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An Analysis of Future Ship Operation System under the e-navigation Environment

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Abstract : *It is clearly understood that e-navigation is beneficial to prevent collision and grounding of ships. The purpose of this study is to define and present a future ship operation system under the e-navigation environment in order to provide clear direction for the design of Korean e-navigation system. The future ship operation system consists of shipboard navigational system, shore supporting system and maritime communication system. To achieve the objectives of this study, the ship operation system was discussed separately into SOLAS ships and non-SOLAS ships in this study. In SOLAS ships, mariners become a system manager, choosing system presets, interpreting system output, and monitoring vessel response. In small ships and fishing vessels, mariners may enjoy their navigation by using the automatic tracking of ship's position on the portable electronic chart display. The improved bridge design, integrated and harmonized navigational system and single window reporting will reduce significantly the administrative and physical workload of mariners. Mariners can concentrate their attention more on navigational duty under the e-navigation environment. To build an effective Korean e-navigation system, the essential navigational functions and e-navigation services for small ships and fishing vessels must be identified and developed taking into account user needs.*

Key Words : *e-navigation, Shipboard navigational system, Shore supporting system, Maritime communication system, Single window reporting*

1. Introduction

Recently, the International Maritime Organization (IMO) has been introducing e-navigation in order to reduce human errors and assist for seafarers' decision making. During the development of e-navigation, it was well recognized that the main benefits of e-navigation are improved safety of navigation through the exchange of reliable information and enhanced efficiency through better integration of shipboard and shore-based systems (IMO, 2008). The IMO's e-navigation Strategy Implementation Plan (SIP) introduces a vision of e-navigation which is embedded in general expectations for the onboard, onshore and communications elements. As the e-navigation system will have an effect in all aspects of ship operation, it is necessary to predict the ship operation system under the e-navigation environment prior to design the national e-navigation architecture.

In accordance with the SIP, a number of required tasks will be performed during the period from 2015 to 2019 in order to achieve the identified e-navigation solutions. As scheduled in the SIP, various technical guidelines on the development and operation of e-navigation will be adopted as a regulation under the International Conventions by 2019 (IMO, 2014a). In addition to the IMO's effort, the SMART-navigation project will be performed by government in Korea. It is planned to perform the national Research & Development (R&D) program to develop core technologies and to expand the national infrastructure.

In order to meet the expectations on the benefit of e-navigation, it is necessary to build a system for the prevention of marine accident based on the e-navigation services. Such a new system should be focused on small ships and fishing vessels rather than ships which are complying with the International Convention for the Safety of Life at Sea (SOLAS), hereinafter referred to as 'SOLAS ships', to reduce the number of marine accident. The reason is that the most of the marine accidents were occurred in fishing vessels and small ships of under 100 Gross Tons (GT) in the Korean coastal waters. According to the statistics, the greater part of the accidents were collision and grounding of ships (KMST, 2014). In addition, the 88.4 % of registered ships are fishing vessels and the 94.9 % of registered ships are small-sized ships of under 100 GT. The 97.5 % of collision and grounding of ships were caused by human errors. In this regard, it is crucial to build a support system for the prevention of marine accident by using the e-navigation system.

With a view to build an e-navigation system in the Korean

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coastal waters, the future ship operation system under the e-navigation environment was discussed in this paper. The purpose of this study is to present a clear direction on the development and implementation of e-navigation in Korea through the discussion on the outlook for the ship operation system taking the e-navigation environment into account.

To achieve the purpose of the study, the ship operation system was discussed through literature reviews. The IMO meeting documents related to the e-navigation SIP were reviewed to examine the development of e-navigation. The national plans and government reports were also examined. The rules and regulations on the IMO Conventions and national laws regarding navigation system were reviewed to examine the current navigation system. Finally, the future ship operation system was presented with a recommendation as per the vision of e-navigation, which is embedded in the shipboard navigation system, shore supporting system and communications elements. The shipboard navigational system was discussed separately into two groups, such as SOLAS ships and non-SOLAS ships.

A great deal of research papers regarding e-navigation has been presented at the international conferences organized by the International Association of Lighthouse Authorities (IALA) and Danish Maritime Authority. However, the most of previous researches had focused on ships which are complying with the International Convention for the Safety of Life at Sea (SOLAS), hereinafter referred to as 'SOLAS ships'. Even though Prof. P. Baglietto presented a research paper on *'challenges of e-navigation for leisure boats'*, there were few or no researches on the development of e-navigation for non-SOLAS ships (Baglietto, 2015).

This study will help for planning and designing of the Korean e-navigation system. It is expected that the further researches on the navigation support systems based on e-navigation will be carried out in order to prevent collision and grounding of non-SOLAS ships.

2. Development of e-navigation

2.1 IMO's Strategy Implementation Plan

The SIP sets up a list of tasks and specific timelines for the implementation of prioritized e-navigation solutions during the period from 2015 to 2019, facilitating a coordination of efforts by relevant Sub-Committees, related international organizations, Member States, relevant regional bodies and the maritime industry.

The SIP identified five prioritized e-navigation solutions. The five prioritized e-navigation solutions focus on efficient transfer of marine information between all appropriate users (ship-ship, ship-shore, shore-ship and shore-shore) and the promotion of the workable use of the information and data onboard.

During the development of the SIP, a number of tasks have been identified in order to continue the further development and implementation of e-navigation (IMO, 2014a). Table 1 presents the list of tasks and schedule.

Table 1. The List of Tasks and Schedule

No	Expected outputs result from Tasks	Schedule
T1	Guidelines on Human Centered Design (HCD) for e-navigational systems	2015
T2	Guidelines on Usability Testing, Evaluation and Assessment (UTEA) of e-navigation systems	2015
T3	Guidelines on electronic equipment manuals	2019
T4	Guidelines on S-mode	2017
T5	Guidelines/Performance Standards of Bridge Alert Management (BAM)	2019
T6	Guidelines on the display of accuracy and reliability of navigation equipment	2017
T7	New or additional modules for the Performance Standards for INS	2019
T8	Updated Guidelines on single window reporting	2019
T9	Technical report on the automated collection of internal ship data for reporting	2016
T10	Resolution/IEC Standard of Built In Integrity Testing	2019
T11	Guidelines for Software Quality Assurance (SQA) in e-navigation	2015
T12	Guidelines on how to improve reliability and resilience of onboard PNT systems by integration with external systems	2016
T13	Guidelines on the harmonized display of navigation information received from communications equipment	2019
T14	Guidelines on a Common Maritime Data Structure and IEC standards for data exchange used onboard including firewalls	2017/ 2019
T15	Guidelines on seamless integration of all currently available communications infrastructure and how they can be used and what future systems are being developed along with the revised GMDSS	2019

As a part of the implementation of the SIP, Guidelines on Human Centered Design (HCD) and Guidelines on Usability Testing, Evaluation and Assessment (U-TEA) of e-navigation systems are under development as key elements for improved, harmonized and user-friendly bridge design. HCD employs the methods of U-TEA, the results of which drive a formal feedback loop in the design stages to ensure usability and continued safety. The fundamental to HCD is the collection of user feedback through systematic and formalized U-TEA. U-TEA enables extended use of standardized and unified symbology for relevant bridge equipment. HCD provides seven Usability Design Principles (UDP) as shown in Tables 2 (IMO, 2014b).

Table 2. List of Usability Design Principles (UDPs)

Usability Design Principle	Description
Suitability for task	Supports the user in the completion of the task.
Self-descriptiveness	At any time, it is obvious to the users which mode they are in, where they are within the mode, which actions can be taken and how they can be performed.
Conformity with user expectations	Conforms with user expectations, if it corresponds to predictable contextual needs of the user and to commonly accepted conventions.
Suitability for learning	Suitable for learning when it supports and guides the user in learning to use the system.
Controllability	System is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met.
Error tolerance	A system is error-tolerant if, despite evident errors input, the intended result may be achieved with either no, or minimal, corrective action by the user.
Suitability for individualization	Capable of individualization when users can modify interaction and presentation of information to suit their individual capabilities and needs.

2.2 SMART-navigation project

Whilst SOLAS ships are fitted with various electronic navigation equipment in accordance with the provisions of SOLAS, non-SOLAS ships are operating in poor navigation surroundings. As shown in Table 3, cargo ships operating in near-coastal zone regardless of it's length and fishing vessels less than 20 meters in length do not have nautical charts for the navigable area. Moreover, small ships less than 12 meters in length and fishing vessels less than 10 gross tons do not have means for position fixing, compass and radar. Global Positioning System (GPS) is applicable to fishing vessels which are fitted with radio equipment as per the Fishing Vessels Act.

Because nautical charts are essential for navigating at sea together with means of position fixing, SOLAS requires all ships, irrespective of size, to carry nautical charts to plan and display the ship's route for the intended voyage, also to plot and monitor positions throughout the voyage. Position information can be achieved by Global Navigational Satellite Systems (GNSS), terrestial systems or radio navigation systems. However, position information is useless without nautical charts. Due to the absence of the chart carriage requirements of the domestic regulation for small ships and fishing vessels, most of non-SOLAS ships are operating without nautical charts and position fixing equipment.

Table 3. Requirements of Shipboard Navigational Equipment

Ships \ Nav. equipment			Chart	GPS	Magnetic compass	Radar	Gyro compass
Cargo ships	less than 12m in length	near-coastal zone	×	×	×	×	×
		coastal zone	○	×	×	×	×
	12m or over in length	near-coastal zone	×	500GT ↑	×	100GT ↑	×
		coastal zone	○	20GT ↑	500GT ↑	100GT ↑	500GT ↑
Fishing vessels	less than 10 GT		×	○	×	×	×
	10 GT or over	lee than 20m	×	○	×	×	×
		20m or over	○	○	×	×	×
		24m or over	○	○	○	×	×
		35m or over	○	○	○	○	×
		45m or over	○	○	○	○	○

On the other hands, GPS plotters are widely used in non-SOLAS ships for convenience reasons. However, GPS plotter is not an officially approved equipment for navigation. The zoom-in and zoom-out functions of chart display in the GPS plotter may jeopardize mariner in danger.

Considering the above mentioned safety issues, SMART -navigation project are especially considered e-navigation services based on IMO's e-navigation services and taking into account navigation surroundings for non-SOLAS ships in Korean coastal water as shown in Figure 1.

The Ministry of Oceans and Fisheries (MOF) established the national strategy plan for the development and implementation of e-navigation in December, 2013. According to the national strategy plan, the vision of SMART-Navigation is to establish a framework that provides a platform for seamless information exchange between ships also ship and shore.

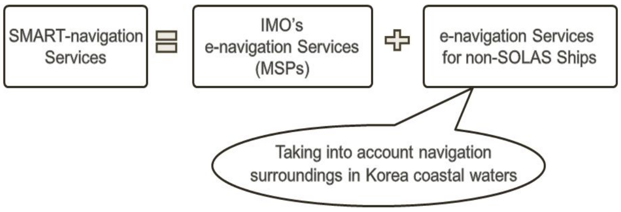

Fig. 1. Concept of SMART-navigation Services.

The project for the development and implementation of e-navigation in Korea, SMART-navigation project, was selected as an appropriate program qualified for the national R&D program. The Strategy Action Plan of SMART-navigation was finalized in April 2015 by MOF. The Strategy Action Plan provides a framework for the development and implementation of e-navigation in Korea. The project focuses on the development of core technologies of e-navigation and on the expansion of infrastructure such as, mobile communications network and e-navigation operating center (MOF, 2013).

3. Ship Operation System Under e-navigation

3.1 Shipboard Navigation System of SOLAS Ships

After the implementation of IMO's e-navigation SIP, it is expected that there will be a great improvement in the shipboard navigation system. Firstly, bridge design and workstation layout will be improved ergonomically and harmonized user friendly in accordance with the Guidelines on HCD and Guidelines on U-TEA of e-navigation systems. HCD would improve user performance, allow for error management and recovery, and save the time and resources required for system maintenance. Most importantly, a system will support users in low and high stress environments; such as during challenging navigation and environmental conditions when users are most vulnerable to making mistakes. Also, U-TEA enables extended use of standardized and unified symbology for relevant bridge equipment.

Secondly, all shipboard navigation equipment will have Standardized mode (S-mode) functionalities such as, standard default settings and save/recall settings. S-Mode is a function to revert, by a single operator action, to a standardized navigation display, with standardized functionality and interface. Because the different equipment manufacturers follow different presentation and terminology, this introduces the risk to mariners or pilots not being able to access or use all the available functions, not being able to produce a familiar setup of the equipment, and consequently not being able to obtain information required for navigational decision making.

S-mode is expected to reduce familiarization time by eliminating the need for ship operators to provide equipment-specific training, through standardizing the functionality and interfaces of navigation displays (IMO, 2014c).

Thirdly, the levels of accuracy and reliability of graphical or numerical presentation of information will be improved and harmonized. All shipboard navigation equipment should follow the requirements of Bridge Alert Management (BAM), the display of accuracy and reliability of navigation equipment and built-in integrity test (BIIT). BAM, as a centralized alert management system, will properly identify alerts that may arise and prioritize them by importance with regards to safe navigation. Relevant bridge equipment should have standardized self-check and BIIT functionalities with interface in accordance with the Resolution and IEC Standard.

Fourthly, bridge navigation systems will be integrated with each other and with other kinds of systems on the ship on the basis of Integrated Navigational Systems (INS). The e-navigation vision of digital integration is supported by the Electronic Chart Display and Information System (ECDIS) complied with S-100 standard. The new generation of ECDIS will be part of the digital integration. ECDIS will become more compatible with more devices, as a main part of INS, where all devices on board are networked and communicated each other in a common language.

Lastly, all bridge equipment including software should have standard endurance, quality and integrity verification testing functionalities according to the Software Quality Assurance (SQA) guideline in e-navigation. As software and data used in software may impact significantly on the ability of users, they should be produced and managed by quality assurance process in order to meet their quality requirements. The SQA guideline is intended to ensure that software and data used in software meet the requirements of relevant regulations and standards throughout the life cycle of an e-navigation system.

3.2 Shipboard Navigation System of non-SOLAS Ships

According to the SMART-navigation implementation plan, technologies and devices will be developed for SMART-navigation services. The SMART-navigation device is an e-navigation platform which has a GPS module, navigation applications and radio communications network. Mariners can plot ship's position on the Electronic Navigation Chart (ENC), plan the ship's route for the intended voyage and monitor positions throughout the voyage. In addition, mariners can use maritime safety information received from the shore.

The SMART-navigation device could settle the issues around GPS plotter. ENC streaming service will be provided for navigating area by LTE-M communications network. Streaming is a technique for transferring data so that it can be processed as a steady and continuous stream. Streaming technologies are useful because users do not have to have an advanced device with big data storage. With streaming, the user device can start displaying the data before the entire data has been transmitted. The nautical chart information in the ENC streaming service will always be newly up-dated by Korea Hydrograhic and Oceanographic Administration (KHOA).

Taking into account ship’s types and operating patterns, the size and the price of SMART-navigation device should have flexibility. For fishing vessels less than 5 gross tons, a portable type of device will be needed because those ships do not have an electric power supply facility. On the other hand, for the ships of 5 gross tons or more, a fixed type of device with more advanced functions could be considered. In order for the successful implementation of SMART-navigation system in the fishing vessels, a financial assistance for the installation of device would be considered as a government support policy.

3.3 Operation of Ship

Mariners become a system manager, choosing system presets, interpreting system output, and monitoring vessel response. Electronic integrated bridge concepts will drive future navigation system planning. Integrated systems take inputs from various sensors, electronically display positioning information, and provide control signals required to maintain a vessel on a preset course. However, e-navigation will not encourage the development of unmanned vessels but assist situational decision making and reduce workload of mariners. Mariners can concentrate their attention more on navigation duty under the e-navigation environment. Especially the improved bridge design, integrated and harmonized navigation equipment and information and single window reporting will reduce the administrative and physical workload of mariner significantly. In small ships and fishing vessels, mariners can enjoy their navigation by using the automatic plotting and tracking of ship’s position on an ENC-based portable navigation display.

In the e-navigation system, shore control centre may cooperate with mariners. When something unexpected happen in ship’s operation, the shore control centre is able to rapidly assess the situation. The shore control centre will keep the track of technical condition of equipment and operational consequences.

Also, mariners should cooperate with shore control centre. Since the improved and higher quality sensor and data fusion becomes necessary in the e-navigation system, mariners need to have ability for control and manage the system and information. Mariners should be familiar with the use of information communication technologies (ICT). The introduction of e-navigation would not encourage the reduction of the number of seafarers on board but to reduce the human error on ship’s operation system.

4. Shore Supporting System by e-navigation

The IMO’s effort on the development of e-navigation has more to do with shore-based authorities and their objectives. It has been mentioned officially that the key elements of e-navigation include enhanced vessel traffic management from ashore. Nevertheless, e-navigation will help to reduce human errors and to improve the maritime traffic management system.

First of all, VTS system will be improved significantly for e-navigation services. S-100, the ENC-based IHO geospatial standard for hydrographic, will be used as a basic map of VTS and Common Maritime Data Structure (CMDS) will be introduced as a data format to exchange information with ships and other shore organizations. Thanks to the development of digital communication technologies under the e-navigation environment, the VTS operators can monitor the integrated ship’s screen by the exchange of multimedia files between VTS center and ships and vice versa. The VTS operators do not have to call ship’s officer on watch in a normal operation situation.

Secondly, the individual elements of General Information Center On Maritime Safety and Security (GICOMS) will be developed as a platform of e-navigation operation system. SMART-navigation project will derive the development of situational identification system, navigation monitoring system, remote safe navigation assistance service and integration of data exchange among the organizations from the traditional GICOMS system.

Thirdly, the e-navigation operation system will be established for e-navigation services to shipboard users as well as shore users.

It consists of platform part and service area. The e-navigation platform consists of digital GMDSS for communications, ENC based on S-100, CMDS, Maritime Cloud, database system, Vessel Monitoring System and data exchange system among organizations.

5. Maritime Communications in e-navigation System

Communications are a key for the implementation of e-navigation. It is expected that a digitalized communication system will be developed based on the traditional GMDSS for SOLAS ships, such as AIS Application Specific Messages (AIS-ASM) and VHF Data Exchange System (VDES).

AIS-ASM transmitted in binary format will be increasingly used to digitally communicate maritime safety information between participating vessels and shore stations. IMO recently published a new Safety-of-Navigation Circular (SN.1./Circ.289) that includes a number of meteorological and hydrographic message applications and data parameters. While there are no specific display standards for AIS-ASM on shipborne or shore-based systems, IMO has also issued general guidance for the presentation and display of ASM (SN.1/Circ.290). It is possible to interrogate a ship for a specific message and automatically receive the requested information, provided that the ship has the appropriate equipment installed. Moreover, AIS-ASM may reduce verbal communications and enhance reliable information exchange and reduce operator's workload. In the near future, it is expected that AIS-ASM will be an important component of the e-navigation concept-of-operations.

Together with AIS-ASM, VDES will prospectively have a significant beneficial impact on the maritime information services including Aids to Navigation and VTS in the future. VDES is a technological concept developed by e-NAV Committee of IALA now widely discussed at International Telecommunication Union (ITU), IMO and other organizations. VDES integrates the function of AIS, ASM and VDE and includes the channels for these functions with satellite transmission and reception. It is anticipated that VDES may be implemented in two parts, terrestrial VDES and satellite VDES. Some radio manufactures have already started to develop the prototype VDE transceiver.

Apart from the GMDSS technologies, Maritime Long Term Evolution (LTE-M) enables small ships which have not fitted with radio equipment to communicate and exchange data within 100km in coastal waters from the shore. LTE, commonly marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. It is expected that LTE-M will improve the safety of small ships and fishing vessels significantly. Thanks to the high-speed data networks, mariners of small ships, fishing vessels and leisure boats can use a ENC streaming service to monitor the ship's position, connect to Internet at sea and receive information from ashore. LTE-M could contribute significantly in the development of communications at sea in line with the modernization of GMDSS. Fig. 2 shows the maritime communications in e-navigation system.

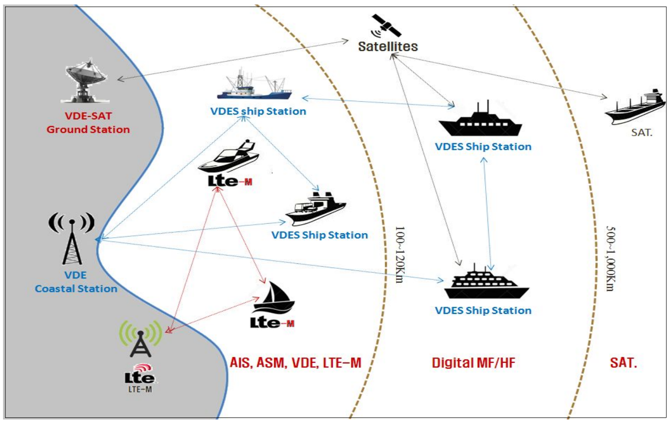

Fig. 2. Maritime Communications in e-navigation System.

6. Conclusion

It is clearly understood that e-navigation will help to improve the safety of navigation. Technologies and standards which will be developed by the e-navigation SIP and MOF will bring great changes in ship operation system. This study examined the development of e-navigation at the international and national level and drew the future ship operation system. Under the e-navigation environment the ship operation will be based on improved and harmonized navigation bridge design and shipboard navigation equipment. New technologies and devices will be developed for non-SOLAS ships to use e-navigation service in the coastal water area. Advanced shore supporting system will be built in the shore control center. Digitalized GMDSS and high-speed mobile technology will be used for the maritime communications. LTE-M provides small ships with data network which enables to use an navigation application with an ENC service.

As discussed on the above, it is important to apply the e-navigation services to small ships and fishing vessels. In order to prevent collision and grounding of ships in the Korean coastal waters by using the e-navigation system, the collision prevention support system should be established. To build an effective collision prevention support system, it is recommended that the essential navigation functions and e-navigation services for small ships and fishing vessels should be identified and developed. A portable type of e-navigation device with essential navigational functions should be fitted on those ships to make use of e-navigation services provided from the shore.

Based on this study, various research works should be conducted in the future to develop a system for the prevention of marine accidents by utilizing e-navigation system.

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