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Aids to Navigation Design for Channels

by

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ABSTRACT

Aids to Navigation (AtoN) provide a significant contribution to the safety and efficiency of navigation in a channel. The quality of AtoN can support efficient channel design and maintenance. The way of marking a channel has been developed under specific local or regional conditions and based on experience and tradition. In the last decades is has more and more become best praxis to use the AtoN in conjunction with the sea chart. The IALA Maritime Buoyage System (MBS) is mandatory since 30 years and defines the meaning of the AtoN for all countries but not the required spacing and quality level for the AtoN.

The importance of good survey and sea charts has increased. The e-Nav-concept, promoted by IMO[4] and IALA-AISM[5], will integrate the different technologies as well on the bridge of the vessels as from the shore-based provider perspective. A systematic description and some kind of harmonized channel AtoN design and a common database, including survey data and charts, will now become even more important.

Though the importance of Radionavigation has significantly increased, practical navigation will be assisted by visual AtoN. The accuracy of positioning the vessel which is required for navigation in a restricted channel should be provided by a proper system of electronic and visual AtoN. When designing the AtoN system for a channel, it should be a principle that the mariner shall never be forced to rely on only one technology. At least one backup system is required.

The PIANC WG 49 (Marcom) is revising the PIANC Guide for Design of Approach Channels. The horizontal dimensions of a channel calculated according to this guide can be used without any additional width factors, if the AtoN system is efficiently designed according to the requirements. Otherwise the width of the fairway has to be increased. The factors for the additional width are still under consideration.

1. INTRODUCTION

1.1 Role of AtoN and principles of AtoN systems

Aids to Navigation (AtoN) provide a significant contribution to the safety and efficiency of navigation. The Aids to Navigation (AtoN) for fairways/waterways including dredged channels and canals should be both relevant to the safety and efficiency of vessel traffic and cost effective to the National Authorities. A systematic approach with the use of performance parameters for defining requirements is proposed for the design of AtoN systems.

Until recently, mariners have used Radionavigation and the short range aids to navigation (AtoNs) in accordance of the distance from the shore. The short range system was mostly used close to shore and in restricted waterways and harbours. On the open seas, vessels were able to navigate safely using the different radionavigation systems.

Today, considering the accuracy, avaibility, reliability and relative low cost of high precision electronic AtoN systems (e.g. GNNS[6]/DGNSS[7]/AIS[8] in conjunction with electronic charts) these are more and

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[4] International Maritime Organisation

[5] International Association of Marine Aids to Navigation and Lighthouse Authorities / Association international de signalisation maritime

[6] Global Navigation Satellite Systems

more used also close to the coast and in the rivers and estuaries. Under these preconditions the visual aids to navigation get a new role. The navigational practise of today can, in some cases and in some places, also require a higher standard for the short range AtoN. So, it can be assumed, that there will not be less AtoN in future, but different ones and in other places

It should be a principle that the mariner shall never be forced to rely on only one technology. At least one backup system is required. The e-Nav-concept, promoted by IMO[9] and IALA-AISM[10], will integrate the different technologies as well on the bridge of the vessels as from the shore-based provider perspective.

When designing the AtoN for a channel modern tools as there are risk assessment and simulation should be used. The risk level for a waterway depends on the type of waterway, the type, number and size of vessels and other factors from the environment. Regarding the risk level the user should use the following parameters and considerations to describe the requirements for the system from the point of the user: navigation accuracy, ship positioning accuracy, availability, integrity of the whole system, limitations of visual AtoNs, identification and conspicuity of visual AtoN, limitations of radionavigation.

1.2 Relevance for Channel Design

The PIANC WG 49 (Marcom) has been revising the PIANC Guide for Design of Approach Channels. The AtoN contribute significantly to the cost effectiveness of improvement measures and maintenance of navigation channels. Planning the horizontal and vertical dimensions of an approach channel has a strong interaction with AtoN design.

The horizontal dimensions of a channel calculated according to the PIANC Guide can be used without any additional width factors, if the AtoN system is efficiently designed according to the requirements. Otherwise the width of the fairway has to be increased. The factors for the additional width were still under consideration when writing this paper.

To a certain degree it can be useful to optimize the AtoN in order to optimize the positioning accuracy for the ship. But there will be a point where a better positioning accuracy will not contribute any more to the navigation accuracy. To find this point would allow for a really optimized AtoN design for a channel.

The parameter "accuracy" for vessel positioning, navigation and fairway width and its interdependence with buoy spacing is described and a new method from Japan for calculating the drift detection when using AtoN in a channel is explained.

An example for a very efficient AtoN design for an existing channel is shown.

But so far we have not found a true calculation method for this. So, judgement on AtoN systems will be based on a lot of experience, assisted by risk assessment and simulation.

Waterways planners, for instance hydraulic engineers and mariners, in the port and waterways authorities should consider the option of a significant contribution to the efficiency of major dredging projects and waterways maintenance by improving positioning accuracy and navigational accuracy due to proper use of Aids to Navigation. Thus in some cases the required channel width could be reduced and also the costs for major and maintenance dredging.

2. Background

2.1 General

Navigation is depending on three factors: Nature, human and technology. Artificial AtoN are a technology with a long history, closely linked with the history of civilization. Their design and their use require a concept and the concept must be the same for the designer and for the user.

[7] Differential Global Navigation Satellite Systems
[8] Automatic Identification System
[9] International Maritime Organisation
[10] International Association of Marine Aids to Navigation and Lighthouse Authorities / Association international de signalisation maritime

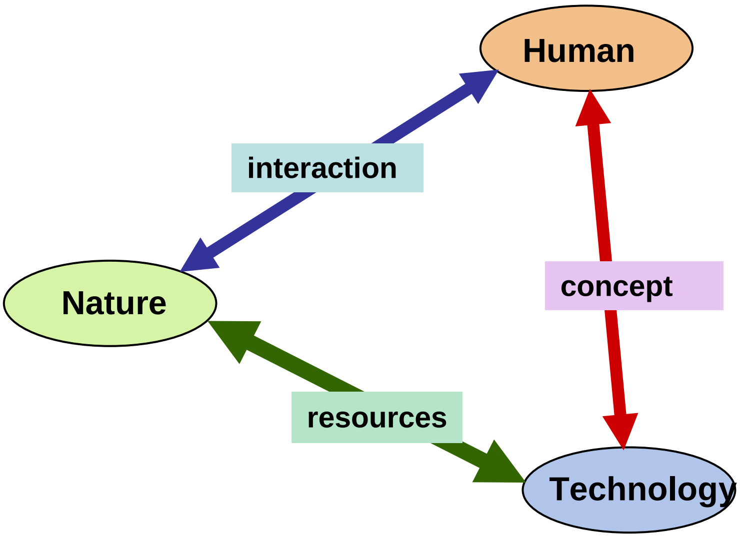


Figure 1: Model of interaction between nature, human and technology

For a holistic understanding of the process of designing and using the man-made AtoN system of a channel, none of the three elements and none of the three interactions should be forgotten. For the design of fairways or routes it is necessary, that navigation experts have a concept or a model in their mind and that they have a structure that they impose on the natural or the partly man-made channels.

For the use of the man-made AtoN system it is necessary that the mariner understands the model, that he has the same concept or the same structure in his mind as the planner. So, it would be good, if the planner is a mariner. Otherwise consultation and interaction with mariners is essential. However, in the past, technology and its development was often the driving force for the development of new AtoN, and the mariners got used to these tools. The idea behind a systematic approach to AtoN design is, that nowadays technology can do nearly everything and anything, and that the user should decide and chose. This shall be ensured by using a systematic approach to AtoN design, considering at the same time, that a significant part of AtoN design is based on experience and good practise.

Even when considering that we are living in a world which consists in major parts of man-made components the original interaction between human and nature is the basic source for the concept as well for the user as for the planner.

According to the idea of sustainable development any major reduction in environmental diversity may restrict the scope for future discovery and development. This does not only count for natural diversity but also for cultural diversity and for human heritage, because it provides a scope for future human life strategies.

In the interaction between humans and nature in our history we find the roots and the basic resource for technological development. Understanding, modelling and drawing conclusions, always in interaction with concepts, acting and changing things is an old tradition especially in navigation.

The navigation in old Oceania, as an example, was non-mathematical and non-instrumental. The palu, the “fully initiated navigator” in the south pacific had a vast quantity of information in his mind, learned from his teachers, not written down in any way. But it can be assumed that the organization and memorization of this knowledge follows an own structure, imposed on the natural waterway by human thinking and feeling.

2.2 What has to be done today

Going out from this point which is long, long ago in our history, a lot of historical development comes into the process, often specifically for certain regions. So it is no wonder, that AtoN systems are quite different in different regions.

But shipping is international. So we need some common international understanding, what the AtoN are telling the mariner. That’s one reason, why we need IALA. There can be no doubt about the basic mandatory IALA Maritime Buoyage System (MBS). But at the time we notice quite different implementation of the MBS regarding e. g. the number of buoys in different regions. The varieties are mostly motivated by different conditions regarding waterway and traffic patterns. However, it was felt that there should be some IALA Guidance to promote the

- systematic approach
- sharing of knowledge and experience from different areas of the world
- cautious development in direction of an equivalent level of AtoN for all IALA members
- reduction of impacts on the environment, energy consumption, light pollution, cost-effectiveness and justification of expenses
- integration of channel marking into the e-Navigation concept (which will be introduced in the next chapter)

The development of technology and the idea that some of the new technologies might be able to replace some of the traditional aids has caused a review of the level of provision of Aids to Navigation (AtoN) and telematic services in many countries in the last decade. A lot of knowledge is now available in the IALA community on determining and validation of requirements, marking principles and standards for an adequate mix of AtoN services and especially on the new role of the visual aids as a part of the whole system. It is sometimes assumed that there will be less visual AtoN in future than nowadays.

3. e-NAVIGATION

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

3.1 Definition

e-Navigation is the harmonised collection, integration, exchange, presentation and analysis of marine 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.

3.2 Background

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.

The advent of larger and faster ships, greater congestion and reduced manning levels has provided major impetus for this development.

There is a clear and compelling need to equip shipboard users and those ashore responsible for the safety of shipping, with modern, proven tools that are optimized for good decision making. For example:

3.3 Elements

- Aboard
  - Navigation systems integrated with ship sensors / supporting information;
  - Standard user interface;
  - Comprehensive system for managing alerts;
  - Mariner is actively engaged in navigation, without being distracted or overburdened.
- Ashore
  - Enhanced management of vessel traffic and services;
  - Provision, co-ordination and exchange of data in formats which can be easily understood;
- Communications:
  - Authorised, seamless transfer of information between ships, from ship to shore and between shore authorities;

- Reduction of single person error.

3.4 Expected benefits

In future the use of e-Navigation will help to improve the efficiency of fairway marking with AtoN by integrating the elements of information. Further on it will provide:

- Improved safety, through promotion of standards in safe navigation;
- Better protection of the marine environment;
- Potential for higher efficiency and reduced costs;
- Potential reduction in bureaucracy - e.g. standardised reporting requirements;
- Improved human resource management by enhancing the experience and status of the bridge team.

The development of designated waterways, within which an authority or a multilateral body supports maritime traffic in the interest of safety and environmental protection through the use of sensors, tracking, monitoring, communications and information exchange, related to electronic chart display systems will be enabled by e-Navigation elements. Such waterways have in some instances been referred to as Marine Electronic Highways (MEH), and a new collective title is under consideration. They should be developed, where appropriate, regarding amount of vessel traffic and risk.

3.5 Considerations

Whilst elements are available to some users, e-Navigation applications (e.g. display of AIS information on electronic charts, mandatory for SOLAS ships above 300 GT by 2018) in channel marking are currently limited by availability of equipment and training of personnel. In addition, there are issues relating to the presentation of information that need to be addressed.

Whenever mariners are in the port approach or confined water phases of a passage they will normally use a combination of visual AtoN, radar, ECDIS and other electronic means for navigation as available.

3.6 e-Navigation and AtoN

e-Navigation will in future integrate the information on visual AtoN for a fairway or a channel into the whole information available on the bridge of a ship and thus contribute to their optimized use. The efficiency of marking might increase and allow some optimization of the AtoN. However, this is subject to further development, because nowadays there are not so many ships with are equipped for the use of e-Navigation applications.

Continuous improvement of the marking principles and the available technology will help to save money and to protect the environment, e.g. by savings in energy consumption for operation and maintenance of AtoN.

A systematic approach to the design of AtoN for a channel or waterway will support the integration of the AtoN system into the e-Navigation concept.

4. Systematic design of AtoN

Steering a ship in a waterway is a process which is determined by different factors as

- Interaction between ship and fairway,
- Fairway width, bank clearance, fairway depth, bottom surface,
- Wind, waves, currents, tide,
- Ship manoeuvrability, speed,
- On-board-equipment,
- Capability of the navigator.

IMO A.915(22) and IMO A.953(23) show a variety of parameters. Not all of them may be applicable to all AtoN. However, the parameters reflect different properties which single AtoN or AtoN systems can have. Therefore it is useful to take the use of some of these parameters into account when defining the requirements for a specific channel or a type of waterway. The values of the requirements for the parameters will be different depending on the type of waterway and the users.

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability	Continuity	Coverage	Fix interval²
	Horizontal (metres)	Alert limit (metres)	Time to alarm² (seconds)	Integrity risk (per 3 hours)	% per 30 days	% over 3 hours		(seconds)
Ocean	10	25	10	10^{-5}	99.8	N/A1	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A1	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Notes: [1] Continuity is not relevant to ocean and coastal navigation.
² More stringent requirements may be necessary for ships operating above 30 knots.

Table 1: Minimum maritime user requirements for general navigation

4.1 Accuracy

Accuracy is a major factor for designing the AtoN for a fairway. The requirement for position accuracy of the vessel depends on the beam of the vessel, the draft of the vessel, the under keel clearance and the bathymetry of the fairway. In general the position accuracy should meet the required navigation accuracy. However, there will be a level where, depending on the properties of vessel and waterway, the navigation accuracy cannot be improved further by improving the position accuracy.

For the mariner it is relevant to know exactly the distance from the vessel to a certain point or line, like a critical hazard or the limitation of a fairway. The distance can be found as the difference between two absolute positions. Then it is determined by the absolute accuracies of both positions.

The distance can also be found directly, if there is a visual aid or a radar target or any other device showing directly the relevant point or line. This is described by the relative accuracy. Both types of accuracy can be relevant for practical navigation and for the ability of a ship to stay on track within a fairway/waterway with the available aids.

For both instances, the position of the AtoN is referenced to the nautical chart. The concept of absolute accuracy is in general more developed for the nautical chart and the GNSS. That is the case where nautical charts are surveyed to high accuracy and the ships position is available throughout the voyage and with high accuracy by the use of GNSS.

Most radionavigation systems provide a very good absolute accuracy for determination of the position based on a geodetic datum. Using the navigational chart the mariner can navigate safely along a waterway. The navigation accuracy is limited not only by the radionavigation itself, but also by the accuracy of the navigational chart and the navigational equipment and performance on the ship.

Short Range AtoN, including most of the visual aids, in many cases do’nt provide such a good absolute accuracy. However, they provide a good relative accuracy, provided that the aids are properly positioned, such that the mariner can use them directly to navigate safely along a waterway.

The position obtained by direct use of visual and radar aids without continuous tracking on the nautical chart or on a modern radar screen is restricted by the relative accuracy and will not remain constant along the track. The concept of accuracy is in this case the ability to keep the intended track and to locate the movement of the ship along this track. It is not easy to determine the effect of buoy spacing on the accuracy of navigation in a fairway and on risk mitigation.

4.2 Drift detection width: new method from Japan

A new method for determining the achievable accuracy of navigation in a channel by means of buoys, ship radar and (D)GPS has been developed in Japan. Details can be found in Ohtsu,K., Yoshimura,Y., Hirano,M., Tsugane,M.and Takahashi,H.(2006) and MLIT (2009).

It was presented in the PIANC WG 49 (marcom) on “Approach Channels – A Guide for Design”.

The method is plausible. Some aspects are not yet covered:

- Ships’ tracks which are not in the middle of the marked fairway
- Use of leading lines
- Effect of ships’ length on manoeuvring width

The method could be an interesting tool for including in risk assessment programs, but some more validation and some amendments might be required. The effect of buoy spacing on the standard deviation of the ships’ paths could be derived using this method.

The accuracy of navigation depends on detection of drift and reaction in order to come back to the accurate track. The manoeuvring lane includes the width for drift detection. Generally it will be bigger than the width for drift detection, particularly if considering the length of the ship.

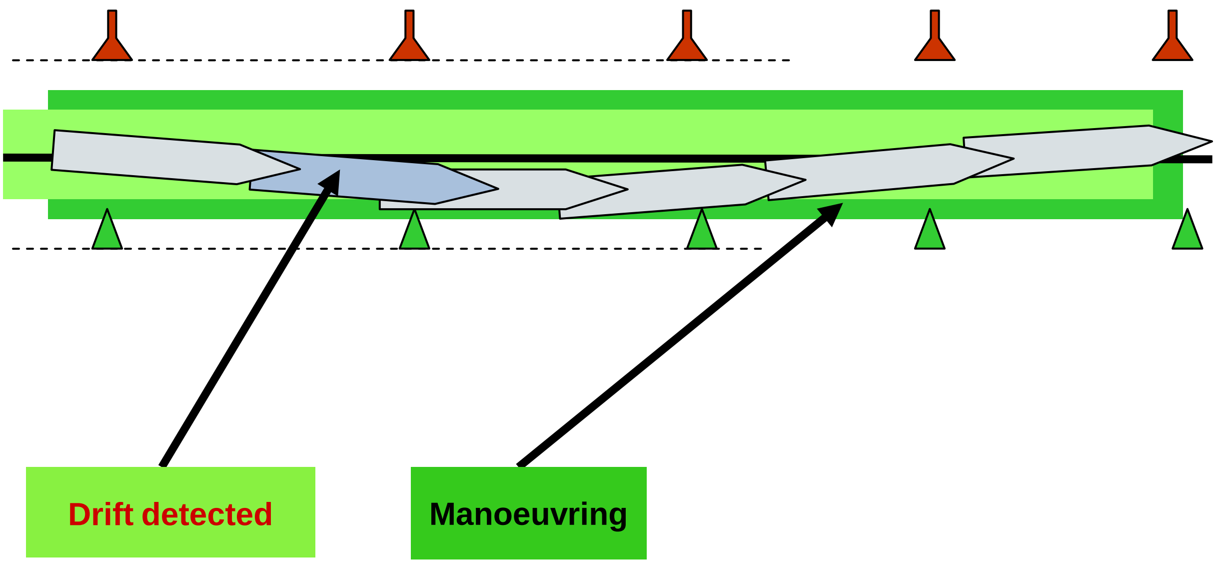


Figure 2: Drift detection and manoeuvring lane

This Japanese method is a contribution to the Section “Fairway Layout and Channel Width” for the report of PIANC MARCOM Working Group 49 “Horizontal and vertical dimensions of channels”.The method assumes that the channel width can generally be assumed to consist of the following fundamental elements.

Channel width can generally be assumed to consist of the following fundamental elements.

Width of fundamental manoeuvring lane:

$$W_{FM} = a(W_{WF} + W_{CF} + W_{YM} + W_{DD})$$

where

W_{WF}: width requisite against wind forces

W_{CF}: width requisite against current forces

W_{YM}: width requisite against yawing motion

W_{DD}: width requisite for drift detection.

a = 1 for one way channel
a = 2 for two way channel
a = 4 for four way channel

Additional width requisites against bank effect forces, against two-ship interaction forces in passing condition and against two-ship interaction forces in overtaking have to be considered.

A ship sailing in a channel usually makes some amount of drift from its course line due to various causes together with external forces even if a ship handler does believe that his ship is running on the right way. Drift detection may be impossible when the drifting amount is small, but a ship handler can recognize a drift when a ship makes some considerable amount of lateral deviation from its course line.

The drifting quantity to be detected plays an important role in the design of channel width. A narrower width may generally be adopted for a channel with a higher level of equipment and systems where the drift detection can be made more easily.

The Japanese document describes the impact of three types of AtoN systems, corresponding with on-board equipment, on the width for drift detection.

- observing light buoys ahead on both sides of channel with the naked eye
- observing buoys ahead on both sides of channel with radar
- GPS or D-GPS

For the drift detection by observing light buoys ahead on both sides of the channel either with the naked eye or with radar, the channel width needed for the drift detection may be estimated on the basis of an angle made by two lines from a ship to two buoys ahead on both sides shown in Fig. 3:

$$\theta = 2\arctan\left(\frac{W_{buoy}}{2L_F}\right)$$

W_{buoy}: clearance between two buoys
L_F: distance for the drift detection between the ship and the buoys ahead along channel centre line

As shown in Figure 3, an angle made by two lines of the channel centre line and a line from a ship to a midpoint of two buoys is denoted as α .

A concept of the maximum deviation is introduced which is defined that almost all ship handlers are able to recognize a drift from its course line. Corresponding to this maximum deviation, the angle of α is denoted with $\alpha_{\max}$ as shown in Figure 3.

Making use of the above concept of $\alpha_{\max}$, the channel width needed for the drift detection by observing light buoys with the naked eye can be calculated by

$$W_{DD}(NEY) = 2\ LF\ tan\ (\alpha_{\max})$$

$\alpha_{\max}$ may practically be estimated with an empirical formula developed on the basis of statistical data by full scale experiments, which is given by

$$\alpha_{\max} = 0{,}00176\ \theta^2 + 0{,}0008\ \theta + 2{,}21372$$

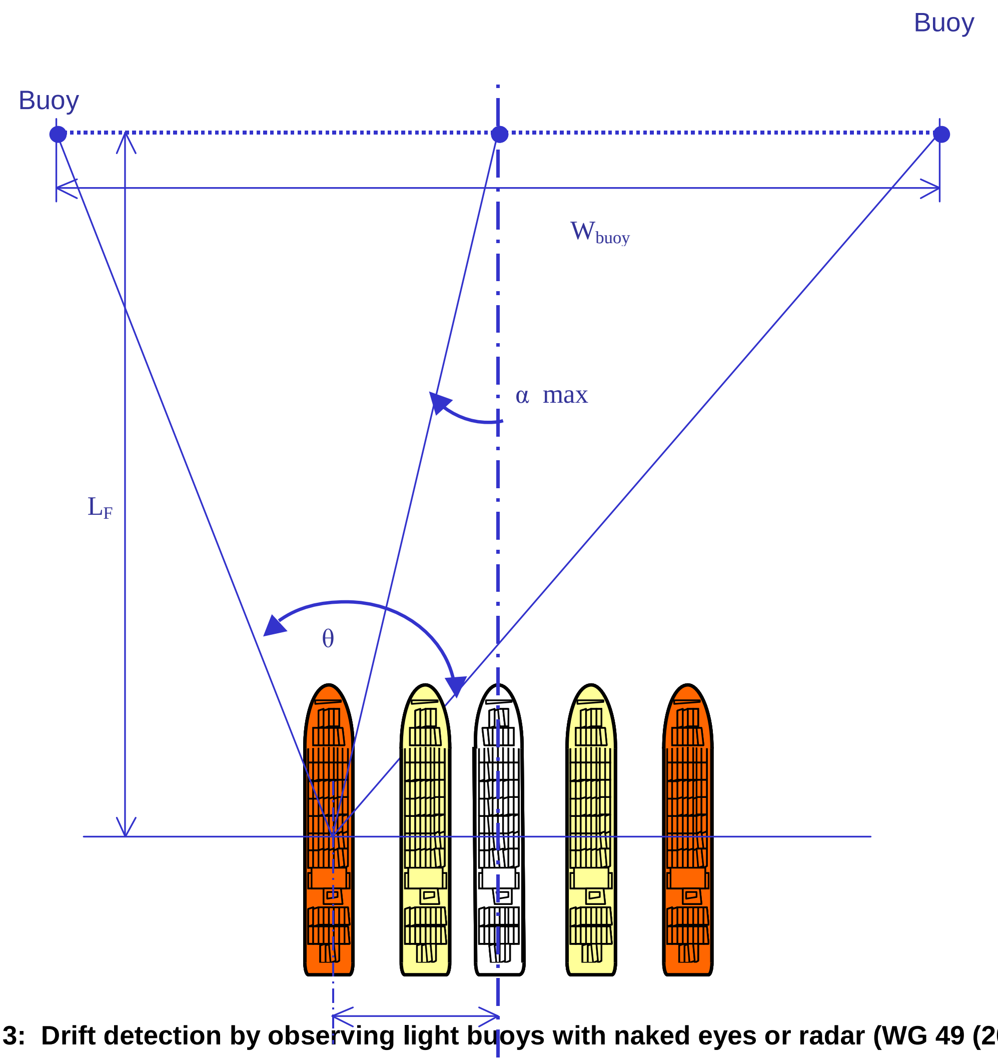


Figure 3: Drift detection by observing light buoys with naked eyes or radar (WG 49 (2010)

The channel width needed for the drift detection by observing light buoys with radar can be calculated by

$$W_{DD}(RAD) = 0{,}0698\frac{W_{buoy}}{\sin\theta}$$ (for 2 degrees observation error of direction by Radar)

$$W_{DD}(RAD) = 0{,}0349\frac{W_{buoy}}{\sin\theta}$$ (for 1 degree observation error of direction by Radar)

For Drift Detection by GPS the Japanese method provides the following equations are proposed

$$W_{DD}(GPS) = B + 60$$ (unit: meter)

$$W_{DD}(D-GPS) = B$$ (unit: meter)

4.3 Proposal for Validation of manoeuvring lane and drift detection models

The “basic manoeuvring lane” according to PIANC (1997) is 1,3 to 1,8 B, with B as the ships width.

As far as the width for drift detection (accuracy of positioning) is included in this basic manoeuvring lane, no additional width for drift detection will be required. If the concept and the value of the basic manoeuvring lane is under consideration and when considering at the same time a wider use of methods for determining width for drift detection some more efforts might be necessary for validation of both. One option could be to compare the theoretical drift – derived from theoretical methods – with historical AIS data in a given fairway. This was already proposed by IALA experts for validation of other theoretical models for fairway width.

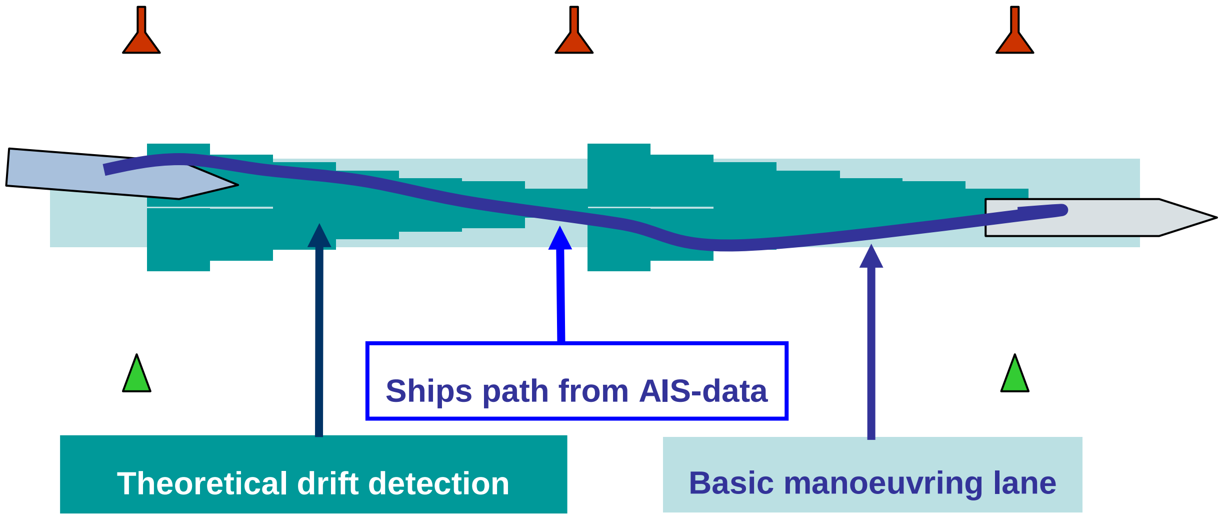


Figure 4: Theoretic manoeuvring lane and AIS track (qualitative example)

In this example the theoretical width pattern is taken qualitatively from a calculation with the Japanese method for different distances from ship to buoy. It can also be validated, if the ships path is – dependant on the distance from the middle line – strongly correlated with the width for drift detection. That distance of the middle line where this is not the case can be assumed as the Basic Manoeuvring Lane.

Additionally the following aspects have to be considered for validation:

- The drift detection width at a given point will determine the manoeuvring lane some ships lengths forward from this point, not at the same point (e.g. the ship would not drift so far from its course directly behind the pair of buoys).
- Use of (D)GPS as primary means for positioning by certain ships

4.4 Positioning Accuracy of the AtoN

The uncertainty of the position of an aid should be not bigger than the uncertainty in survey and charting. The requirements can be found in IHO (2008). In chapter 2 of this Standard, - 'Positioning' - 2.1 "Horizontal Uncertainty" is defined as 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 aids to navigation should be surveyed and positioned using the same accuracy as the nautical chart. The following table 2 gives an extract from Table 1 of the IHO Standards for Hydrographic Surveys (S-44) and shows minimum standards. However, these will not everywhere and always be achievable for floating aids.

Reference (1)	Order	Special	1a	1b	2
Chapter 1	Description of areas.	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but features of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Chapter 2 and note 5	Positioning of fixed aids to navigation and topography significant to navigation. (95% Confidence level)	2 metres	2 metres	2 metres	5 metres
Chapter 2 and note 5	Mean position of floating aids to navigation (95% Confidence level)	10 metres	10 metres	10 metres	20 metres

(1) In the document IHO Standards for Hydrographic Surveys, 5th Edition, February 2008, Special Publication No. 44

Table 2: Horizontal uncertainty, IHO

4.5 Perception of AtoN

To describe the navigational requirement for the visual perception of AtoN the useful range can be used as a parameter. This is the practical convenient range for a mariner to identify an AtoN. This range can be found using scientific knowledge about the light, the atmosphere and the human eye and using experience.

Generally there are different qualities of visual perception:

- The object is visible (Pure visibility). The aid can be seen but appears still too small to be recognized as a certain type of AtoN according to IALA buoyage system;
- When the daymark is visible and its shape and outline can be seen, but the colour remains unclear – object is partly recognizable;
- The object can be identified (identification): The aid can be identified, e. g. as a certain type of buoy of the IALA buoyage system. Usually this will be the quality of perception which is needed for a practical use of the AtoN for the navigator. Therefore this quality will determine the useful range.

In some cases the conspicuity of an object is relevant or limited in its visibility and particularly for its identification and use by the navigator. An object is conspicuous if it appears outstanding in a complex visual scene.

In every case it is necessary that the visual information, provided by the AtoN, is confirmed (Confirmation, Verification). This process can take time and could thus be a limiting factor, if the visual information emitted from the aid is influenced or interrupted by intermittent influences like movement of a floating aid by waves.

However, this process can also provide a level of redundancy, which means an increase in the safety of the use of the aid. The AtoN sends out its information in different ways (light, shape, colours, marking by letters and numbers, other means). As long as the information from one aid, received by different means, is conflicting, there is no confirmation of the information from the aid.

The parameter to define the user requirement for a light is the luminous range. This is the distance from which – under defined conditions - the user can identify the light.

The identification and confirmation of a light includes also its colour and character.

The parameter to describe the light itself is the intensity, the colour and the distribution of the light. The IALA-Recommendations of the E-200 series provide methods on how to calculate the luminous range which can be obtained when observing a light with a given intensity.

The distance at which a daymark can be identified depends on:

- Size
- Shape
- Colours (one or more on one aid)
- Geographical range

A simple rule for the estimation of the distance in which a daymark of a simple shape can be identified, provided the contrast to the background is sufficient, is as follows:

The object can be normally identified when it appears at the eye of the user under an angle of more than 3' (three minutes). This means that the arctan of the quotient 'main dimension of the object / distance of the object' must be more than 3'.

The contrast to the background and the identification of the colours depends on the chromaticity of the paint of the AtoN, the specific meteorological visibility in the area; colour and illumination of the background and conspicuity.

Perception can be ensured in situations with bad visibility by ship borne radar and by means of additional electronic devices on AtoN like e.g. AIS as an AtoN.

5. Some general and generic rules

The sections between the bends and junctions of a fairway should be divided into the same distances between buoys. In general, the useful range (identification) of buoys at daytime and night time should be greater than the distance between the buoys. Their appearance on the on-board-radar screen should also be considered. The most-used range on ship borne radar is 3 nautical miles in fairways and channels. So, the buoy to buoy distance of continuous buoyage should not exceed 3 nautical miles.

Simulation tests for lighted buoys in narrow waters with 150 m to 600 m width have shown buoy separation distances of 1 - 1.5 nautical miles as the best for navigation. The distances between unlighted buoys are based on their size and daytime visibility.

In general, the buoys or beacons of one fairway section should have the same distance from the axis (centre) of the channel. Generally the buoys marking a fairway shall be established as pairs ("gates"), especially if high navigation accuracy or a very clearly distinct channel with continuous buoyage is required.

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

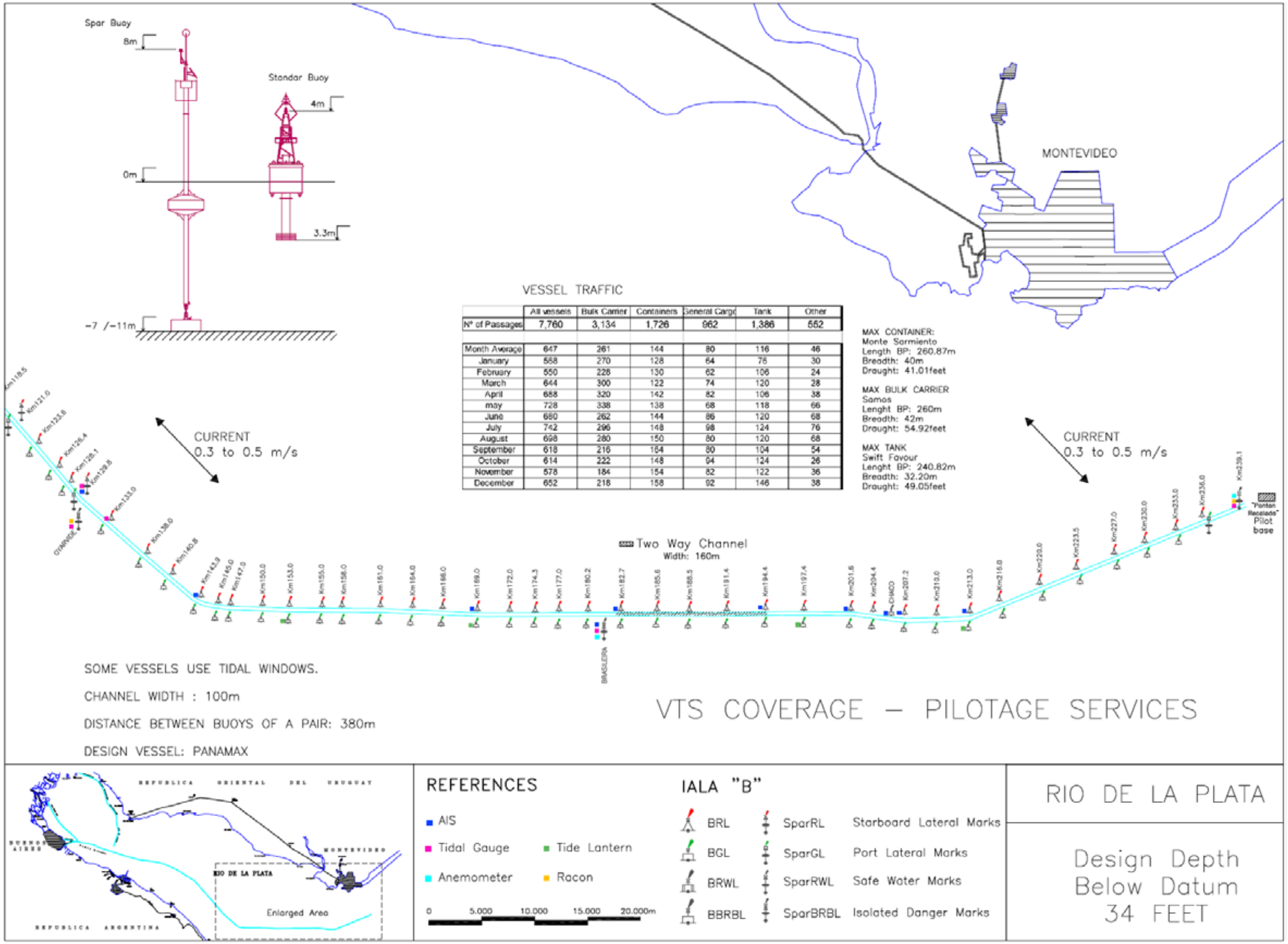
1. Establish a conspicuous buoy or pair of buoys for the point where the fairway starts;
2. Place buoys on points.
   a. where ships have to alter their course; or
   b. where the fairway boundary line or the middle line has a bend or curve; or
   c. where critical shallows and rocks or other hazards form the boundary of the fairway or channel; and
   d. at fairway / channel intersections.
3. Distribute buoys between these points with regard to the distance, at which they can be detected and identified

The buoy separation distance should be chosen in such way, that the next one or two buoys are recognized approximately 100 m or more before the nearest one has been passed, or, in other cases approximately 100 m before the last buoy can no longer be detected and identified. So, the buoy separation distance D can have different relations to the distance L, at which the marks can be detected and identified.

$D < L / 2$, if high navigation accuracy or a very clear and continuous buoyage is required

$D < L$, "normal" for fairways

$D < 2$ L for some purposes in the open sea, e. g. for a Ship Routeing System



	All vessels	Bulk Carrier	Containers	General Cargo	Tank	Other
N° of Passages	7,760	3,134	1,726	962	1,386	552
Month Average	647	261	144	80	116	46
January	568	270	128	64	76	30
February	550	228	130	62	106	24
March	644	300	122	74	120	28
April	688	320	142	82	106	38
may	728	338	138	68	118	66
June	680	262	144	86	120	68
July	742	296	148	98	124	76
August	698	280	150	80	120	68
September	618	216	164	80	104	54
October	614	222	148	94	124	26
November	578	184	154	82	122	36
December	652	218	158	92	146	38

Figure 5: AtoN design on the Rio de la Plata

6. AtoN design for the Rio de La Plata Navigation Channel

As an example the Rio de La Plata Navigation Channel is shown here.

The Rio de La Plata Navigation Channel is a partly straight and partly curved channel with buoys from a position of 129.1 miles seawards of the harbour entrance of Buenos Aires.

More data can be seen on the following chart.

Some basic data:

Waterway in analysis	
Length:	63.8 M
Width:	100 m (one way channel) (there is a two way channel sector of 160 m)
Design Depth:	34 feet
Tidal range	0,60 m

The Vessel Traffic

Total Traffic in the Area in 2006:	7.760 vessels
including	
Containerships:	1.726
Bulk Carriers:	3.134
General cargo:	962
Oil Tanker:	1.386
Other:	552

Vessels Dimensions. Maximum size of:

	Length BP	Beam	Design Draught
Containership	261 m	40 m	41 feet
Bulkcarrier	260 m	42 m	42 feet
Tanker	241 m	32,2 m	49 feet

Aids to Navigation

The buoyage system is designed as “paired buoys” with the following parameters:

Buoy separation distance average 3000 m (max 5.000 m, min 1.100 m)

Buoy types: Floating buoys and Spar Buoys

Size above water level Floating Buoy 4 m, Spar Buoys: 8 m

Additionally there are the following AtoN:

DGPS coverage (on demand- private service), VTS and AIS control by Prefectura Naval Argentina (National Coast Guard) and Mandatory Pilotage services

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