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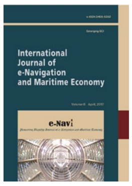

Original article

Study on Customized Digital AtoN Service

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Abstract

With the development of maritime ICT, the introduction of e-navigation and the MASS (maritime autonomous surface ship), the types and scope of maritime communication networks are expanding, and the need for digital AtoN services is increasing. However, due to problems such as the aging of fishing crews, coastal backlight, weather conditions, and inexperience with regard to the use of advanced navigation equipment on board, the visual and electronic perception of AtoN is degraded, and it is difficult to ensure safe ship navigation. In this study, in response to the introduction of the MASS, a plan for the development of an active customized virtual digital AtoN service system in consideration of ship operating conditions and geographic conditions is proposed. The proposed service system may facilitate electronic identification of AtoN and contribute to preventing marine accidents by ensuring the safe navigation of ships.

Keywords: e-Navigation, MASS (Maritime Autonomous Surface Ship), Customized Virtual Digital AtoN Service

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1. Introduction

Aids to Navigation assists the vessels in preventing the marine accident as well as maintaining safe navigation by means of light, shape and color while color beacon assists by means of light, shape, color, sound and radio signal. However, the factors such as backlight from developed port hinterland, restricted visibility due to weather condition, crew's aging and poor handling of sailing equipment reduce the visibility to recognize the Aids to Navigation, making difficult to assist the safe sailing. In fact, more than 77% of marine accident over past 5 years was attributable to poor recognition of surrounding environment and vessel location.

Table 1: Cause of marine accident

Year	Negligence	Defect	Others
2016	264	38	28
2017	261	47	43
2018	189	46	28
2019	204	32	21
2020	230	28	12
Total	1,148	191	143

IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities) in a bid to cope with the problems such as limited visibility of Aids to Navigation, recommends installing AIS to Aids to Navigation, thereby providing directly the vessels sailing in the vicinity with location information and the current status of Aids to Navigation. Accordingly in Korea(Website of Korean Maritime Safety Tribunal. Retrieved), location of Aids to Navigation and safety information including weather and current collected from marine meteorological signal mark and current signal mark, using AIS (AtoN AIS) at the waters where marine accident would possibly occur due to heavy traffic or weather condition is provided in real time through VHF radio network for safe navigation. Operation of AIS AtoN is the virtual AtoN for the area where AtoN cannot be installed but the information limited only to the simple location of AtoN or weather data is provided without considering geographic environment or vessels sailing in the vicinity.

Virtual Aids to Navigation can be used to indicate the location of beacon or buoy as well as the means to supplement for sage navigation and particularly, it's very useful in indicating the important temporal situation or the territory where navigation condition is changeable.

Such virtual Aids to Navigation has such advantages as timely notice, easy and quick deployment, easy modification or change, low installation and maintenance cost and replacement of physical Aids to Navigation when physical Aids to Navigation cannot be installed.

In line with development of ICT (Information and Communication Technologies) such as expansion of the kind and range of marine communication network, demand for digital information is increasingly growing, following the introduction of e-Navigation and Maritime Autonomous Surface Ship, but at the current stage of traditional Aids to Navigation and virtual AtoN in operation, the role of linking to MASS is limited. To cope with such challenge, the study on digital Aids to Navigation which will play the role of user-centered lateral mark, azimuth mark, safe zone mark and hazards mark is necessary.

This paper is intended to carry out the study on customized digital AtoN service to solve reduced visibility of Aids to Navigation as well as to be prepared for e-Navigation and Maritime Autonomous Surface Ship, and it also describes about the status of Aids to Navigation and the definition of customized digital AtoN service and configuration of functional system.

2. Virtual AtoN service

International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), in a bid to deal with the problems such as restricted visibility caused by natural factors or port hinterland, recommends installing AIS to Aids to Navigation, thereby providing directly the vessels sailing in the vicinity with location information and current status of Aids to Navigation, using the specific message (MSG #21) And information obtained from weather and marine sensor installed in addition to Aids to Navigation is provided to the vessels through #6 and #8 message rule.

Aids to Navigation is classified into actual, mixed, and virtual AIS AtoN by IALA, depending on methodology (IALA R-0143, 2021).

Table 2 shows the classification of AIS AtoN by IALA

Table 2: Type of AIS AtoN

Type	Remark
Real AIS AtoN	AIS physically located on the AtoN
Synthetic AIS AtoN(Monitored)	AtoN physically exists without AIS unit, but the location and status of the AtoN confirmed by AtoN
Synthetic AIS AtoN(Predicted)	AtoN phtsically exists without AIS unit, the location and status of the AtoN does not confirm by AtoN
Virtual AIS AtoN	AtoN does not physically exist, but msg 21 is transmitted by other station.

Virtual AtoN doesn't physically exist, but it transmits the information on virtual location to indicate the Aids to Navigation, providing the vessels with the information on safe route, cautious and dangerous zone. It's used in case of freezing, when the marker is not physically installable, sunken vessel or hazards exists, or at turning point or port entrance.

It's necessary to provide safe navigation information based on real-time data for safe sailing and to respond to MASS and self-extinguishable information to assist the safe navigation. Thus, the study on customized digital AtoN service which will support user-centered sailing is required in consideration of sailing condition, real-time climate and geographical environment.

3. Customized digital AtoN service

The information used for customized digital AtoN service uses static information of the navigation vessels, surrounding geographical environment and navigation information of the vessels in the vicinity, Particularly, leading light or directional light which indicates the sea route at narrow channel or port entrance is often undistinguishable due to limited visibility or location of vessel. Furthermore, collision between the vessels or stranding may occur due to guard negligence. Customized digital AtoN service assists in displaying the information temporarily on monitor depending on vessel direction, status, and varying positioning.

Configuration of customized digital AtoN service is as follows. The server identifies virtual route boundary after analysing the marine condition and electronic navigation chart based on digital map and real-time AIS data, thereby generating the optimal navigation information.

Navigation data generated by the server is displayed on terminal to help the vessel navigate the route safely.

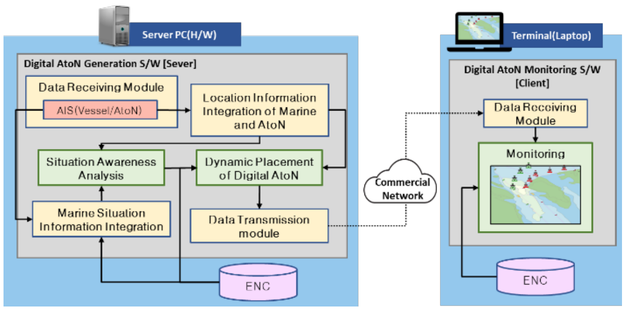

Figure 1: System structure of customized digital AtoN

Configuration of customized digital AtoN service is as follows. The server identifies virtual route boundary after analysing the marine condition and electronic navigation chart based on digital map and real-time AIS data, thereby generating the optimal navigation information.

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The service includes.

First, lateral mark service within the navigable waters. Physical Aids to Navigation is insufficient to distinguish the boundary at both sides and virtual lateral mark helps recognize the boundary more intuitively. Temporary service in case of repair of aids to navigation is also possible.

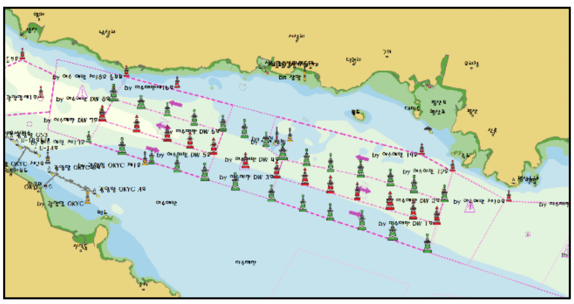

Figure 2: Example of digital aids to navigation 1

Second, variable and navigable water service. It provides the flexible route when the vessel size is considered within variable and navigable waters and when ship accident occurred, or navigation condition was changed temporarily due to inclement weather.

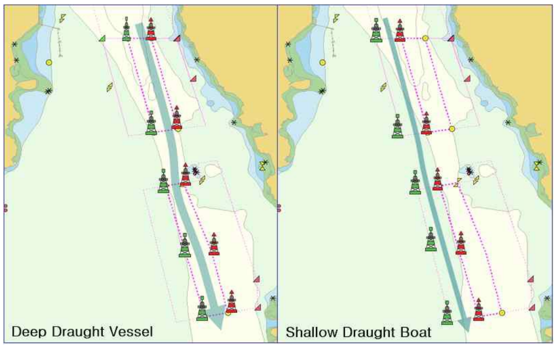

Figure 3: Example of digital aids to navigation 2

Lastly, dangerous zone guidance service. It may provide guidance at the route where many crossing occurs, accident occurs frequently, gun-firing or leisure facility is built.

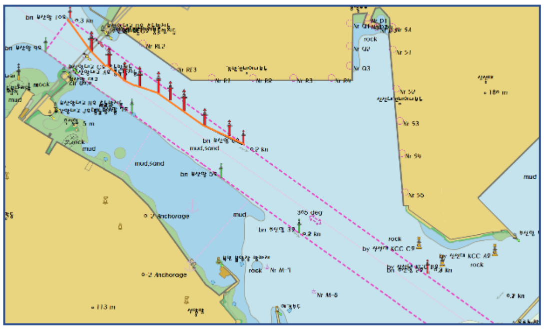

Figure 4: Example of digital aids to navigation 3

Customized digital AtoN service will improve the typical function of aids to navigation or provide the warning and bypass for safe sailing.

Table 3: Study related to collision avoidance

Category	Information
Research related to Situational awareness	- Martineau E. & Roy J.(2011) - Brax C.(2011) - Riveiro M(2018) et al
Research related to collision risk analysis	- Last P.(2014) et al - Sang L. Z.(2016) et al - Shen G(2013) et al
Research related to stranding risk analysis	- Mazaheri A(2009)
Research related to collision avoidance	- Minne P. K. E(2017) - Kuwata Y.(2013) et al - Johansen T.A.(2016) et al

Algorithms for preventing collisions between ships are also being conducted, and based on this, service supplementation will be possible.

In this paper, the function is defined considering the manned vessel. In the future, in consideration of autonomous ships, the function to avoid collisions between ships by utilizing static information of ship specifications and dynamic information of ship should be additionally considered.

4. Provision of services

Draft depending on data of vessel and loading status and information on entry and exit port are the basic data in determining the navigable waters, collision and stranding risk waters, and UKC (Under keel clearance) to pass the shallow waters, Air Draught to pass under the structure such as bridge and LOA (Length over all) to estimate the turning circle. It may be obtained through Port-MIS and AIS Static Data Report message (5,24) Geographic location of vessel and dynamic information is the basic data for route estimate, risk identification and navigation intent identification and AIS Position Report message (1,2,3,18,19) may be used.

Table 3: Marine environment information

Category	Information	Source
ship static information	- Draught Air Draught Length Width - Departure or Arrival Port	PortMIS, AIS
ship dynamic information	- Time and Positions - COG(Course of ground) - SOG(Speed of ground) - ROT(Rate of Turn)	AIS, V-Pass

Geographical information	- Beacon - Bouy - Bridge - Cable, overhead Conveyor - Depth Area Floating dock L and area Pipeline, overhead Pontoon - Shoreline construction Traffic separation zone - Traffic separation scheme lane part Underwater/awash rock - Wreck	ENC
environmental information	- navigational warnings notice to mariners risk of collision - risk of ground volume of traffic	
regulation	- COLREGS(International Regulations for Preventing C ollisions at Sea)	

The data to distinguish the geographical situation in the vicinity of the route may be used, making use of ENC (Electronic Navigational Chart), which includes existing physical aids to navigation (Beacon, Buoy), structure above (Bridge Cable, Conveyor), topographic information (Land, Shoreline), water depth (Depth), structure under the vessel (Underwater rock, Wreck) and route information. And surrounding environmental factors include sailing notice (notice to mariners, navigational warnings) and sea traffic and estimated danger information, but in this study, real-time connection to navigational warning was not considered, but using the existing information.

4.1. Identification of geographic situation

To provide Customized Virtual AtoN service, vessel navigation situation as well as surrounding geographic environment are critical. Judgment of obstacle elements to navigation and real-time determination of navigable safe waters are important factor. For determination of real-time navigable safe waters, Electronic Navigational Chart (ENC) can be used as important data. ENC refers to digital map produced for safe navigation. ENC, which is the new data provider, not only indicates the paper map visually but also provides digital information by integrating the geographical information and navigation information. S-57 is the international standard for Electronic Navigational Chart (ENC) and was approved as official waterway data exchange standard at the 14th general meeting of International Hydrographic Office (IHO) held in 1992.

ENC contains various information including safe route and other information for arrival and departure of the vessel such as water depth, rock, hazards, shape of seabed and islands, port facilities, lighthouse, buoy as well as coastal target for self-localization, land shape, tidal movement, tide or sea current with the direction and velocity.

S-57 ENC data model comprises of feature information and spatial information which are interlinked. Feature information can exist independently while spatial information is linked to feature information.

Spatial information which is indicated in the standard spatial model is divided into Node, Edge and Face which corresponds to point, line and side, respectively. Node comprises of independent node and connect node. ENC, in spatial model, expresses all spatial information using the node and edge information which corresponds to the point and line, respectively, and the information corresponding to the face is expressed in a way of connecting it to the edge.

To optimize the computing speed and specification, navigational chart data is converted as follows for use. It's converted to the Grid form for easy computation and the grid size is set to about 55m to allow geographical identification for safe navigation. Unnecessary objects of S-57 were integrated by divided cell in ENC.

Port zone was divided for identification of geographical situation. Grid-based zone within the certain distance was analyzed.

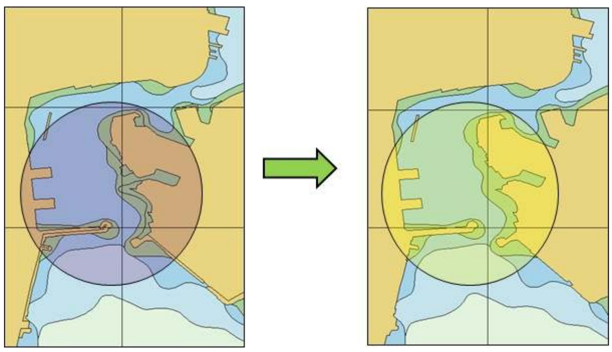

Figure 5: Identification of port zone

It's also divided to 0m, 2m, 5m, 10m and 20m, depending on ENG coastline and shallow water to make it variable grid-base zone.

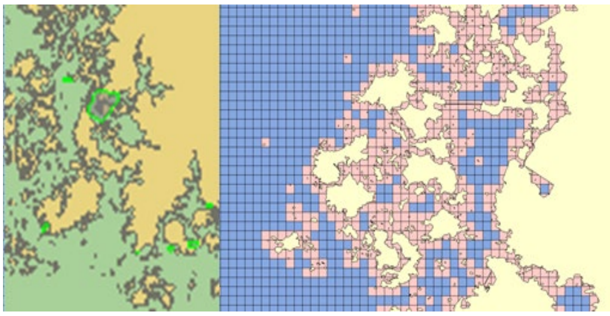

Figure 6: Identification of harbour limit

Sea-Area in INM unit grid was identified, depending on ENC coastline and artificial coastline and was excluded when it's close to the coast.

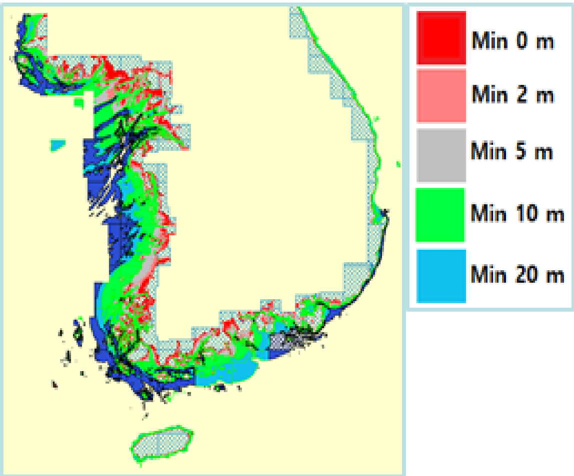

Figure 7: Identification of shallow water

Port zone was divided for identification of geographical situation. Grid-based zone within the certain distance was analyzed.

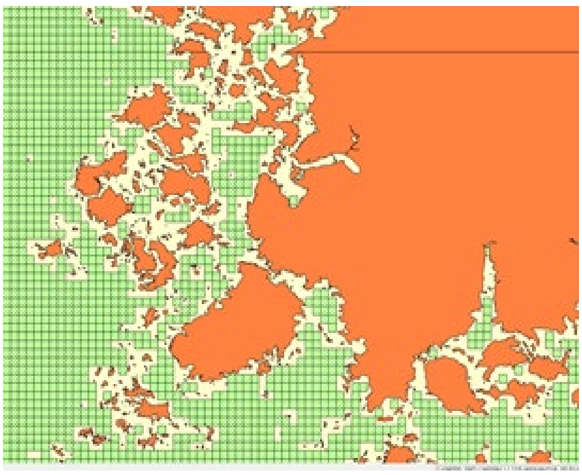

Figure 8: Identification of Sea-Area

4.2. Identification of navigation status

Turning circle was estimated to consider the vessel size in identifying the navigational status. Typical turning circle was estimated based on IMO Resolution A.751(18) and ship manoeuvring theory. Turning circle was estimated by applying 4L Advance to the time necessary for evasive manoeuvring.

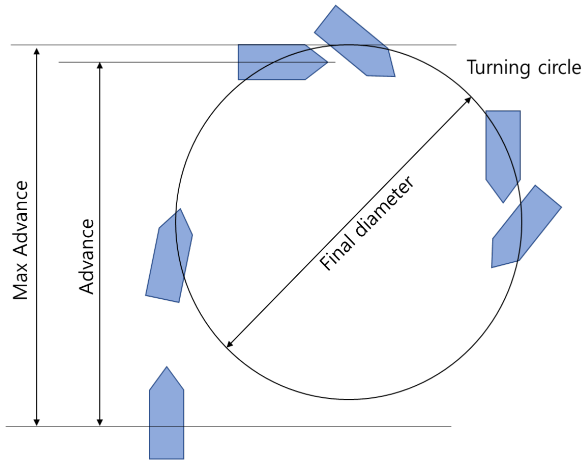

Figure 9: Estimate of turning circle

$$(2L * \pi) / 0.8 = 7.85 L \quad (1)$$

Estimate of escape zone within navigable port was made using Circular Domain(3L) for easy calculation.

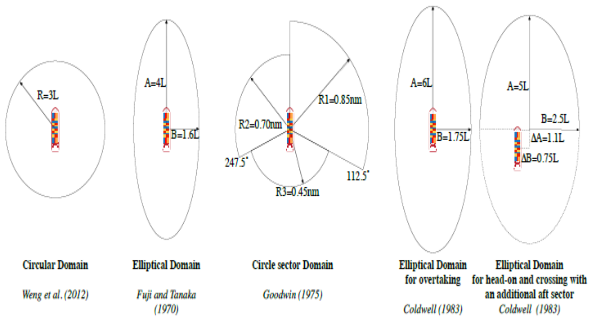

Figure 10: Estimate of escape zone

4.3. Digital aids to navigation layout algorithm

Virtual route arrangement is made by placing the aids to navigation at user-designated width and spacing on estimated optimal route. According to IALA document, virtual aids to navigation is not limited to point-based aids to navigation but the line or area as needed. Particularly when many digital seamarks are indicated on ENC, it may rather cause confusion to the navigators due to information overload. According to IALA, aids to navigation in the form of line or area may be provided in such a case. Should the aids to navigation in the form of the point be provided, the spacing between the navigation aids shall be reduced at the critical route such as principal turning point when the hazards exist around the route, while the spacing may be widened to the normal spacing at the less cautious area. Optimal route depending on degree of risk in the area may be in zigzag, not a straight alignment, because of the effort to seek the optimized solution. The vessel, however, is heavier than land vehicles and is manoeuvring on water surface, making it difficult to turn and thus turning needs to be minimized in proper way. Hence, to simplify the route, Douglas & Peucker algorithm is used(Douglas D. H., & Peucker T. K, 1973).

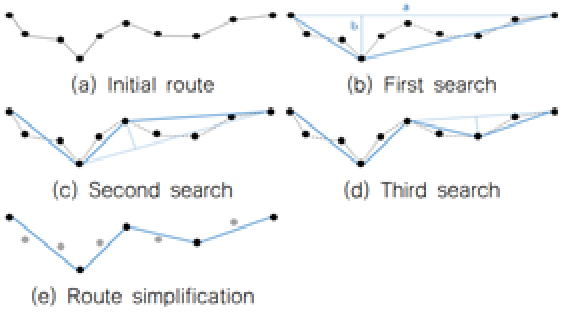

Figure 10: Douglas & Peucker Algorithm

This algorithm seeks the straight line linking the start point to the end point at initial route and then seeks the farthest point from that line. Should that distance be greater than established critical distance, farthest point remains intact. Such process is repeated to every point on initial route. Should any specific area be less than the critical distance, this point shall be removed and is connected to previous point, thereby simplifying the route. The Fig below shows the process of simplifying the route by stage.

The system generates the virtual aids to navigation based on digital information on navigating vessel.

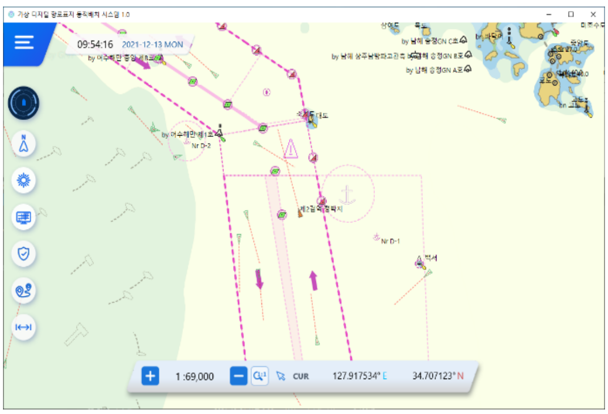

Figure 11: Service Prototype System

5. Conclusions

In line with increasingly developing technologies, many changes to ship operation also follow. Particularly, development of digital navigation equipment and system based on electronic means has made a great commitment to enhancing the efficiency and reliability in the area of safe navigation as well as other areas such as marine environment and logistics. Aids to navigation provides the guidance for safe navigation in a way of typical visual expression such as shape in the daytime and the features of group occulting light in the night-time. However, due to restricted visibility by natural factors such as sea fog and increased coastal backlight on the back of development of port hinterland, there might be a limit in visibility with the shape and lighting. IALA, in a bid to cope with such problems, recommends installing AIS communication module to Aids to Navigation, thereby providing directly the vessels sailing in the vicinity with location information and the status of Aids to Navigation, using the specific message (MSG 21). In line with introducing MASS (Maritime Autonomous Surface Ship), various real-time information required for identification of autonomous situation and safe navigation is needed and furthermore, piloted vessel also is in need of further detailed information for safe navigation. Virtual aid to navigation doesn't exist physically, but it transmits the virtual location to indicate the aids to navigation, thereby notifying the navigators of safe route, cautious route and dangerous route, and the coverage is defined as digital items or item groups that is controllable or adjustable by computer, irrespective of the type or form.

In this paper, customized digital aid to navigation was proposed, depending on definition of aids to navigation. Estimate of turning circle and burdened zone was made as well as the algorithm identifying the port area, water depth and Sea-Area was demonstrated. Guidance service of lateral mark, navigable waters and dangerous zone to the vessels requesting for the service so as to be able to cope with the limited visibility of the aids to navigation and provision of digital information for autonomous navigation would be possible.

In this paper, the function and composition of the digital aids to navigation are described. The study is aimed at providing the service through AIS 6 message and AIS ASM standard message is designed for use of message 6. Currently, MMSI is assigned to each the aids to navigation, and it is necessary to consider the definition of MMSI in order to use AIS communication. In addition, when providing to multiple ships, the problem of AIS communication saturation should be considered. In order to solve these problems, the service linking to IALA S-200 standard is planned.

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