Optimization of the maritime signaling in the Venetian Lagoon

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***Abstract*—Aids to Navigation (AtoN) are supporting devices to nautical operations. They include both electronic and traditional signaling systems (e.g. buoys and lights), for which international organizations together with local authorities define operative and technical standards. Work still being finalized in the Venetian Lagoon made it necessary an assessment of the existing signals, with the aim of optimizing their position to guarantee the maximum level of safety in the waterways.**

This paper presents the procedures followed to reach a solution in line with the safety and efficiency standards given for the AtoN systems in terms of position and luminous characteristics. Moreover, to ensure the continuity of port operations even in poor visibility conditions, an alternative aid system has been studied and formalized for the first time in Italy. It is based on electronic and identification devices which show Virtual AtoN, AtoN that are not physically at sea.

Keywords*—*AIS, AtoN, Visibility

I. Introduction

The International Maritime Organization (IMO) gives standards on security, safety and environmental performance of shipping, encouraging innovation and efficiency. IMO works, among the others, with the International Association of Lighthouse Authorities (IALA), a nonprofit technical organization which aims to harmonize Aids to Navigation (AtoN) worldwide considering the needs of mariners and authorities and the technological developments. To assure the maximum level of safety and efficiency of maritime navigation, IALA publishes recommendations and guidelines on the use of auxiliary devices that improve maritime operations, such as Vessel Traffic Services (VTS), Automatic Identification System (AIS) and marine AtoN signal lights.

The Maritime Buoyage System (MBS), as published in the IALA Recommendation R1001, aims to harmonize AtoN in terms of shape, color and destination [1]. Standards are also given for their light, as it is the only AtoN identifier at night. This classification provides seven categories of Marks: Lateral, Cardinal, Isolated Danger, Safe Water, Special, Emergency Wreck and Others.

The development of ports and fairways, together with the recent improvements of technologies and the increasing demands on navigation services make worldwide a dynamic optimization of AtoN systems necessary. The reasonability of the AtoN placement will directly influence the marine traffic safety, so consideration should be given either to the Collision Regulations (COLREG) and local traffic rules. The basis to achieve the goal is knowing the weaknesses and problems of the existing system.

In this regard, J. Chen et al. proposed the Success Degree-Fuzzy comprehensive evaluation method to post evaluate the existing AtoN system to clarify the needs and to point out its optimization. This model works with a series of index, derived in accordance with the AtoN system characteristics and elaborated on the basis of users' consideration to guarantee its accuracy. The final algorithm allows the valuation of the system's overall score in a rank from 0 to 100 [2].

The analysis carried out by our team arises from the immediate need of the Venetian institutions and local seafarers to redesign the AtoN system to assure the highest level of safety in the Lagoon. In fact, the installation of the Experimental Electromechanical Module (MOSE or MOdulo Sperimentale Elettromeccanico) at the inlets of the Lagoon led to a series of changes in the navigating area (such as the new artificial island at Lido), with remarkable effects on local traffic.

We followed a heuristic method which combined IALA, IMO and local normative with the practical need of the users to reach the optimal AtoN disposition. One of the key points of the tuning process has been the iterative and constant update of the system, based on the visibility parameters optimization.

Afterwards, the effective visibility of the signals has been verified using the theoretical considerations given by the IALA Recommendations E-200-2 [3]. While the optimal AtoN system complies with the safety requirements, the data resulting from the analysis show that the signals' light cannot always assure their visibility.

For this reason, an alternative AtoN system has been developed using the AIS to virtualize the AtoN with a coded message containing the required information. Therefore, the AtoN does not have to be physically located at sea, as it will be shown on appropriate electronic system, usually Electronic Chart Display and Information System (ECDIS). This method was first tested in Italy in the Venetian Lagoon to give planning information to the crew on-board. Following the ships routes in the Lagoon, Virtual AtoN were positioned on the points in which the ship changes course or Waypoints (WP). This information on the route is digitized, so it can be modified and sent according to the needs, thus making this type of AtoN a considerable support to the navigation.

This paper illustrates the study on the optimal AtoN system's effective visibility based on IALA guidelines, then concludes with the analysis carried out to position the Virtual AtoN.

II. MARINE REAL ATON

The Maritime Buoyage System provides a single distinction for lateral signals depending on the country's membership in the IALA A or IALA B system: the countries in Region A use red to indicate the left and green for the starboard while the countries of the region B do the opposite. Other signals are standardized for all IALA countries in terms of destination, shape, color and luminous characteristics. For example, the Safe Water signal indicates an area where navigation is safe. This AtoN has white and red vertical stripes, a red spherical mirage (in case of minor buoys) and a 12-seconds-period white light with a single 10-seconds flash.

One of the most important characteristics of the light signal is its range, indicating the maximum distance at which the light is perceived. In the field of navigation, the luminous range *D* in nautical miles is used; it is defined as the maximum distance to which the detection of the light beam is guaranteed (not the light source, still hidden due to the terrestrial curvature), and also considers the meteorological visibility *v* and the illuminance required at the observer's eye or threshold, E_T. To identify the illuminance it is necessary to introduce some photometric quantities.

From a quantum point of view, the light is characterized by a power W in Watt that is function of its own wavelength λ: the product of the power for the function visibility factor V, which expresses the actual perception of light to the human eye, gives the luminous flux Φ as in (1):

$$\Phi = V(\lambda) * W(\lambda). \quad (1)$$

The luminous intensity I is the quantity of flux measured in a certain direction and is calculated as the ratio between the luminous flux Φ and the solid angle ω of emission (2). It is measured in candles:

$$I = d\Phi / d\omega. \quad (2)$$

The illuminance E is the ratio between the luminous flux Φ and the area of the surface A on which it impacts (3). It is measured in lumens on squared meters or lux:

$$E = d\Phi / dA. \quad (3)$$

This illuminance E can be expressed as a function of meteorological visibility v and the distance to the observer d through Allard's law as at (4):

$$E(d) = I * 0.05^{d/v} / 3.43 * 10^6 * d^2. \quad (4)$$

From (5) it is possible to estimate the luminous range of a signal D, which can also be obtained with the diagrams given by the IALA (Figure 1) [3] [4] [5]:

$$I = 3.43 * 10^6 * E_T * D^2 * 0.05^{d/v}. \quad (5)$$

Considering both IALA and local regulations together with seafarers needs, we proposed a maritime signaling system that combines structural efficiency with the highest level of navigational safety for the Venetian Lagoon.

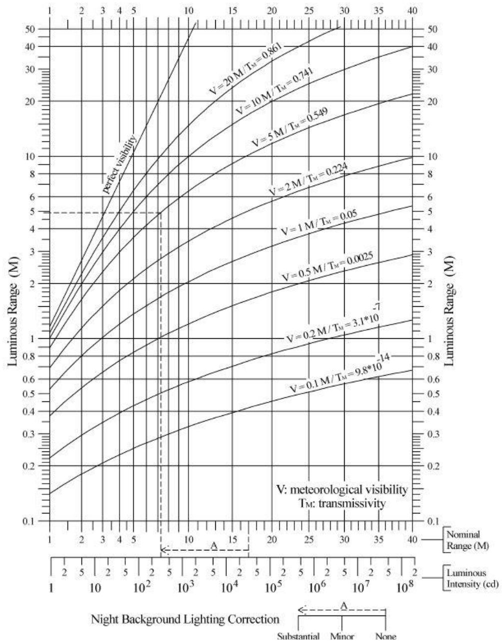

Fig. 1. Luminous and nominal range at night.

To reach this solution, an accurate survey of the actual AtoN disposition was carried out to check the correspondence between the functional AtoN at sea and those reported by the official cartography. This allowed the compilation of an updated database containing all the existing signals with their position and characteristics, according to the IALA standards.

Ji-Min Yeo et al. studied the implementation of an AtoN database including the integrated system design, to develop an AtoN simulator system [6]. In the same way, we set an elementary simulation process using Google Earth as supporting tool. Among other features, this software allowed the overlap of the Lagoon official bathymetric and cartographic data to the satellite images. We could then import all the AtoN from our database with their precise position and characteristics to get an overall view on the area, thus allowing a more intuitive detection of the current issues and the consequent optimization of the entire AtoN system.

We started with the theoretical analysis of the area searching for the best solution in line with IALA standards, considering the morphology of the canals as well. Having presented this plan to the Authorities, we integrated the actual needs of the seamen together with those of the involved institutions, trying to reach a trade-off between benefits and costs of an optimal AtoN system.

Some areas needed particular attention. The main examples are the inlets of the Lagoon, where the presence of the MOSE had to be signaled. As previously mentioned, in the specific case of the Port of Lido an artificial island supports the gates, thus requiring a functional AtoN placement to prevent hazardous conditions. We proposed the installation of yellow flashing lights on the Port entrance lighthouses, to be activated simultaneously to the raising MOSE's gates. For the island, four yellow structures could be positioned on its corners; their lights will be red and green for the starboard and the port side respectively of the island (correctly showing the starboard side of the main fairway and port side of the secondary one) and will turn in a yellow flashing light when the MOSE's gates are raised, alerting both the units entering and exiting the Lagoon. Since lateral AtoN should be placed in pairs to better indicate the fairway, we assured to the AtoN on the island the correspondent one alongside the canal to identify the main and the secondary canals (Figure 2).

We also proposed some facultative improvements, like a Preferred Channel signal located before the artificial island to distinguish the main channel on the port side (St. Nicolò Canal) from the secondary one on the starboard side (Treporti Canal). The same has been proposed for the Malamocco's area where the main fairway turns on the right of the St. Leonardo canal. These buoys are modified Lateral signals: in the first case it will be a horizontally striped green-red-green buoy with a green flashing light while in the second case the stripes will be red-green-red with a red flashing light.

Considering the necessary and the recommended proposals, we used SketchUp to create 3D model of each AtoN which were then imported on Google Earth, to more accurately simulate the expected situation in the Lagoon (Figure 2).

Once the optimal solution has been reached, a purely theoretical analysis has been carried out to verify if the range of the proposed AtoN (in accordance to those already present) was effective even in poor visibility conditions. The mean distance between each AtoN d and their nominal range D_N were known, so we could calculate the intensity produced by each signal (5) using the illumination values required by the IALA [3]:

- $E_T = 2 * 10^{-7}$ lx at night;
- $E_T = 1 * 10^{-3}$ lx in the daytime hours (to overpower sunlight).

We used the standard visibility of 10 nautical miles, as it is related to the nominal range. With the obtained intensity values, we therefore calculated the actual illuminance produced by each AtoN (4) in three different visibility conditions obtained from the visibilimeters placed in the Malamocco Canal: perfect, medium and poor visibility. We could then check the effective AtoN visibility as at (6):

$$E_d > E_T. \qquad (6)$$

As we expected, results show the efficacy of the proposed AtoN signaling in all the situations except for those of extremely poor visibility, thus making the system not sufficient to guarantee the maximum levels of safety in these occasions.

Fig. 2. View of the artificial island (Port of Lido). SketchUp models simulate the expected situation.

An innovative tool to complement the existing AtoN system, which can therefore solve the problem of the ban on navigation in the Lagoon in case of thick fog, should be introduced.

III. Marine AIS AtoN

The automatic identification system (AIS) is a VHF-FM communication tool that allows the automatic broadcast exchange of information in real time between all the units and the monitoring stations on which it is installed: it can be considered as a transponder and it is usually integrated to other onboard systems, in particular ECDIS and radar. Since 2000, the Maritime Security Committee (MSC) protocol made the AIS mandatory for ships over 300 gross tons and for passengers ships regardless of size; it can also be mounted on all other ships [7].

The peculiarity of this system lies in the fact that the information is automatically and continuously transmitted without any intervention by the staff. The technical characteristics of the messages are defined by the International Telecommunication Union (ITU) together with their frequencies.

The AIS is multifunctional: it can be used for traffic management and it is an excellent means of recognition for ground stations, giving a detailed and real-time scheme of all the units in the port or in the landing phase. Unlike radar, the AIS can identify even the smallest unit that has the system mounted on board [8]. However, radar remains the preferred anti-collision system as the AIS is GPS-dependent.

AIS messages are sent at relatively short distances within the VHF coverage; most of these occupy a time slot, but some can use up to a maximum of five consecutive slots. In this case, considering a significant number of units in the operating area, the risk of not decoding the message by the more external ones is higher; the information sent via the VHF Data Link (VDL) connection is then monitored, in order to avoid possible situations of messages overload and to ensure efficient communication [9].

Standard messages, in accordance with ITU-R M 1371, contain basic information and each one has an exact identifier for a total of twenty-seven IDs; the Maritime Mobile Service Identity (MMSI) numerical code helps to recognize the message-emitting unit [10, 11,12].

A. AIS AtoN

The AIS can be mounted on AtoN as well, in order to increase their visibility. In this way, the AtoN can transmit the details of its position (in a very accurate way if obtained by differential method), identity and nature of the signal, system integrity as well as information messages, including for example weather and tide conditions of the area. For this reason, ITU recognizes its potential [13].

The cost of the used technology, however, makes it not advisable to equip each AtoN with an AIS system; on the other hand, it is possible to send the message from an AIS unit not positioned on the AtoN. In this regard, the concepts of synthetic and virtual AtoN have been introduced.

B. AIS Virtual AtoN

A synthetic AIS AtoN is physically present but not equipped with a transmitter: the AIS message containing the technical specifications and the position of the AtoN is then sent from an AIS station (depending on its range).

A virtual AIS AtoN, on the other hand, is not physically present at sea: its coordinates and other data are solely provided by its AIS message. This constitutes a huge advantage as it increases the flexibility of use in relation to the efficiency of the guaranteed service [14].

The use of virtual AtoN is strongly recommended for areas subject to frequent different nature variations and critical issues, or where the positioning of real AtoN is complex or dangerous. In particular, Virtual AtoN can send information regarding new situations of danger, temporarily recommended routes, changes in the structure of the channels, specifications on port operations, measures to protect marine environment, areas of poor visibility, weather conditions and marine details, emergency situations or accidents: in general, any warning concerning safety.

The resulting advantages are therefore numerous, starting from their versatility. The accuracy of the positioning, independent from the canals' morphology, is ensured by the on-screen display and does not require high installation and maintenance costs. Moreover, the notification is instantaneous, easy and unambiguous to interpret and, above all, limited to the area of interest to avoid overloading the system with unnecessary information [15].

As any electronic tool, however, the use of Virtual AIS AtoN involves limitations and risks that should be highlighted: firstly, as already anticipated, their dependence on the Global Navigation Satellite System (GNSS), which in general makes the AIS vulnerable to any problems related to satellite transmission. For this reason, it is generally recommended not to rely on a single information source, but to provide other means, including non-electronic ones, which can ensure a valid support in any situation of malfunctioning of the previous ones [15].

Another risk can derive from misinformation: the ship officer could not be aware of the presence of Virtual AtoN. He could then ignore its message and consequently not identify the AtoN: for this reason, it is recommended a thoughtful and essential use of Virtual AtoN. For example, a channel already defined on the screens does not need to be also delimited by virtual signaling, which would give unnecessary redundant information [14].

Consequently, we decided to use Virtual AIS AtoN to define the points of a broken line that constitutes the safe route for ships entering the lagoon even in conditions of poor visibility, thus allowing the execution of port operations.

The first approach to the Virtual AIS AtoN provision started assuming that ships navigate in the deepest part of the canals: we traced these safe routes based on the official bathymetric data imported on QGIS software and at each intersection point or Waypoint (WP) we placed a Virtual AtoN. We could not use the "Route Information" Application Specific Messages (ASM) due to complications connected to the number of WP that each AIS Station can send [16].

Fig. 3. Statistical positioning of Virtual AIS AtoN (view of the Giudecca's area of Venice).

Annex I of the IALA Guideline 1081 expressly recommends the use of Safe Water signals as temporary Virtual AIS AtoN to increase safety in areas where navigation is obstructed by fog, heavy rain and in general subjected to reduced visibility conditions [14].

Following this directive, we defined a first set of measures with the objective of verifying the maneuvers safety requirements of a large ship approaching the Venetian Lagoon, in relation to its characteristics and theoretical principles of maneuverability. This led, however, to the definition of a Virtual AtoN system which, although respecting the safety standards, was based on theoretical conditions and for that particular ship. Therefore, in order to standardize the message, we decided to carry out a statistical study of the AIS tracks recorded by the Venice Coast Guard stations. By importing the dataset in QGIS, we were able to trace the most statistically followed routes of ships navigating in the Lagoon independently from their size: in correspondence of every course change, we identified a WP and then positioned a Safe Water V-AtoN (Figure 3).

The geographic coordinates of those points have been sent to the competent Authority which will create the AIS Messages using the MMSI AIS AtoN specific code, $9_1 9_2 M_3 I_4 D_5 X_6 X_7 X_8 X_9$. The first two digits are 99 then it follows the Maritime Identification Digit (MID) indicating the Country the AtoN belongs to; the sixth digit is equal to 6 for virtual AtoN (1 for real and synthetic AtoN) and the last three can vary from 0 to 9.

In this way, the ship that needs support during navigation will receive, only in case of poor visibility, the WP which will be displayed on the on board ECDIS, defining the recommended route through consecutive Safe Water Virtual AtoN (Figures 4 and 5).

IV. CONCLUSION

The main topic of our research is to take fully advantage of systems such as AIS to maximize navigational safety levels, in step with technological evolution.

The need arises from the inability to use the classic navigational aids, due for example to conditions of poor visibility. This situation sometimes occurs in the Venetian Lagoon. Upon the local Port Authority request, we studied an optimal provision of the maritime signaling in the area in line with IALA normative and IMO requirements; then we checked its effective visibility. Results show that in case of restricted visibility even the optimal classical AtoN system results inadequate to guarantee the safety requirements needed to properly conduct port operations. A different solution was then necessary.

Studying the various IALA publications on the AIS, we deepened the concept of Virtual AIS AtoN, recognizing their potential and advantages. Based on the statistical study of the safe routes followed by ships in the Lagoon, we could define a set of maneuvering points, the waypoints, to be sent to the onboard AIS to support the navigation in case of poor visibility. Identified as Safe Water signals and displayed on the ECDIS, these Virtual AIS AtoN allows the ship officer to detect the recommended safe route, making navigation equally possible. To maximize the AIS AtoN system's effectiveness, its transmission should be protected, as it is the AIS major vulnerability. Consideration could also be given to the use of application specific messages to find a solution to the limitations on the number of AtoN to be sent.

In the meantime, the use of a Virtual AIS AtoN system thus defined represent a valid support to navigation, being the only safe alternative to closing ports in case of restricted visibility conditions.

Fig. 4. Virtual AtoN in the Ports of Lido and Malamocco.

Fig. 5. Virtual AtoN in the Port of Chioggia.

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