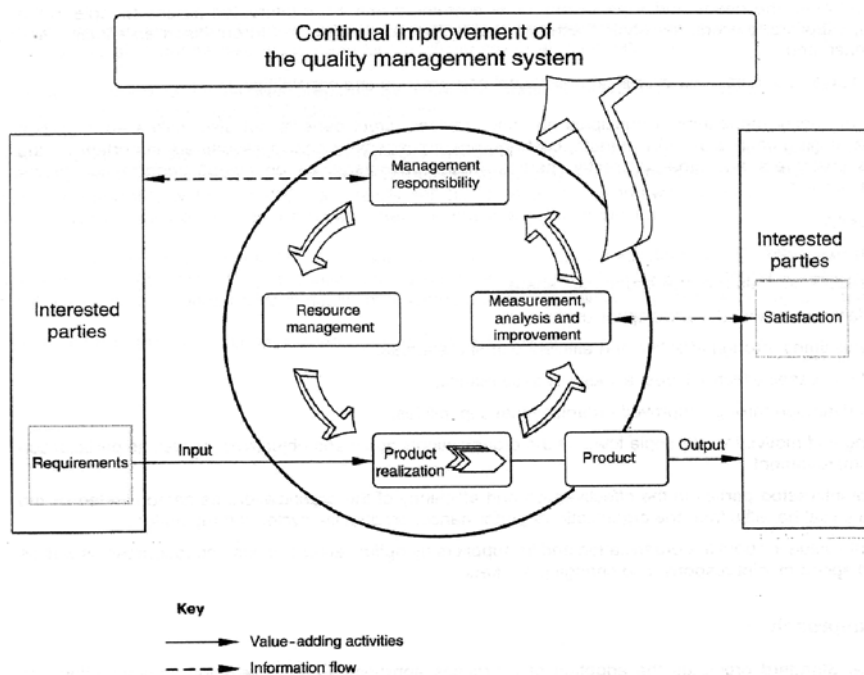


Figure 33 – Diagram from ISO 9001 showing the emphasis on satisfying customer requirements.

### ISO 14000

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.

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.

### 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.

## 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 Ownership Cost. 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 be seeking 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 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 for required maintenance, 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. To accomplish this, the focus of the design effort should be on ensuring that the attributes of ‘reliability,’ ‘maintainability,’ and ‘supportability’ are key components of the equipment or system. These three factors contribute to AtoN availability.

### **Minimise Impact on the Environment**

Legislative obligations and community expectations require AtoN authorities to ensure that their activities do not have an adverse impact on the environment. Cleaning up after pollution incidents and the associated rehabilitation of the environment can be costly.

### **Comply with Legislation and International Standards**

AtoN authorities are required to ensure that AtoN maintenance is carried out in compliance with their local legislation. AtoN services should also be delivered in accordance with international standards and best practice to ensure that a seamless worldwide network of AtoN is provided for mariners. In order to comply with relevant legislation, Competent Authorities may need to consider environmental, safety, heritage, category of AtoN and compliance with the latest standards in their maintenance strategy.

### **Consider Health and Safety of Workers and Public**

Authorities should be aware that many of the activities described in this document have applicable worker health and safety requirements. These requirements vary from region to region, and Authorities should comply with the specific requirements in their area. The health and safety of workers and the public is of paramount importance. Maintenance strategies should include training and awareness programs to ensure that all staff are adequately trained in the activities and tasks that they are required to carry out.

### **Assess and Improve Performance**

A continuous assessment of reliability, maintainability, and supportability should be undertaken to permit the ongoing improvement of equipment design and maintenance procedures. Consistent feedback on equipment performance from the maintenance personnel is fundamental to this process. Keeping track of maintenance is absolutely necessary to measure and thus improve the efficiency of a system.

Breakdowns to AtoN systems can have a significant impact on the cost of service provision. Thus, maintenance of systems to ensure continuing performance is critical. There are two main ways to carry out maintenance: corrective maintenance and preventive maintenance. Corrective Maintenance restores the functions of an item after failure has occurred, or performance fails to meet stated limits. Preventive maintenance may be carried out at planned intervals (Planned Maintenance) or according to condition-based criteria (Condition-Based Maintenance) to reduce the probability of failure or degradation in order to retain the functioning of an item or to detect a hidden fault.

#### **Refer to IALA publications:**

*IALA Guideline 1077 on Maintenance of Aids to Navigation.*

*IALA Guideline 1052 on Quality Management in Aids to Navigation Service Delivery.*

*IALA Guideline 1076 on Building Conditioning of Lighthouses.*

### 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 for lightkeepers or allow for de-staffing, which reduces:

- staff costs (payroll);
- 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;
- give more flexibility on 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, 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.



## 8.9 Service Delivery

Authorities with the responsibility for the provision of aids to navigation are generally at a state or national level. They are usually the sole national regulator of marine aids to navigation infrastructure and services, but are not necessarily the sole provider of these services. In some countries there is a division of responsibility between the authority representing the national government and other organisations that include:

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



*Photo courtesy of Northern Lighthouse Board (Scotland)*

### 8.9.1 Service Delivery Requirements

The SOLAS Convention applies to a range of vessels, depending on the chapter that is being invoked. For SOLAS Chapter V, Regulation 13 on aids to navigation, the Convention applies to:

*“...all vessels on all voyages, except:*

*.1 warships, naval auxiliaries and other ships owned or operated by a Contracting Government and used only on government non-commercial services; and*

*.2 ships solely navigating the Great Lakes of North America and their connecting and tributary waters as far east as the lower exit of the St. Lambert Lock at Montreal in the Province of Quebec, Canada.”<sup>52</sup>*

Where more than one local authority provides aids to navigation services, the Contracting Government has ultimate responsibility for obligations under the SOLAS Convention.

Aids to navigation may be provided to meet the specific needs of these vessels and it is these that are often operated by state, territories and local government organisations or private groups.

### 8.9.2 Contracting Out

In many parts of the world governments have been selling off government business activities to the private sector. The motivation for this varies, but includes:

- adding flexibility to how work is carried out;
- breaking down entrenched work practices that are perceived to be inefficient;
- accessing a wider range of skills and resources on demand;
- recognition that as aids to navigation become more reliable and maintenance intervals are increased, it becomes more difficult to:
  - justify having permanently staffed maintenance depots;
  - maintain the currency of work skills;
  - using on-call contractors in regional locations to improve fault rectification times through reducing the travelling time to the aid.

The key elements to success when contracting out are:

- a) to retain sufficient skills within the Authority to understand the functional requirements of the aids to navigational network. This includes:
  - good contract management skills to handle the day-to-day operational issues;
  - personnel to engage in user consultation and forward planning;
  - the knowledge to act as an “informed purchaser” of services;
- b) to retain control of intellectual property such as:
  - original drawings;
  - documentation covering the design and configuration of individual aids to navigation;
  - a register of assets and spares;
  - defining a set of key performance indicators to measure the performance of the contractor.

**Refer to IALA publication:**

*IALA Guideline 1005 on Contracting Out Aids to Navigation Services.*

<sup>52</sup>SOLAS, Chapter V, Regulation 1 refers.



## 8.10 Environment

Aids to Navigation (AtoN) 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 AtoN equipment and activities themselves can create significant environmental damage through pollution, waste generation, and the disruption of ecosystems. It is essential to minimize these negative impacts so that the benefits of AtoN are not outweighed by unintended harm to the environment, and to eliminate the potential for pollution and waste of the Earth's limited resources.

### Refer to IALA publication:

*IALA Guideline 1036 on Environmental Considerations in Aids to Navigation Engineering.*

### 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<sup>53</sup> 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 degC ).

#### 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

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<sup>53</sup>The quantity of mercury used in higher order optics is shown in Section 8.11.1.



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: can lead to acute mercurial poisoning;
- Absorption through the skin: 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.

**Note:** 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.



*Photo courtesy of Instituto Hydrografico (Portugal)*

### **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).

## 8.11 Preservation of Historic Aids to Navigation

Many lighthouse authorities are still responsible for the management and maintenance of historic lighthouse structures and their associated aids to navigation equipment. 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). Objectives:

- to encourage deeper commitment by members to preserve historic values;
- to encourage member countries to see the preservation of their own lighthouses in an international context;
- to share information on the subject between both members and non-members, with particular attention being given to the complementary use of lighthouses;
- to research and document strategies on the conservation of historic lighthouses, particularly in relation to changes in technology and working practices.

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.

The purpose of the Working Group was reaffirmed in the Conclusions of the XV1th IALA Conference in Shanghai, China in 2006 as follows:

- IALA should continue to play a role in the conservation of historic lighthouses, associated aids to navigation and equipment;



*Photo courtesy of Instituto Hydrografico (Portugal)*



*Photo courtesy of IALA*



- regarding the conservation of historic lighthouses, IALA should continue to:
  - develop documentation;
  - promote international cooperation programmes; and
  - provide advice on lighthouse conservation.

The IALA seminar in Santander, Spain in June 2009 produced several key conclusions and recommendations:

- change is inevitable. Ideally, changes made during the development of an historical AtoN site should be reversible and in all cases properly documented.
- the preservation and documentation of AtoN 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 AtoN, as well as those involved in their conservation.
- radionavigation aids were an important part of AtoN technology in the 20th century and there is a need to document and disseminate this aspect of AtoN heritage.

With strong public interest from local communities, it is prudent and important for Competent Authorities to have a consistent approach to branding and/or marketing of their lighthouses. A consistent approach will help maintain the authority's reputation as good maintainers and operators of their historic structures. It also offers the Competent Authority an opportunity to promote maritime safety, raise public awareness and increase visitor numbers, has the potential to improve security through awareness and may offer local community employment opportunities.

The following options could be considered when developing a marketing strategy for a particular lighthouse:

- using internal or external marketing consultants to develop a strategy which could include logos, publications and links with other lighthouses;
- soliciting the support of local groups who have an interest in the lighthouse and their surroundings;
- using the internet to advertise heritage lighthouses and visitor services offered at each site;
- advertising availability for special events (e.g., anniversary's in local newspapers); and
- the use of lighthouses for commercial advertising in the media and for television filming (the feasibility of this can depend upon each authority's regulations which will differ from country to country).

**Refer to IALA publications:**

*IALA Lighthouse Conservation Manual.*

*IALA Guideline on Agreements for complementary use of lighthouse property.*

*Report of the IALA Seminar on Heritage Issues of Introducing New Technologies in Aids to Navigation Santander, Spain June 2009.*

*IALA Guideline 1074 – Branding and Marketing of Historic Lighthouses.*

*IALA Guideline 1075 on a Business Plan for the Complementary Use of a Historic Lighthouse.*

### 8.11.1 Lens Size and Terminology

Table 29 provides information on terminology for historical glass lens systems and the typical amount of mercury held in mercury float pedestals (for rotating lens systems).

**Table 29 – Terminology for historical glass lens systems and associated quantities of mercury used in rotating lens systems**

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		

Many lighthouse services are removing or decommissioning traditional optics and installing new, smaller, self-contained devices. There are good economic reasons for doing this but sometimes there is a need to retain large traditional optics. There has been more pressure on lighthouse services in recent years from conservationist lobbies to retain original equipment in working order. At the same time there is the need to provide an efficient service without tending to obsolete and labour intensive equipment. A compromise can often be reached by retaining important features of an optic and running them efficiently. In this case the choice of light source is important and the options include lamps and LEDs.

### 8.11.2 Third Party Access To Aids To Navigation Sites

In 1998, IALA conducted a survey to investigate the extent to which Authorities were permitting aids to navigation sites to be used for collecting “non-aids to navigation” data. This study was associated with investigations of the Advisory Panel on the Preservation of Historic Lighthouses into alternative uses of lighthouses and other aids to navigation.

The responses came from a wide range of IALA members and shared several common themes:

- the predominant applications were for the collection of meteorological data (i.e. weather, wind speed and direction), tidal/ current data and for telecommunication installations;
- data collected for or by other governmental agencies generally did not attract a fee, but fees were often charged for data obtained for commercial purposes;
- data acquisition equipment had to have its own separate power supply unless that aids to navigation site had mains power available.

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 (eg 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 mains 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 mains 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.

**Refer to IALA publications:**

*IALA Lighthouse Conservation Manual.*

## 8.12 Human Resources Issues

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'. The footnote includes appropriate Recommendations and Guidelines produced by IALA, clearly identifying the role that IALA has to play in ensuring harmonized delivery of AtoN services.

In addition, Resolution 10 of the 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, 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 ANM and EEP Committees are currently studying the training requirements for AtoN Management and Engineering Personnel respectively.

### 8.12.1 Source of Skills

In planning, establishing and implementing AtoN, the Government or the Competent Authority should:

- ensure that the AtoN Authority is provided with sufficient staff, appropriately qualified, suitably trained and capable of performing the tasks required, taking into consideration the type of AtoN and the level of services to be provided.

- establish appropriate qualifications and training requirements for the AtoN staff, taking into consideration the type of AtoN and the level of services to be provided.
- ensure that the standards set by the Competent Authority for levels of service and staff qualifications are met.

In order to discharge the duties required when implementing and maintaining AtoN, all personnel involved should obtain an AtoN qualification before being considered competent to intervene in AtoN matters.

The ISO 9001 Quality Management standard places considerable emphasis on competence, awareness and training. (See Section 8.7.1)

Table 30 provides an overview of the skill development process for aids to navigation work.

**Table 30 – Skill development processes for aids to navigation work**

Skill	Process
Education	school tertiary institution
Experience	work experience related work experience
Training	induction training on-the-job training apprenticeships specific training programs refresher courses

### 8.12.2 Training for Maintenance Personnel

A number of IALA surveys have indicated that, in some areas, maintenance personnel lack the training to perform their tasks effectively. The situation can be addressed by:

- the Authority formulating and documenting its maintenance philosophy;
- carrying out a skills audit to identify the gaps between available skills and skills required for the various maintenance tasks;
- arranging for training programs to fill the gaps, preferably by:
  - providing modular training courses that can be adapted to the particular needs of each trainee or group of trainees;
  - providing computer based training and distance learning methods which are useful ways of achieving continuity of training when personnel are also engaged in field activities. Some adjustment to work schedules would be necessary to allow for training time.
- using training courses that are accredited with a recognised institution. This has several benefits:
  - providing training that leads to a formal qualification as a trainee may be more highly motivated if he/she can see accredited courses leading on to a formal qualification (ie. career path prospects);
  - recognising accredited courses (providing “portable” accreditation that can be of benefit to those changing jobs);
  - recognising courses and referencing these in position descriptions to broaden the range of applicants for job vacancies.



*Photo courtesy of U.S. Coast Guard*



### 8.12.3 IALA World Wide Academy

In order to provide a means of ensuring a minimum, standard level of competence of personnel involved in the delivery of AtoN services, there is a requirement to provide a consistent and practical approach to training.

The majority of training in AtoN fields other than VTS is through on-the-job and apprentice style training. While this may work on a one-on-one basis, there are concerns that this approach does not provide for a minimum standard of competence.

In providing guidance to its members on the harmonized delivery of aids to navigation services, IALA recognises the challenges that exist. In the context of AtoN personnel this includes, but is not limited to:

- Differing roles of AtoN service providers (management, engineering, VTS, lamp replacement, etc.).
- National and international requirements regarding labour laws, affirmative action, educational requirements, etc.
- Variance in equipment in service, and facilities to train on the equipment.
- Language requirements for AtoN personnel.
- Access to training facilities and instructional staff – through physical locality or language.

In order to respond to the requirement for consistent, high quality service delivery there is a need for consistent, high quality training. Many of the challenges identified can be overcome through a 'community of experts' approach, making best use of the IALA network and knowledge. It is possible to develop a training element that can provide 'just on time' training in locations where the training is needed and in the language of the students.

IALA is currently introducing a new section within the IALA Secretariat – 'The IALA Worldwide Academy' to help address these AtoN training needs.

The model courses are initially being provided in English, but the training institutes are free to translate them into their own language. In this manner, IALA training will penetrate deeply into other countries that are using the same language (eg – Spanish, Arabic, etc.).

Benefits include:

- No limit to the numbers that can be trained;
- Students trained in their own language;
- Ensures correct application of IALA Recommendations and Guidelines etc.
- Training to an agreed international standard, easy to verify and audit.

The introduction of the IALA World Wide Academy will result in the management and maintenance of aids to navigation and VTS by personnel who are trained and assessed to a similar competency standard worldwide. IMO has experienced harmonization in training through the introduction of the STCW coupled with the three world institutes in Malmoe, Malta and Trieste. The proposed IALA Worldwide Academy is flexible, making optimum use of all modes of communication, and more



adapted to the VTS and aids to navigation activities. The proposed solution as shown in Table 31 and Figure 34 should provide a cost effective response to the ongoing concerns over standardized training for Aids to Navigation Personnel.

**Refer to IALA publication:**  
*Recommendation E-141 – Standards for Training and Certification of AtoN Personnel.*

**Table 31 – IALA Worldwide Academy Responding to the Challenges**

Challenge	IALA Worldwide Academy Response
Differing roles of AtoN service providers (management, engineering, VTS, lamp replacement, etc.)	Provide training as developed by IALA expertise (ANM, EEP Committees) to respond to all roles of AtoN personnel
National and international requirements regarding labour laws, affirmative action, educational requirements, etc	Training model developed to an international standard, with ability to tailor to meet specific requirements, prior learning assessments of students, etc
Variance in equipment in service, and facilities to train on the equipment	Training to take into account actual, on-site requirements while providing access to a network of training facilities through the IALA network
Language requirements for AtoN personnel	While development will be in English, members will be encouraged to translate to language of choice
Access to training facilities and instructional staff – through physical locality or language	Use of modern educational techniques, including computer mediated communication (CMC) will improve access to training

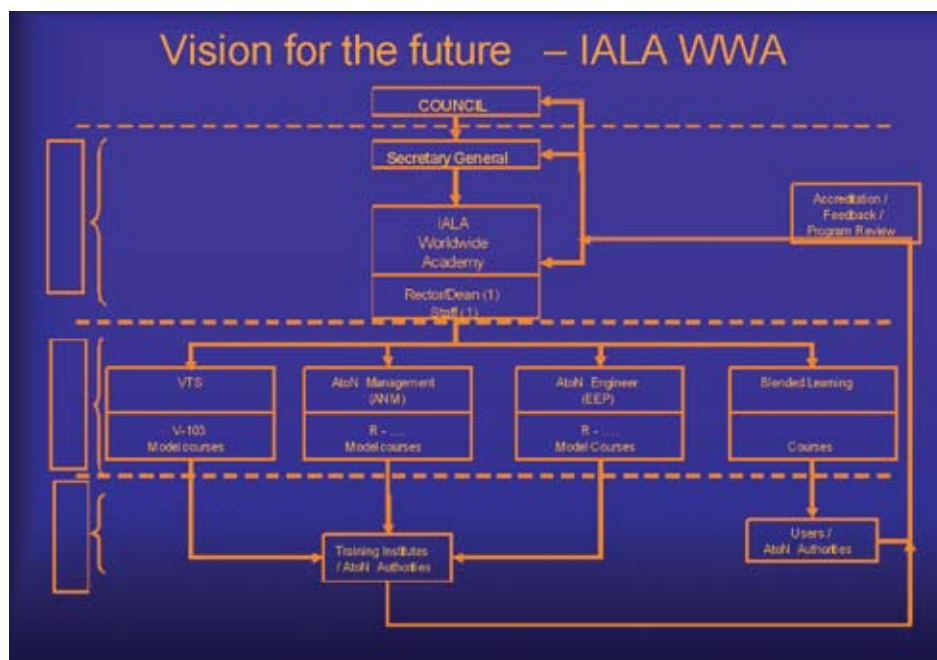


Figure 34 – Potential IALA World Wide Academy Organisational Structure



# A

## IALA MARITIME BUOYAGE SYSTEM



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# Contents

Historical background .....	<b>3</b>
General Principles of the System .....	<b>5</b>
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Map showing Regions A & B .....	<b>12 &amp; 13</b>



# MARITIME BUOYAGE SYSTEM

## and Other Aids to Navigation

### Historical Background

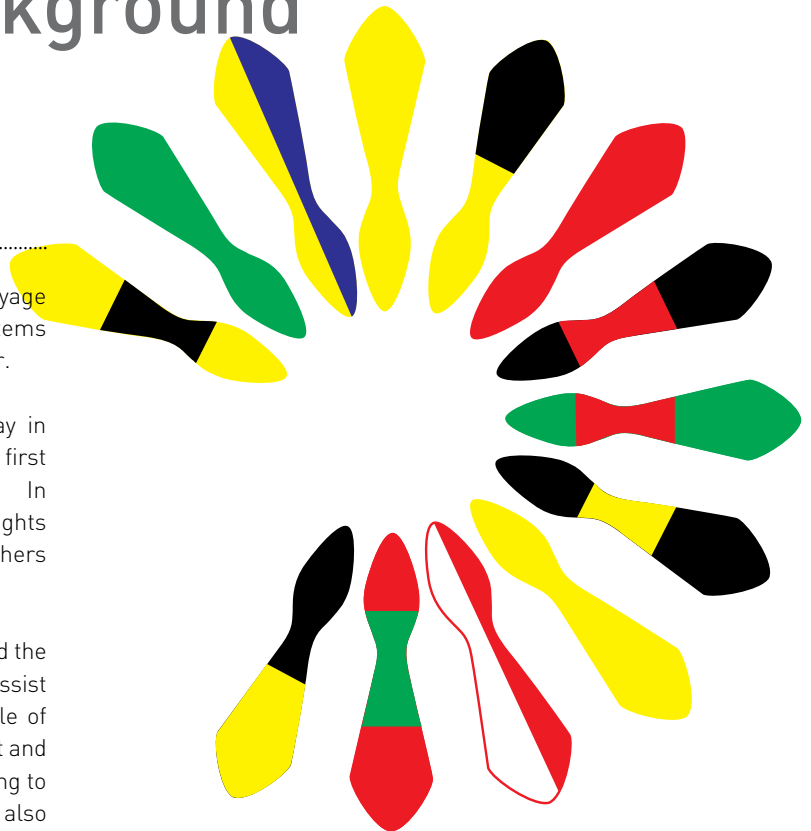
#### PRIOR TO 1976

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.



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:

- i) the need to retain existing equipment as far as possible to avoid undue expense
- ii) the need to define how the colours green and red were to be used when marking channels
- iii) 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 co-operation 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.

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 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 for 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 preferred 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.

## Cardinal Marks (continued)

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:  
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. Isolated Danger Marks are black with one or more broad horizontal red bands. 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.

### 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 sufficiently 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.

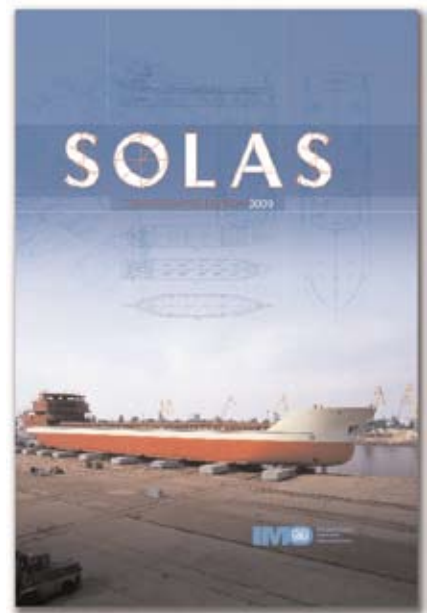
- Leading lines / Ranges allow ships to be guided with precision along a portion of a straight route using the alignment of fixed lights (leading lights) or marks (leading marks), in some cases a single directional light may be used.
- Major floating aids include lightvessels, light floats and large 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).

## 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.



# RULES

## 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.

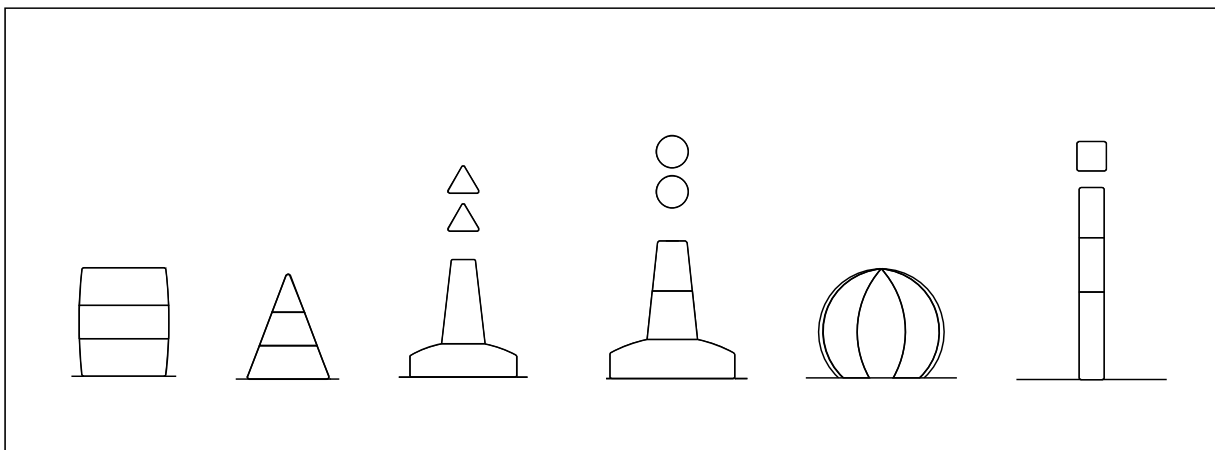
- 1.2.5 Special marks to indicate an area or feature referred to in nautical documents, not generally intended to mark channels or obstructions.

- 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 on the centrefold of this booklet.

### 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

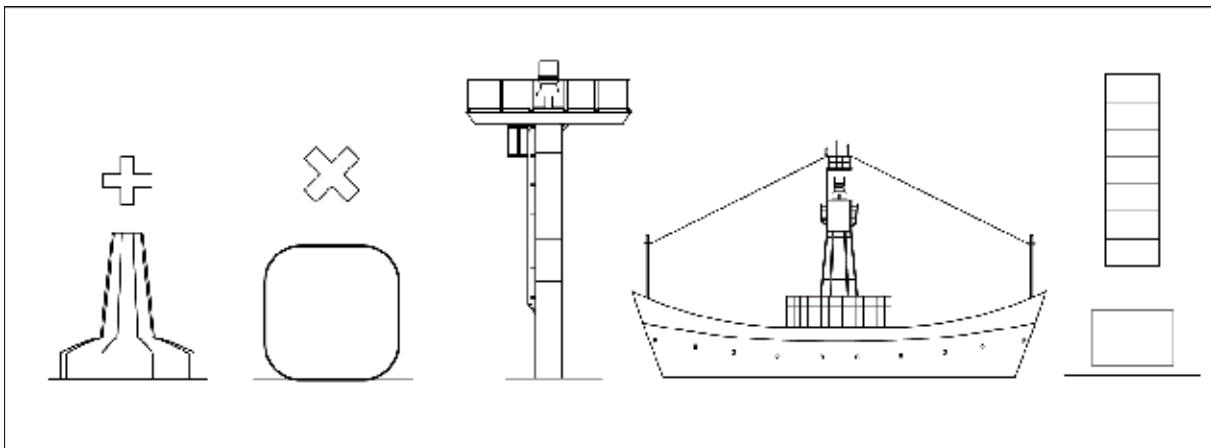
Lateral marks should be of cylindrical and conical shape. However, where they do not rely on a distinctive shape for identification, they should, where practicable, carry the appropriate topmark.

#### 2.3.3 Numbering or lettering

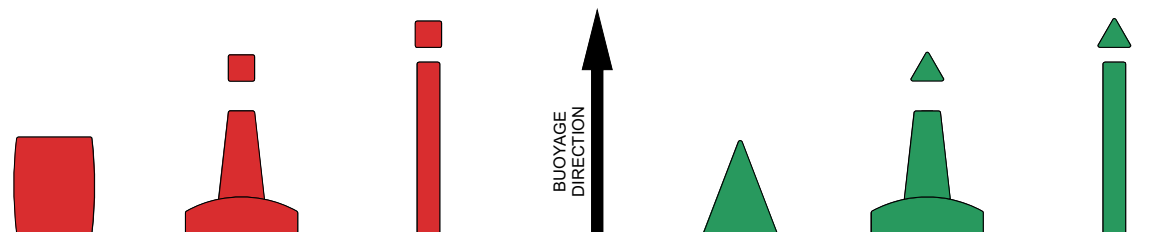
If marks at the sides of a channel are numbered or lettered, the numbering or lettering shall follow the 'conventional direction of buoyage' i.e. numbered from seaward. The protocol for numbering lateral marks, especially in confined waterways, should be 'even numbers on red ~ odd numbers on green'.

#### 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.

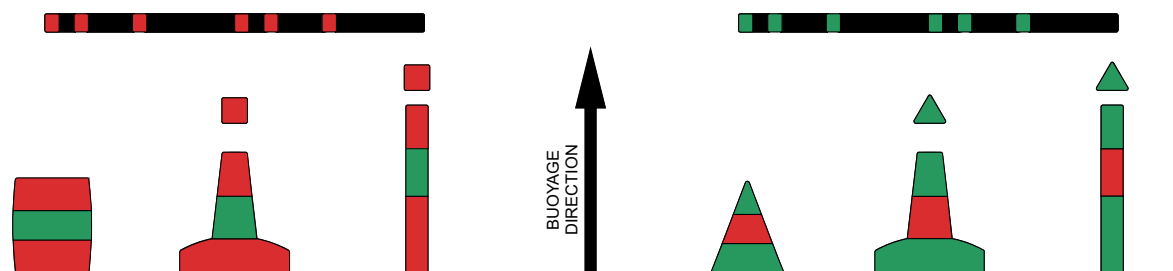


## 2.4 Description of Lateral Marks used in Region A



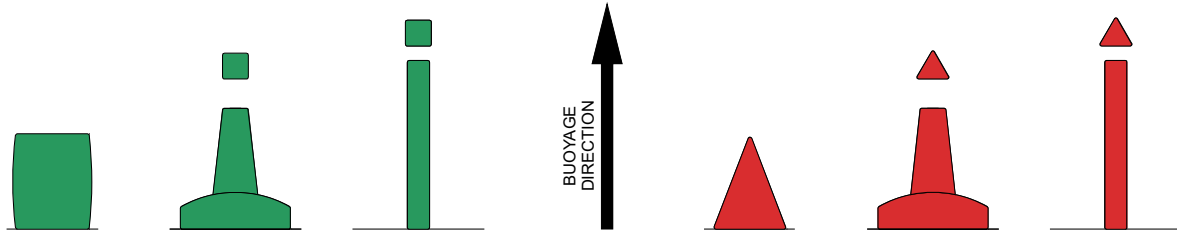
2.4.1 Port hand Marks		2.4.2 Starboard hand Marks	
<b>Colour</b>	Red	Green	
<b>Shape of buoy</b>	Cylindrical (can), pillar or spar	Conical, pillar or spar	
<b>Topmark (if any)</b>	Single red cylinder (can)	Single green cone, point upward	
<b>Light (when fitted)</b>			
<b>Colour</b>	Red	Green	
<b>Rhythm</b>	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:



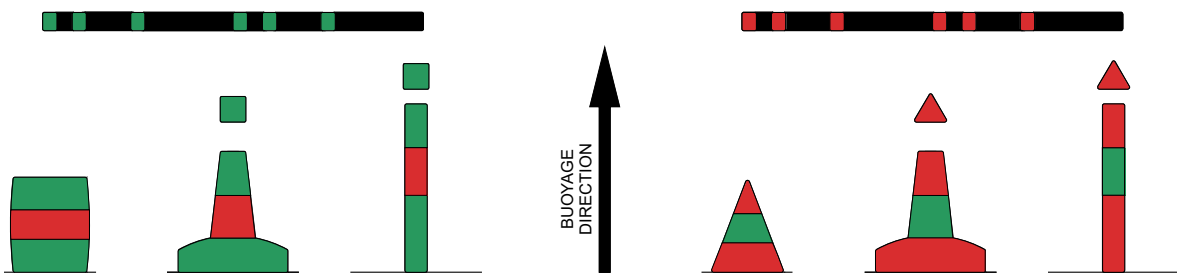
2.4.3.1 Preferred channel to Starboard		2.4.3.2 Preferred channel to Port	
<b>Colour</b>	Red with one broad green horizontal band	Green with one broad red horizontal band	
<b>Shape of buoy</b>	Cylindrical (can), pillar or spar	Conical, pillar or spar	
<b>Topmark (if any)</b>	Single red cylinder (can)	Single green cone, point upward	
<b>Light (when fitted)</b>			
<b>Colour</b>	Red	Green	
<b>Rhythm</b>	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	
<b>Colour</b>	Green	Red	
<b>Shape of buoy</b>	Cylindrical (can), pillar or spar	Conical, pillar or spar	
<b>Topmark (if any)</b>	Single green cylinder (can)	Single red cone, point upward	
<b>Light (when fitted)</b>			
<b>Colour</b>	Green	Red	
<b>Rhythm</b>	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:

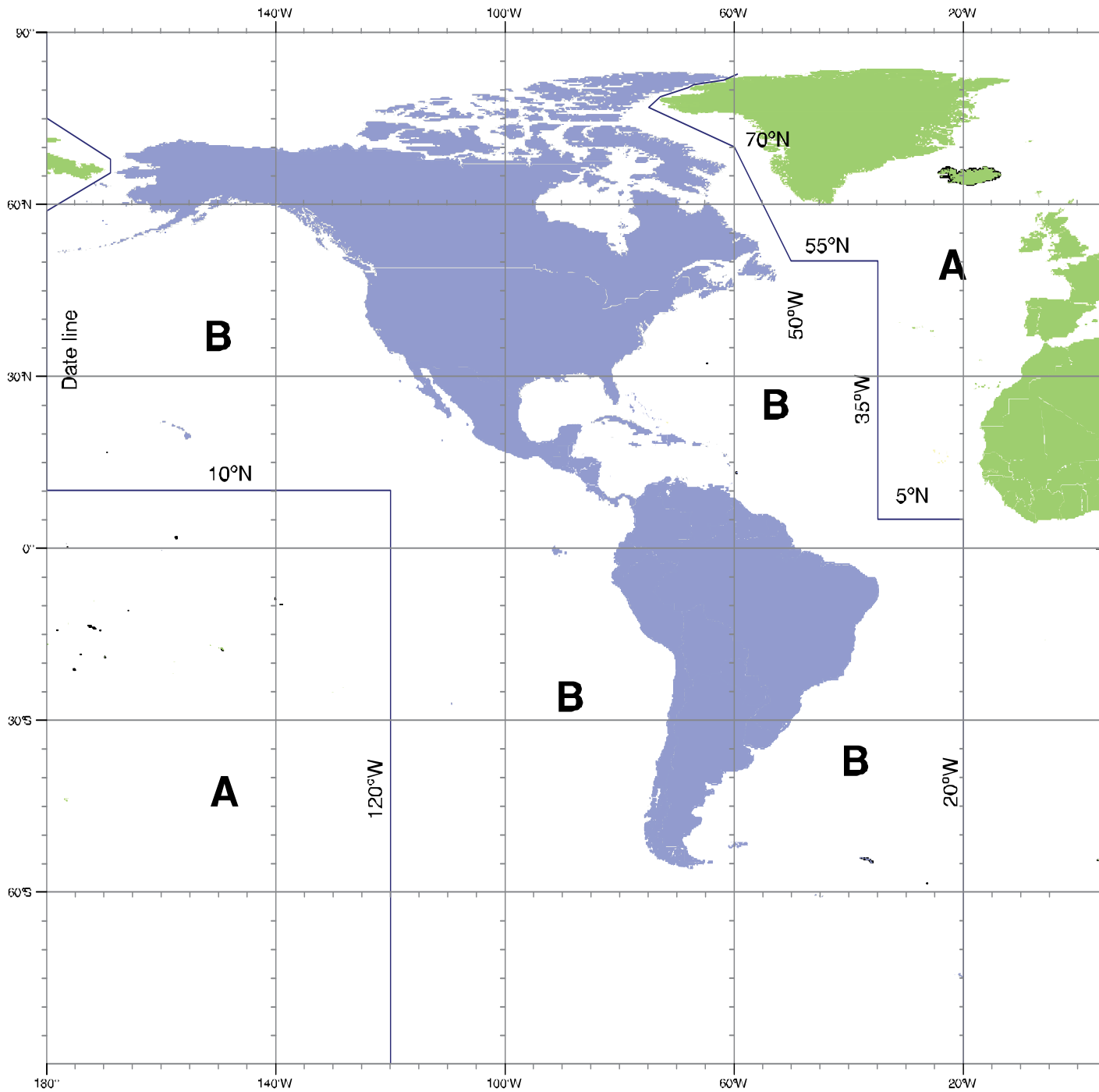


2.5.3.1 Preferred channel to Starboard		2.5.3.2 Preferred channel to Port	
<b>Colour</b>	Green with one broad red horizontal band	Red with one broad green horizontal band	
<b>Shape of buoy</b>	Cylindrical (can), pillar or spar	Conical, pillar or spar	
<b>Topmark (if any)</b>	Single green cylinder (can)	Single red cone, point upward	
<b>Light (when fitted)</b>			
<b>Colour</b>	Green	Red	
<b>Rhythm</b>	Composite group flashing (2 + 1)	Composite group flashing (2 + 1)	



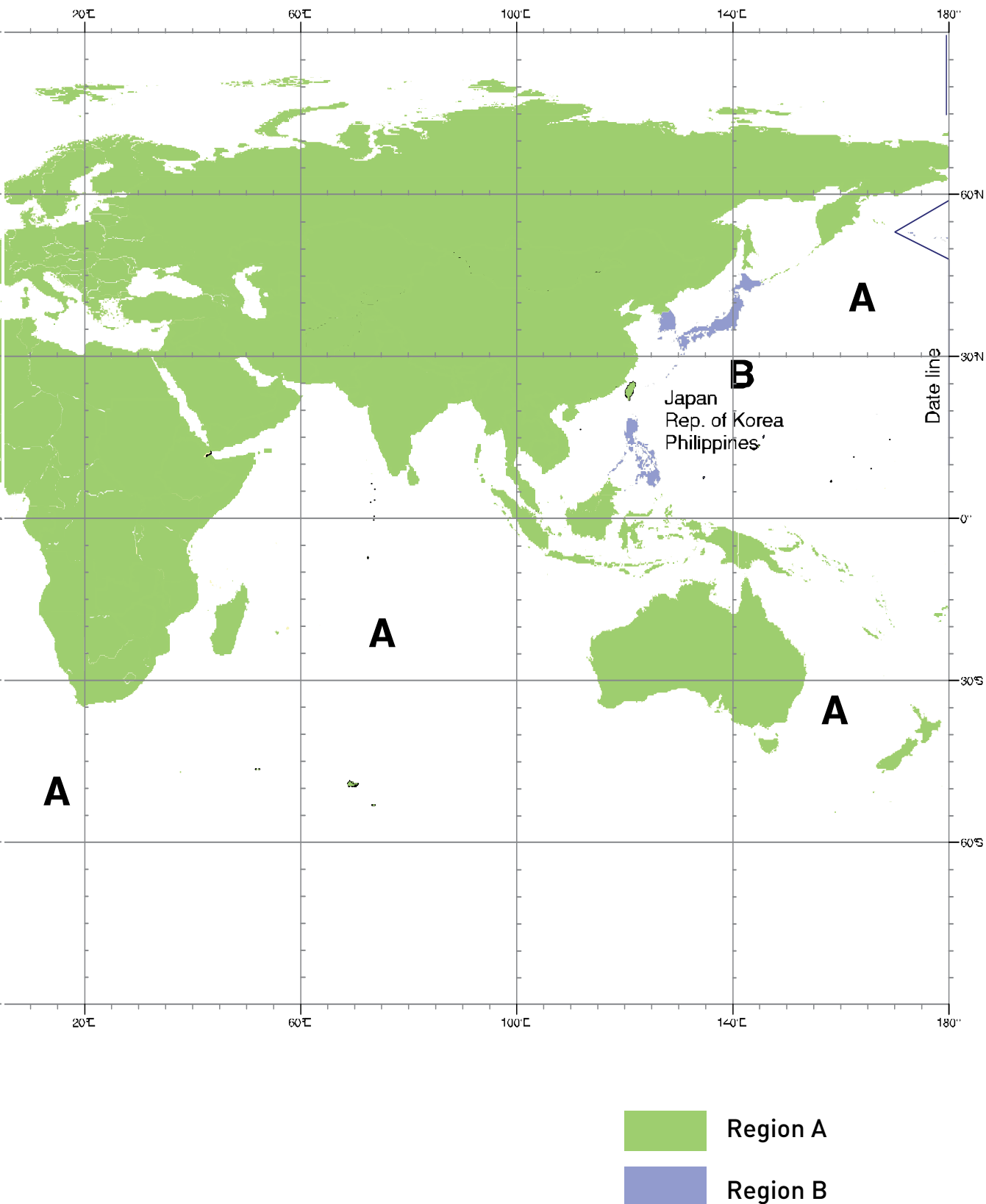
# IALA / AISM MARITIME

## Buoyage Reg



# BUOYAGE SYSTEM

## Regions A and B



### 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.

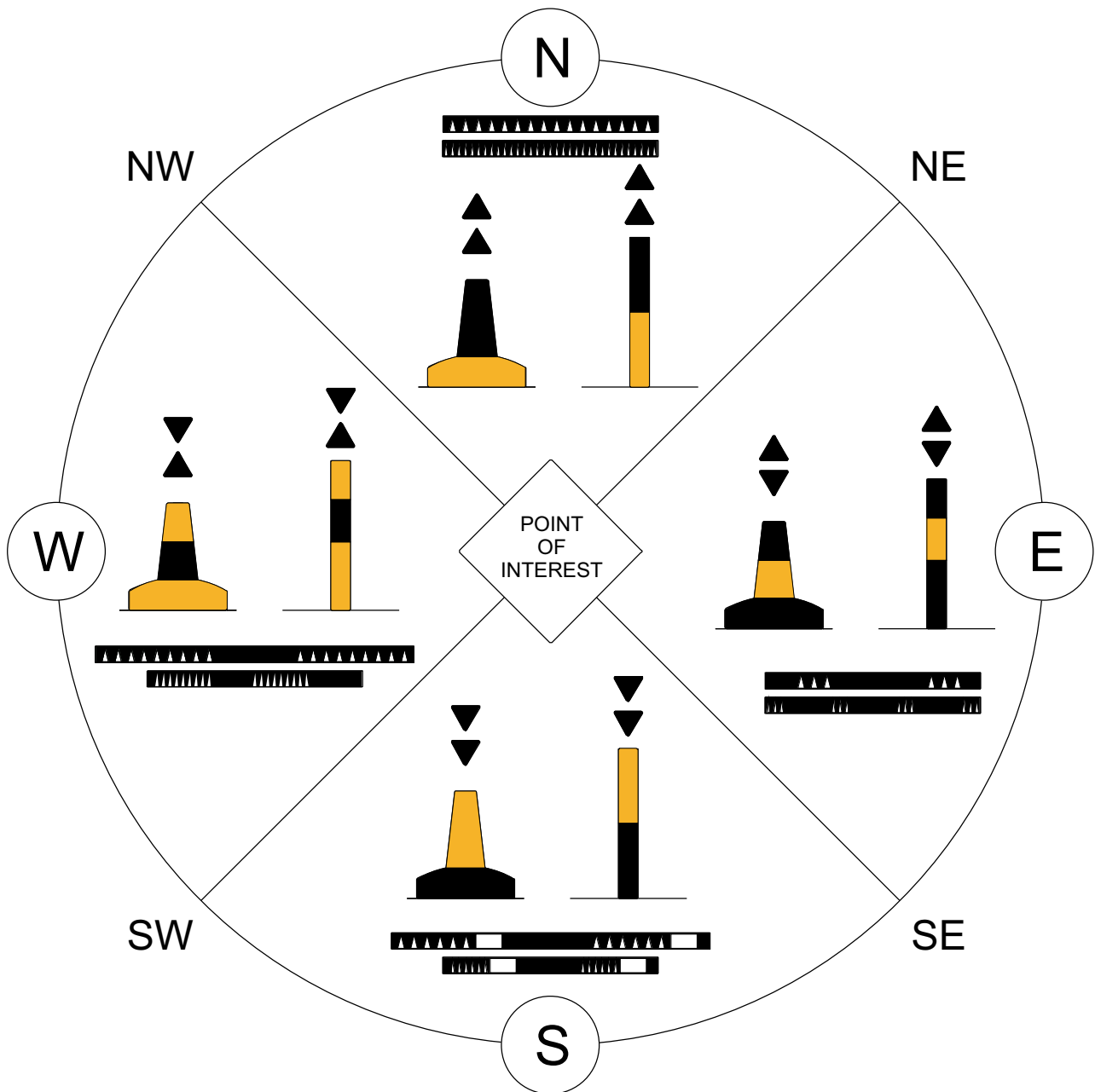
**3.2.4** Competent authorities should consider carefully before establishing too many cardinal marks in a waterway or area as this can lead to confusion, given their white lights of similar characteristics.

#### 3.3 Description of Cardinal Marks

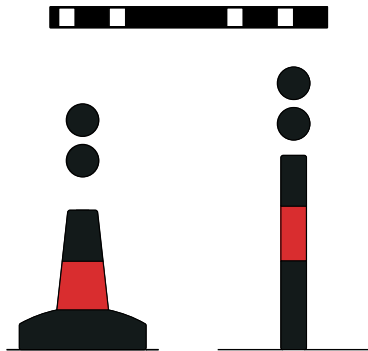
	3.3.1 North Cardinal Mark	3.3.2 East Cardinal Mark
<b>Topmark</b> <sup>(a)</sup>	2 black cones, one above the other, points upward	2 black cones, one above the other, base to base
<b>Colour</b>	Black above yellow	Black with a single broad horizontal yellow band
<b>Shape of buoys</b>	Pillar or spar	Pillar or spar
<b>Light (when fitted)</b>		
<b>Colour</b>	White	White
<b>Rhythm</b>	VQ or Q	VQ(3) every 5s or Q(3) every 10s

	3.3.3 South Cardinal Mark	3.3.4 West Cardinal Mark
<b>Topmark</b> <sup>(a)</sup>	2 black cones, one above the other, points downward	2 black cones, one above the other, point to point
<b>Colour</b>	Yellow above black	Yellow with a single broad horizontal black band
<b>Shape of buoys</b>	Pillar or spar	Pillar or spar
<b>Light (when fitted)</b>		
<b>Colour</b>	White	White
<b>Rhythm</b>	VQ(6) + Long flash every 10s or Q(6) + Long flash every 15s	VQ(9) every 10s or Q(9) every 15s

**Note**<sup>(a)</sup>: 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.



## 4. ISOLATED DANGER MARKS



### 4.1 Definition of Isolated Danger Marks

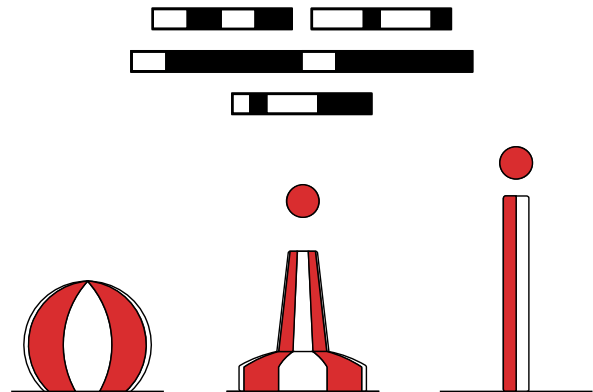
An isolated Danger mark is a mark erected on, or moored on or above, an isolated danger which has navigable water all around it.

### 4.2 Description of Isolated Danger Marks

Description	
<b>Colour</b>	Black with one or more broad horizontal red bands
<b>Shape of buoy</b>	Optional, but not conflicting with lateral marks; pillar or spar preferred
<b>Top-mark <sup>(b)</sup></b>	Two black spheres, one above the other
<b>Light (when fitted)</b>	
Colour	White
Rhythm	Group flashing (2)

**Note <sup>(b)</sup>** : 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

Description	
<b>Colour</b>	Red and white vertical stripes
<b>Shape of buoy</b>	Spherical; pillar or spar with spherical topmark
<b>Top-mark (if any)</b>	Single red sphere
<b>Light (when fitted)</b>	
Colour	White
Rhythm	Isophase, occulting, one long flash every 10s or Morse "A"

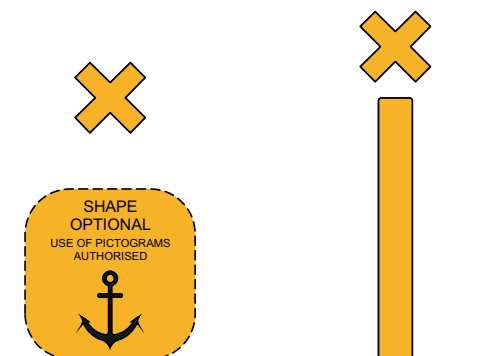
## 6. SPECIAL MARKS

### 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

Description	
<b>Colour</b>	Yellow
<b>Shape of buoy</b>	Optional, but not conflicting with lateral marks
<b>Top-mark (if any)</b>	Single yellow "X" shape
<b>Light (when fitted)</b>	
<b>Colour</b>	Yellow
<b>Rhythm</b>	Any, other than those reserved for cardinal, isolated danger and safe water marks.
<b>Pictogram</b>	The use of pictograms is authorized, as defined by a competent authority.



## 7. MARKING NEW DANGERS

### 7.1 Definition of New Dangers

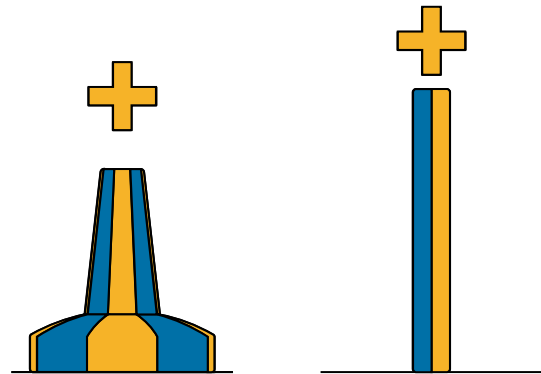
The term “New Danger” is used to describe newly discovered hazards not yet shown in nautical documents. ‘New Dangers’ include naturally occurring obstructions such as sandbanks or rocks or man-made dangers such as wrecks.

### 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.

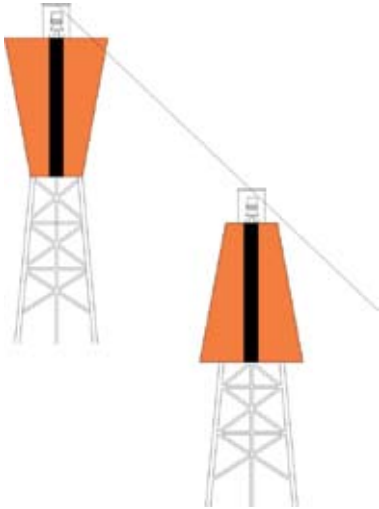
### 7.3 Description of New Dangers Marks

Description	
<b>Colour</b>	Blue/Yellow vertical stripes in equal number dimensions (minimum 4 stripes and maximum 8)
<b>Shape of buoy</b>	Pillar or spar
<b>Top-mark (if any)</b>	Vertical/perpendicular Yellow cross
<b>Light</b>	
<b>Colour</b>	Yellow/blue alternating
<b>Rhythm</b>	One second of blue light and one second of yellow light with 0.5 sec. of darkness between



## 8. OTHER MARKS

### 8.1 Leading Lines/Ranges



#### 8.1.1 Definition of Leading Lines/Ranges

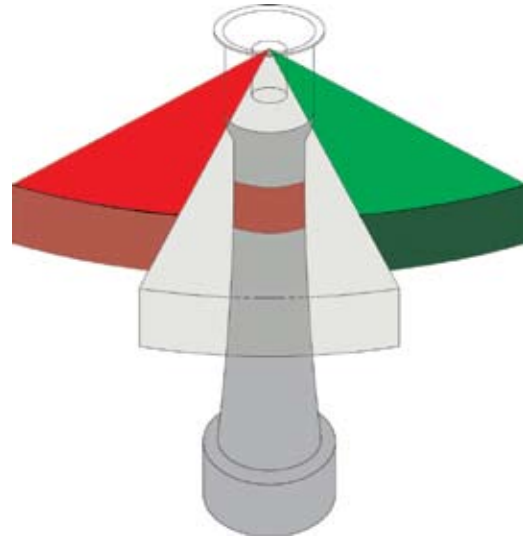
A group of two or more marks or lights, in the same vertical plane such that the navigator can follow the leading line on the same bearing.

#### 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	
<b>Colour</b>	No colour significance. Competent authority determines the optimum colours to contrast with the dominant background colour at the location
<b>Shape</b>	No shape significance. Rectangular or triangular figures are recommended.
<b>Light (when fitted)</b>	
<b>Colour</b>	Any colour. Competent authority determines the optimum colour to contrast with the dominant background colour at the location.
<b>Rhythm</b>	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

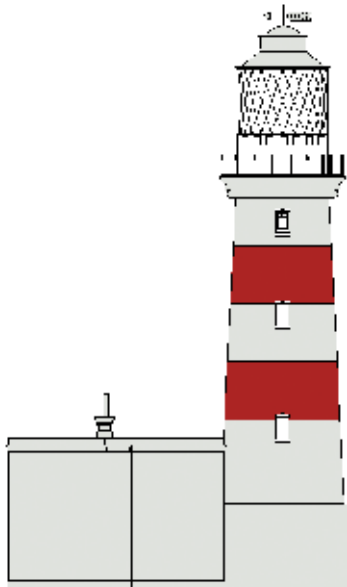
A sector light may be used:

- 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	
<b>Colour</b>	Not applicable
<b>Shape</b>	None, light only
<b>Light</b>	
<b>Colour</b>	If using to mark channel limits follow convention for IALA region indicated in Section 2. Lights may have oscillating boundaries
<b>Rhythm</b>	As appropriate



## 8.3 Lighthouses



### 8.3.1 Definition of a Lighthouse

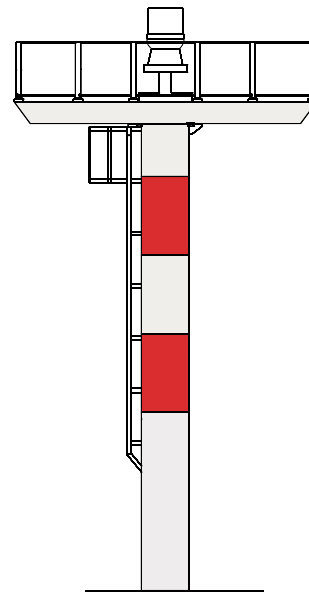
A lighthouse is a tower, or substantial building or structure, erected at a designated geographical location to carry a signal light and provides a significant daymark. It provides a long or medium range light for identification by night.

### 8.3.2 Description of a Lighthouse

It may provide a platform for other AtoN such as DGNSS, Racon or AIS as an Aid 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	
<b>Colour/Shape</b>	Lighthouse structures can be of any colour, shape, or material generally designed to provide a distinctive daymark.
<b>Light</b>	
<b>Colour</b>	White, Red, or Green
<b>Rhythm</b>	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

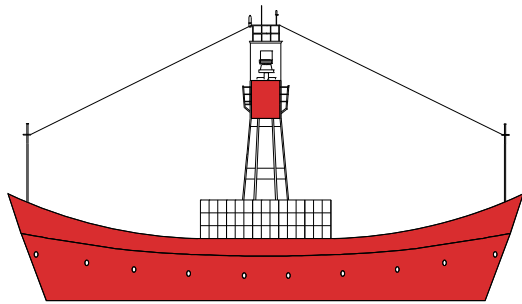
A fixed man-made navigation mark that can be recognised by its shape, colour, pattern, topmark, or light character, or a combination of these.

### 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	
<b>Colour</b>	Any
<b>Shape</b>	As appropriate, including cardinal mark
<b>Topmark (if any)</b>	As appropriate
<b>Light (when fitted)</b>	
<b>Colour</b>	White, Red, or Green
<b>Rhythm</b>	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 Aid to Navigation to assist marine navigation.

Description	
<b>Colour</b>	As appropriate - predominantly red
<b>Shape</b>	Vessel or buoy shape with light tower
<b>Light (when fitted)</b> including off station lights	
<b>Colour</b>	As appropriate
<b>Rhythm</b>	As appropriate

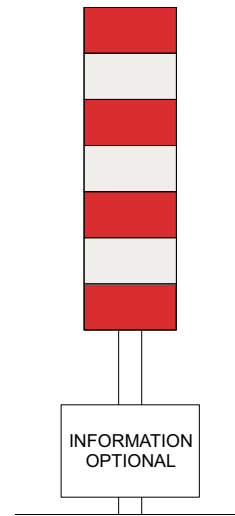
## 8.7 Port or Harbour Marks

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.

## 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](http://www.iala-aism.org). 

## 8.6 Auxiliary Marks



### 8.6.1 Definition of Auxiliary Marks

Minor aids that have not been previously described.

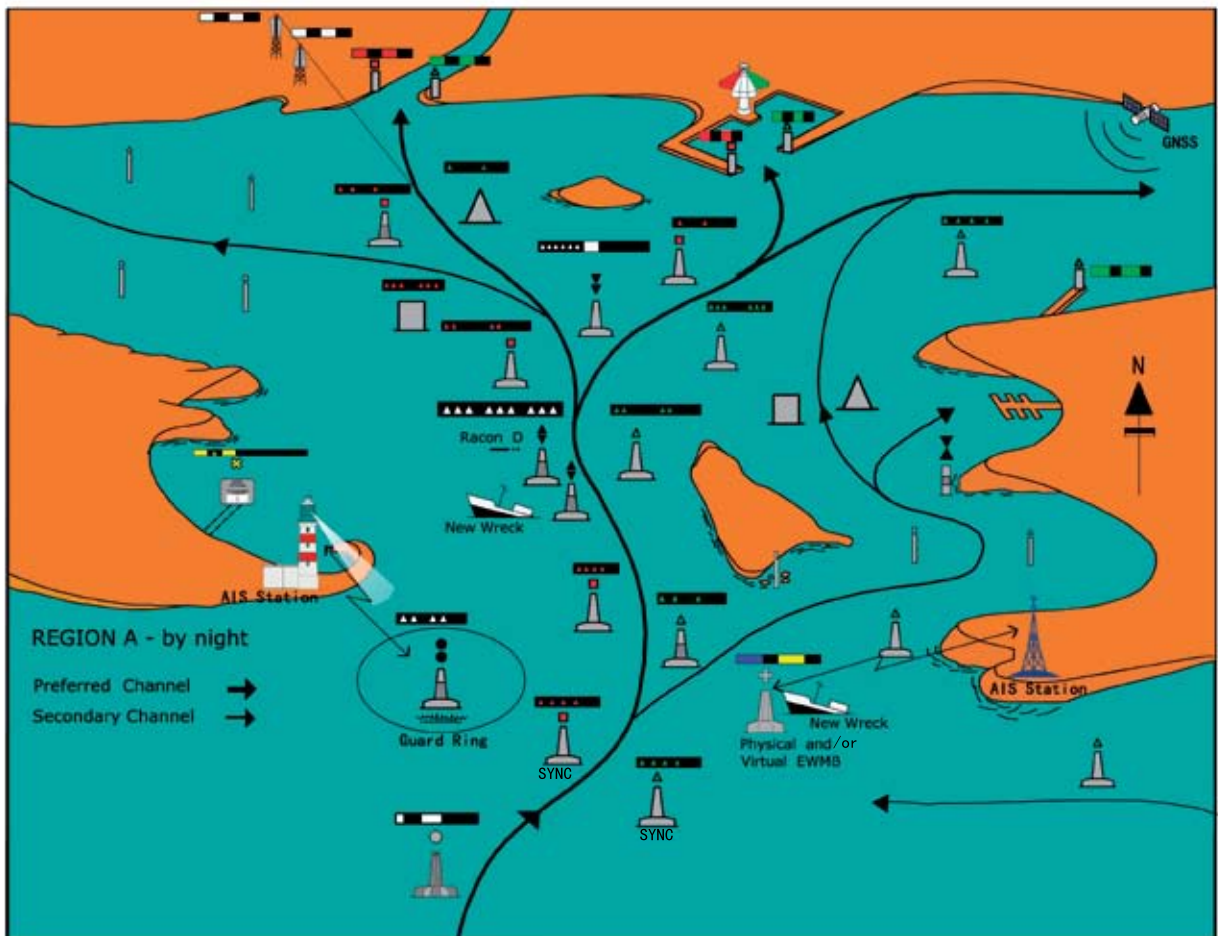
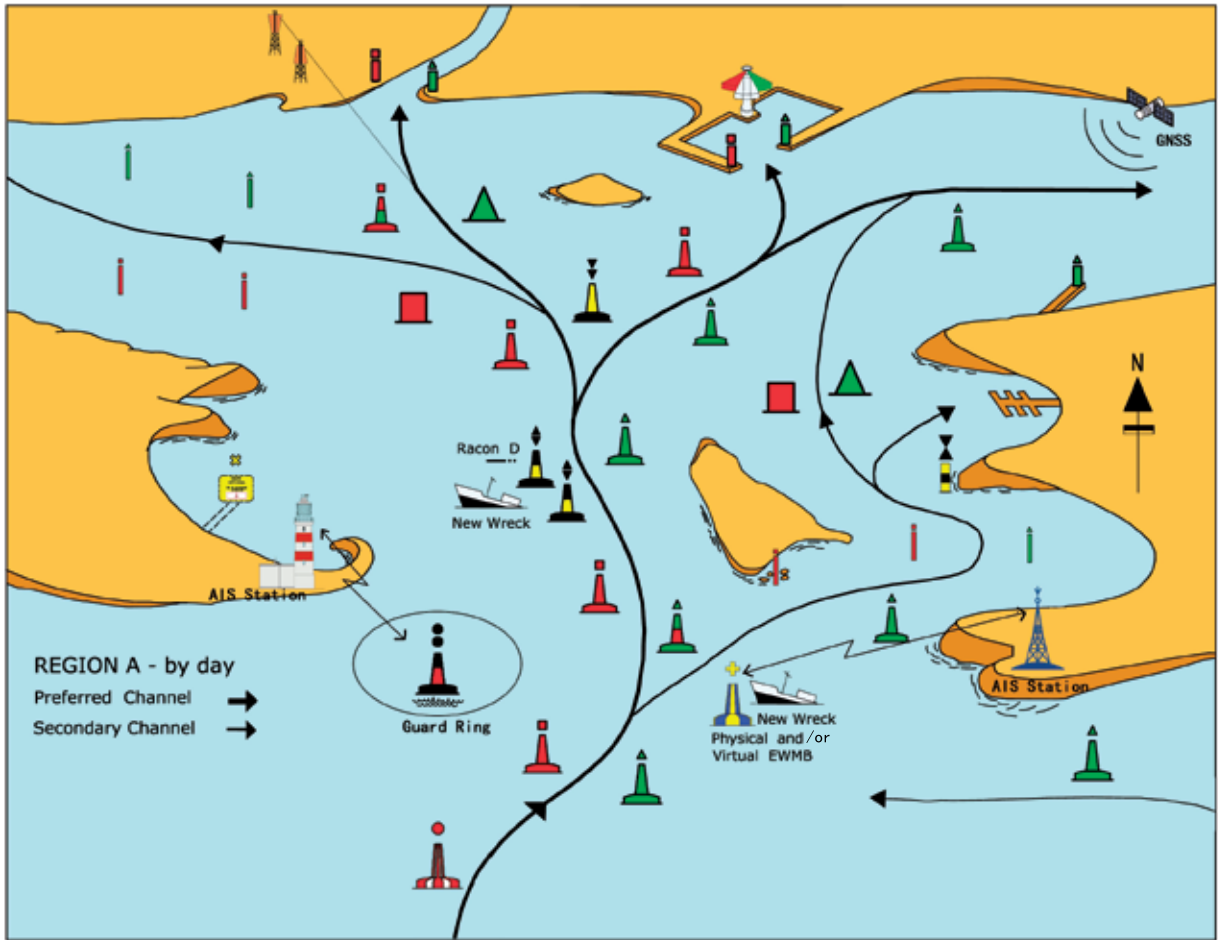
### 8.6.2 Description of Auxiliary Marks

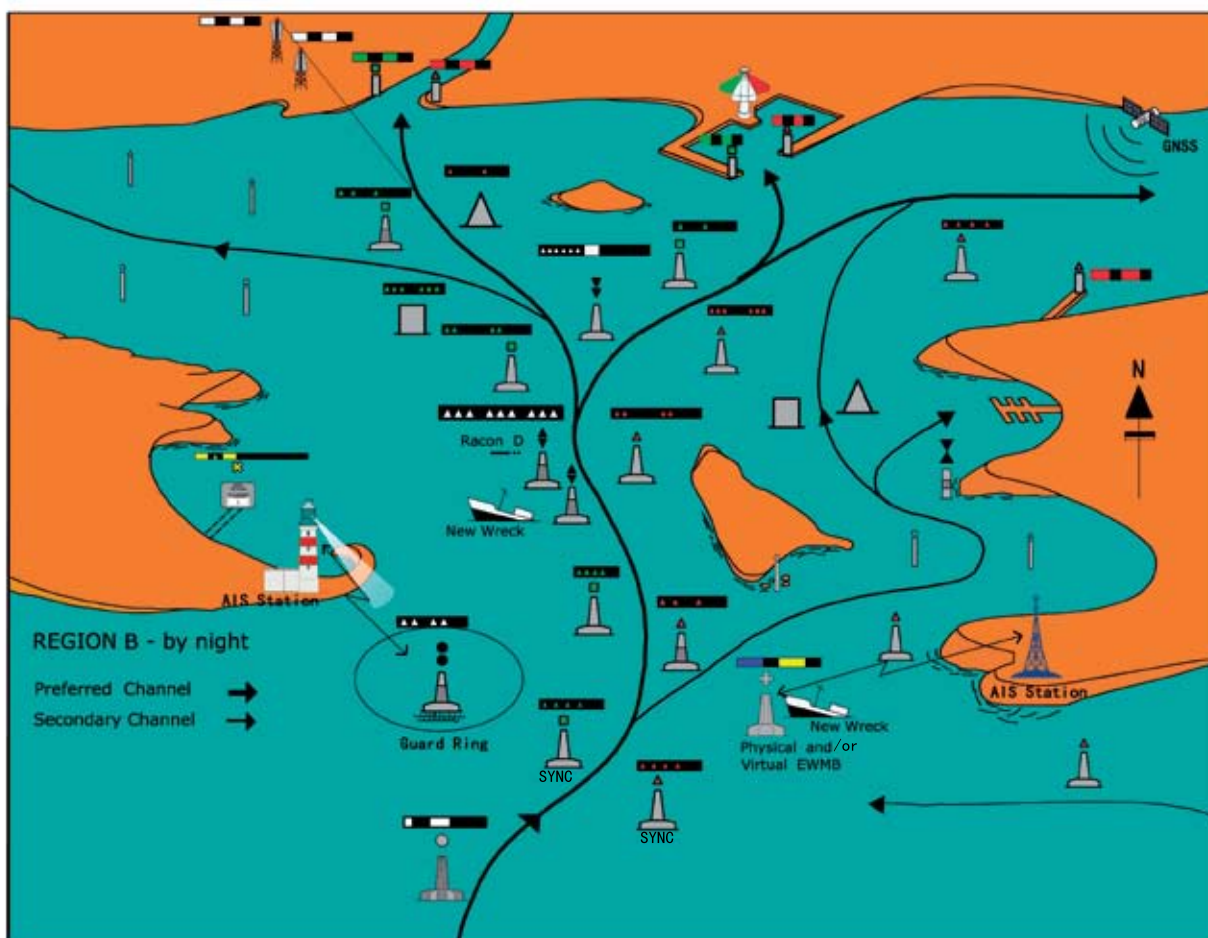
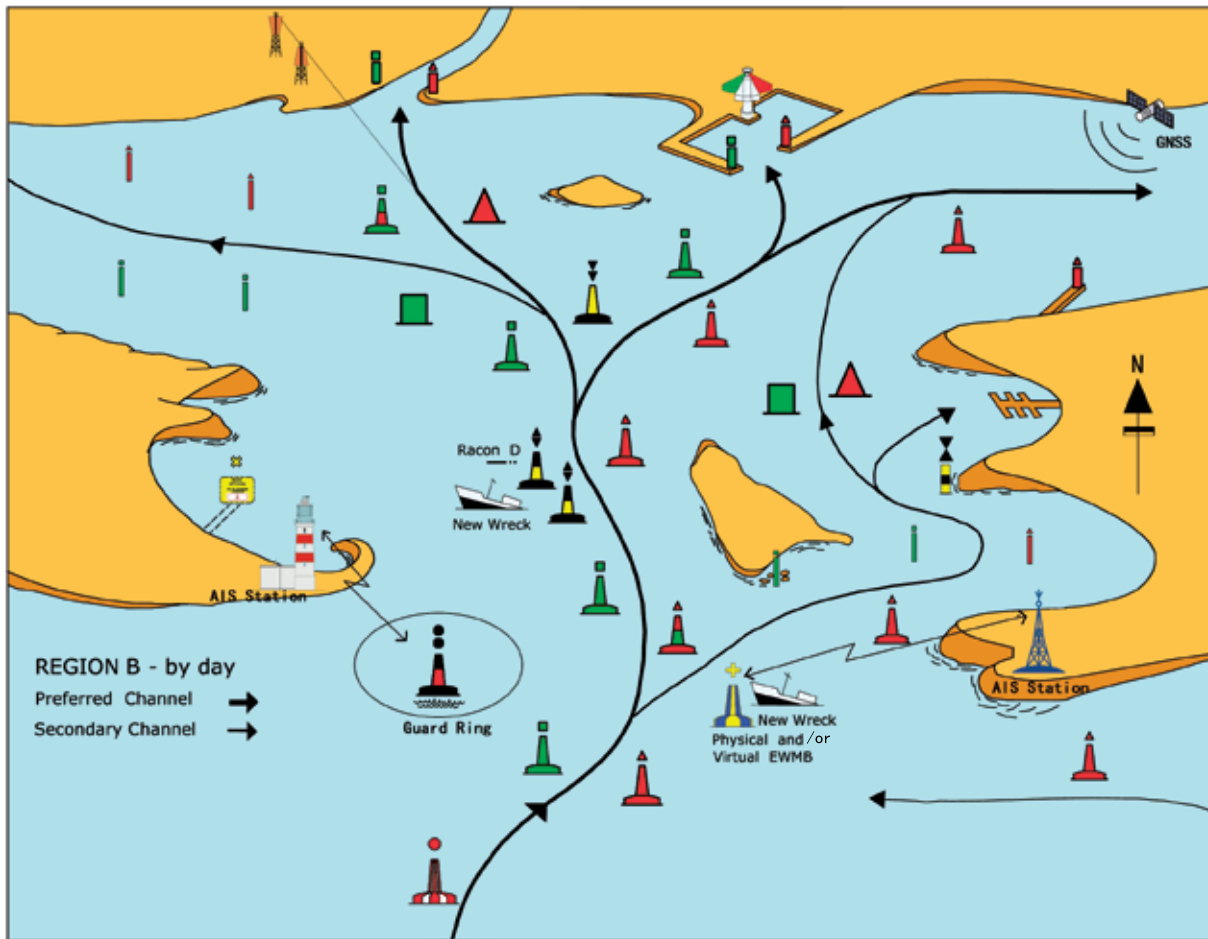
These marks are usually outside of defined channels and generally do not indicate the port and starboard sides of the route to be followed or obstructions to be avoided. They also include those marks used to convey information related to navigation safety. These marks shall not conflict with other navigational 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.

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 rivers, channels, canals, locks and waterways marked within the responsibilities of competent authorities.







# B

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