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Study of the research status on e-navigation

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STUDY OF THE RESEARCH STATUS ON E-NAVIGATION

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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Date: 1st July 2015

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ABSTRACT

Title of Research paper: **Study of the Research Status on e-Navigation**
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Navigation is important for human economic and social activities. The progress of science and technology promotes reforms in navigation. In the era of information, automation systems are more often applied in navigational operations. An effective integration is in need for a variety of systems to work better, unified technical and management standards are required to ensure an efficient system operation environment involving a multi-party. Therefore, e-Navigation arises at the historic moment. E-Navigation is neither the combination of one or several information systems, nor a means of navigation or state, but a navigational "ecological environment" with multi-party participation and joint operation of various systems, which emerges and develops in the era of information. Development and prosperity of e-Navigation need joint efforts of member states in relevant international organizations to formulate and implement the standards, to promote progress of e-Navigation technology, and eventually to guide e-Navigation to develop on the way of "cleaner ocean, safer navigation".

This paper describes current situation of e-Navigation research and comes to the conclusion that communication system is fundamental to e-Navigation based on analysis and discussion about current situation. This paper conducts performance analysis and cost analysis of present maritime radio communications, and makes a point to achieve communication in e-Navigation by NAVDAT of 500KHZ frequency, and it also analyzes the development and application of NAVDAT. Finally it offers expectations and suggestions on development direction of e-Navigation, as well as communication technology in China.

KEY WORDS: E-Navigation, Framework, Communication Technology, NAVDAT

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
ANM	Aids to Navigation Management Committee
ARPA	Automatic Plotting Radar
ASM	AIS Special Message
CCTV	Closed-Circuit Television
CMSA	China Maritime Safety Administration
COMSAR	Radio Communications and Search and Rescue Committee
CSSA	Common Shore-based System Architecture
DGPS	Differential Global Positioning System
ECDIS	Electronic Chart Display and Information System
E-Nav	E-Navigation
ENC	Electronic Navigation Chart
FAQ	Frequently Asked Questions
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
IALA	International Association of Lighthouse Authorities
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organization
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite
IS	Information Services
ITU	International Telecommunications Union
LPS	Local Port Service
MAS	Maritime Assistance Service
MSC	Marine Safety Council
MSI	Maritime Safety Information
MSP	Maritime Services Portfolios
NAS	Navigation Assistance Service

NAV	Subcommittee on Safety of Navigation
NAVDAT	A digital broadcasting system
NAVTEX	Navigational Telex
OOW	Officer Of Watch
PNT	Positioning, Navigation and Timing
RBN	Radio Broadcast Network
RTCM	Radio Technical Commission for Maritime Services
SAR	Search And Rescue
SARSAT	Search And Rescue Satellite Aided Tracking
TMAS	Telemedical Assistance Service
TOS	Traffic Organization Service
UMDM	Universal Maritime Data Model
VDES	VHF Data Exchange System
VDL	VHF Data Link
VHF	Very High Frequency
VSTA	Very Small Aperture Terminal
VTMIS	Vessel Traffic Management Information Service
VTS	Vessel Traffic Services

CHAPTER 1 INTRODUCTION

1.1 Research background and significance

Navigation is important for human economic and social activities (Feng, 1992). Along with the advance of science and technology, navigation technology obtains rapid development with the appearance of VTS, ENC, ECDIS, AIS, GPS and other navigational technology or system. All kinds of navigational information have greatly increased, which provides a rich means of aid to navigation. But at the same time, some problems also occur (Bai, 2011), such as incompatibility of a variety of independent guidance and navigation systems, difficulty in sharing information. All these problems make it difficult for seafarers to be fully familiar with this content and hard to operate vessels, therefore the burdens incurred are increased for ship operation, and also affects the enthusiasm of seafarers to use these systems so as to reduce the effect of these systems. Moreover, traffic management at sea is changing from supervision management to a pattern of supervision management together with information service, etc.

People hope to integrate all kinds of ships, shore-based systems, and navigation systems to form a comprehensive ship-shore navigation information system, to realize more extensive and comprehensive sharing of navigation information, in order to further improve management efficiency of navigation between vessel and shore, and promote maritime safety and environment protection.

Since the beginning of this century, international shipping industry has started to make research on current development of navigation technology, evaluate development trend of shipping economy, analyze existing problems of ship navigation by collecting user demand, then the international shipping industry put forward the concept of e-Navigation. This is the need of business development in nautical field, customer demand, development of marine environmental protection and standardization.

E-Navigation is neither the combination of one or several information systems, nor a means of navigation or state, but a navigational "ecological environment" with multi-party participation and joint operation of various systems, which emerges and develops in the era of information. (Zhang, 2013). In this circumstance, all participants are both beneficiaries and operators. Development and prosperity of e-Navigation need joint efforts of member states in relevant international organizations to formulate and implement the standards, to promote progress of e-Navigation technology, and eventually to guide e-Navigation to develop on the way of "cleaner ocean, safer navigation".

In the era of information, navigation operation such as route planning, shipping control, positioning and orientation, communication navigation and environmental monitoring are more often applied in computer information systems. In order to meet requirements of function and management rules, there are more and more communication and navigation systems on the vessel, and seafarers are inclined to rely more on the equipment. In recent years, bridge automatic system with integrated bridge as the core has gradually improved. With AIS and VTS, VTMIS (vessel traffic management information service) as the representative of shore-based service system, its function has been increasingly richer, information interaction between shore and vessels has become increasingly frequent and shore-based navigation service has been increasingly richer.

The application of a variety of systems provides technical support for safe navigation; autopilot system reduces working strength of officers; automatic plotting radar (ARPA), AIS system and etc. make the seafarers be clear about situation around the ship and improve shipping safety to a certain extent. But the application of a variety of systems leads to accumulation of equipment and repetition of function. International Maritime Organization (IMO) believed it has affected the navigation safety and efficiency, and therefore started a research project called “e-Navigation” with the purpose to reduce the mess caused by too much information.

Secretary-general of IMO held the sixteenth conference of International Association of Lighthouse Authorities (IALA) in Shanghai in May 2006, and put forward the concept of e-Navigation. NAV54 of IMO from June 30 to July 4, 2008, passed a draft about the development and application of e-Navigation, including a draft about the framework of concrete implementation of e-navigation, and made specific schedule for all the work (IMO, 2012).

Draft of e-Navigation on NAV54 of IMO defined the basic concept of e-Navigation: collect, integrate exchange, describe maritime information on the ship and shore in electronic ways to improve services provided by berth shipping, and to achieve the purpose of maritime safety, security and marine environment protection (IMO, 2015).

E-Navigation in the future is a kind of highly efficient network for collaboration, with the integration of intelligent driving, navigation, communications and other functions, to secure a high level of integrity in its application on the shore and on the vessels. In the meantime, e-Navigation also simplifies all kinds of modes of information report, optimizes the human-computer interface, takes advantages of human operation and machine operation, minimizes defects of human operation and machine operation, in order to improve the shipping safety and efficient operation and reduce the impact on marine environment. E-Navigation is a platform for

information sharing, and it is an “ecological environment” with continuous optimization and growth, which should be played by the government, and maintained together by navigation related organizations and individuals. Everyone in the environment enriches their information through their own activities, at the same time, shares information and services with other participants.

E-Navigation is a new concept, under discussion of organizational mechanism, system framework, technology and standard with many technical problems to be solved. In order to speed up development of e-Navigation technology in China to provide the world shipping industry with qualified and integrated navigation service, related policies, standards and technologies, especially sailing communication technology research need to be strengthened. That is because communication system is mainly responsible for communication between shore-ship, ship-shore, ship-ship and shore-shore, which is the basis of e-Navigation facilities with fundamental influence.

1.2 Objectives of the study

E-Navigation is a concept concluded when marine technology develops into the age of information, which highly involves social practice. Research on related technologies and methods should start from requirement of actual application, according to the problems encountered in the process of application. E-Navigation involves many kinds of technology and with the progress of information technology; some problems related to e-Navigation have been solved. But at the same time, many new problems are brought by information explosion. In the age of information, with the progress of marine technology and equipment, construction of berth and shore-based equipment should be updated, for example, Loran A has quit the historical stage and Loran C is facing upgrade; audio signs such as fog signs and fog signals are no longer used. Many traditional expression and application also need to

be updated. From another perspective, we will find that some tricky problems have been solved.

This paper introduces the development of e-Navigation, and makes it clear that communication system is the foundation of e-Navigation. This paper conducts performance analysis and cost analysis of present maritime radio communications, and makes a point to achieve communication in e-Navigation by NAVDAT of 500KHZ frequency, and it also analyzes the development and application of NAVDAT. Finally it offers expectations and suggestions on development direction of e-Navigation, as well as communication technology in China.

CHAPTER 2 SUMMARY OF E-NAVIGATION RESEARCH STATUS

2.1 Research conducted by international organizations

Strategic research of e-Navigation was conducted under the coordination and leading by IMO and IALA is mainly responsible for related technology research and technical standards. Under the organization of IMO and IALA, research and study on user requirement analysis, user demand gap analysis, technical architecture design of e-Navigation strategic system, product design of maritime service prototype, system data exchange between service model and standard are gradually initiated.

2.1.1 Work of IMO

Since 2006, in the process of strategic development of e-Navigation, the main work of IMO is as followed (IMO, 2015):

- to promote and maintain e-Navigation strategic blueprint;
- to define a variety of services and its category;
- to determine the design, implementation, operation and responsibility of enforcing e-Navigation; to clarify rights, obligations and constraints of the flag state, coastal states and port state;
- to define transitional period of e-Navigation to achieve early benefit; reuse existing and new equipment, systems and services;
- to formulate leading e-Navigation strategic standards, including standards related to ships, shore and communication technologies; to ensure that

these standards are based on customer demand, and to encourage interoperability of technology neutrality and system component;

- to ensure that the concept of e-Navigation can adapt to and be built on the existing maritime system and budget;
- to make it more convenient to get finical support from the international fund, such as World Bank, regional development banks or international development fund, etc.;
- to assess and define various training needs related to e-Navigation, and assist relevant institutions to develop and deliver necessary training programs;
- to monitor the implementation of e-Navigation strategy; to ensure that states parties meeting its obligations; to ensure that users within its jurisdiction complying with these requirements;
- to lead and coordinate external communication to gain support for e-Navigation related affairs.

2.1.2 Work of IALA

IALA e-Nav committee is the main implementer of IALA e-Navigation strategy research. Since its inception, e-Nav committee, under the guidance of IMO, has started technology research on various fields in e-Navigation, especially the shore-based e-Navigation. The committee drew up a series of e-Navigation files, which has made great contribution to the development of international e-Navigation.

In 2013, the e-Nav committee set up 7 working groups according to the development of e-Navigation research on its 14th session, which are respectively:

- working group 1: operation, strategy and information description drafting;
- working group 2: PNT/sensor;
- working group 3 and 4: AIS and communications;

- working group 5: technical framework;
- working group 6: data model;
- working group 7: testing system.

To date, IALA has mainly finished the following work (Andy, 2012; IALA, 2007 & 2012) :

- to definite and clarify strategic concept of e-Navigation, and won the recognition of IMO (e-NAVre-NAV3);
- to maintain and update the shore-based user needs and user demand gap analysis;
- to conduct risk analysis and cost benefit analysis on e-Navigation strategy;
- to complete global radio Navigation plan, and be responsible for the maintenance and update of the plan, which covers all navigation technology available in the future of e-Navigation strategy;
- to be responsible for the relevant research on positioning technology of radar and promote related work;
- to actively promote research and standards on comprehensive PNT equipment (system) of e-Navigation;
- to revise and improve standard of ITU-R m.1371, and be about to make ITU a series of standards on ITU-R m.1371-5;
- be responsible for the formulation and revision of suggestion on A-124 of IALA. The second version standards of A-124 has now been completed, including basic services, main specification, abbreviations, service model, technical framework and DGNSS application document;
- be responsible for the next generation of AIS technology research and formulation of standards, and currently the basic framework of AIS2.0 has been basically established;
- be responsible for determining and monitoring formulation and revision of AIS related work with IEC standard working group. Standards of the AIS base station, A Class AIS terminals, B Class AIS terminal technology, AIS

SAR terminal technical and AIS AIDS to navigation technology have now been completed, space-based AIS technical standards is under work;

- to formulate and complete global radio communication plan, and be responsible for its maintenance and update, now it has been updated to the second edition. The program covers communication technologies which are potentially available in e-Navigation strategy system all over the world;
- to formulate the most basic communication technology available in the future of e-Navigation strategy, specifically AIS2.0, digital communication based on VHF and data communications over 500 kHz;
- to complete application of VHF channel specialized in digital communication to the ITU; four digital communication channels and six digital experiment channels newly added into AIS2.0 have now been approved;
- to formulate technical standards on various communication technology in e-Navigation strategy with the IMO, IEC and ITU;
- to formulate shore-based technology service framework system of e-Navigation, and be responsible for maintenance and update of technical framework;
- to conduct research and put forward framework system of e-ship Navigation technology service; e-Navigation technology framework is being developed, including shipping and shore-based technology framework, which are planned to be written into the next version of IALA NAVGUIDE;
- conducting research on e-Navigation technology service, and planning to determine technical service component about the future of e-Navigation strategy together with IMO, IEC and ITU related working groups;
- to improve technical standards as IALA domain users of S-100 and working groups registered in IHO;

- to encourage members to formulate S-100 IALA domain product specifications, and be responsible for its update and maintenance.

From the situation as illustrated above, IMO and IALA are actively promoting work on e-Navigation strategy, policy, user demand, risk, technical framework, technical standards, etc. But as for related technology and product standards, the investment is relatively small and there are only a few successful results.

2.2 Research conducted by various countries

Research on e-Navigation in the world mainly includes two aspects. First, actively participate in and cooperate with IALA related international researches, conduct test and study on related research topics, in support of the relevant research results, for example, Japan, South Korea and other countries have conducted experiment by AIS DGNSS; Canada ComDev company has been engaged in the construction and operation of space-based AIS system, etc. Second, it is about overall construction of e-Navigation system platform. All kinds of existing systems and services in the field of navigation should be integrated to provide unified service, in the form of e-Navigation framework, to ensure safety of maritime navigation, security, and marine environment protection, for instance, SeaSafeNet, MarNIS, and e-Maritime which have been gradually developed by European Union (EfficienSea project) and projects of ACCSEAS demonstration system in 2012, etc. All of these reflect the highest level of the construction of e-Navigation system in the world (Bentzen, 2012).

2.2.1 United States

As a major advocate of e-Navigation, the United States Coast Guard (USCG) has played an important role in the development of e-Navigation. Unlike the European Union, the United States is not on track of pan-American research on development of navigation, but it is promoting AIS, R.B.N./DGPS, and LRIT system and making technical guidance, it also conducts survey and analysis on IALA maritime user demand. PORTS system has been constructed, monitoring of the marine environment and navigational environment, as well as information services have also been carried out.

2.2.2 European Union (EU)

European Union made great contributions to the development of e-Navigation concept. Influenced by e-Navigation concept of IMO, European Union has started to develop e-Navigation related test and practice system since 2006. With funding and support from the sixth framework, there are totally 11 members and 44 organizations in Europe participating in research and development of pan-European MarNIS information service (at sea) system. This system, with reference to the concept of e-Navigation, mainly secures maritime safety and protection of sea environment to improve efficiency of maritime transport and economic benefit of transport at sea. And two demonstration centers were constructed respectively in Italy and Portugal in September and October in 2008. This system is completely based on e-Navigation framework to achieve systematic integration.

Funded by North Sea Project of European Union, CCSEAS test system platform has been started by Denmark, Sweden, Britain, Germany, Netherlands and other countries, which is a typical cooperative project of "study-research-enterprises-application". The objective and principle of the test system is specified to design, exploit and apply into practice in accordance with e-Navigation technology framework, based on requirements of users to build

e-Navigation test and offshore business platform in the North Sea area. The project lasted 3 years from the beginning of 2012 to the end of 2014. The research mainly includes:

a) to conduct research and analysis on traffic demand of vessels in the north sea area and analyze shipping density and traffic congestion;
b) to design e-Navigation technology framework proposed by IMO/IALA;
c) develop a series of e-Navigation prototype system and services, and selectively exploit a series of maritime service, basic PNT service for vessels and shore-based communication services;
d) to set up e-Navigation demonstration system.

2.2.3 Japan

Japan is one of the most active countries in developing e-Navigation in Asia. Represented by Japanese Coast Guard, maritime institutions in Japan were actively engaged in e-Navigation technology research, including some universities and manufacturers of marine electronic equipment. Actively engaged in research on e-Navigation technology, Japan first made a proposal to formulate a set of "electronic Navigation support system standard (ENSS)" on the 3rd IALA e-Navigation conference, and carried on detailed explanation on IALA assembly. Japan has started soft task about e-Navigation, at the same time, it is also actively engaged in the research of related practical application services. Furuno Company and Japan Maritime Institute are representatives working on research on related equipment and system. In the meantime, Furuno Company developed a three-dimensional electronic chart system, which has been put into related applications. Japan Maritime Institute has developed a "integrated navigation information system for image at sea". This system collects radar images, CCTV images, AIS and ARPA information and direction-finding system into a

human-machine interface, which comprehensively reflects real-time information ahead during the course and effectively improves shipping safety.

2.2.4 South Korea

Since e-Navigation concept is put forward; the South Korean government has been actively studying and participating in the development of e-Navigation. In early 2009, the South Korean government invented GICOMS (General Information Center on Maritime Safety & Security) system, and put into use in August 2009. The system uses AIS and public communication systems to provide safety data information broadcasting. The content includes navigational warnings, accident information and the main news. The South Korean government plans to invest 14.5 billion won in five years (2010-2014), to comprehensively reform and implement the system. It can improve the efficiency of information release system GICOMS in safe navigation, enhance the way to provide maritime safety information of GICOMS system in the field of navigation, prevent maritime accidents and protect sea environment through the construction of globalization GICOMS system service network which can provide global shipping service.

2.2.5 Canada

As one of the developed countries in the world, Canada also attaches great importance to the development and research work of e-Navigation. The project in St. Lawrence River is Canada's oldest e-Navigation research project which mainly includes networking services of the ship sailing plan, comprehensive application of guide equipment and research and development of information structure of the standard in the process of information transmission. Therefore, in the process of

sailing plan, the system supports comprehensive consideration about electronic chart, tidal/water level information, information on non-marine, channel information, vessel traffic management information, etc., and with the help of VTS system, AIS system, information exchange and information display electronic chart, etc, finally is applied to the information structural optimization, risk analysis, communication channel optimization and operating model information optimization.

2.2.6 China

As member of IMO and IALA, China has been actively involved in research on e-Navigation technology and policy. In May 2006, China as IALA presidency undertakes the 16th IALA conference in Shanghai. The theme of the conference was "aids to navigation in a digital world", and participants communicated international management and technology development. The concept and main content of e-Navigation was formally put forward (Bao, 2007).

Since then, China began a large-scale construction of digital aids to navigation. So far, AIS system covering main channels along the coast and inland rivers have been built, and more than 50% of aids to navigation have achieved digitization and remote control. Construction of AIS National Center and three sea area centers has been completed to undertake management and service of international MS data as one of the three international centers.

At present, security system of Ministry of Transport, Dalian Maritime University, Xiamen University and other units are developing research on e-Navigation related technology. Achievements have been made in framework of test platform, data transmission, and management of aids to Navigation, but a completed system has not been built yet.

Shipping business groups such as telecommunications network also actively carry out relevant system construction, and effective application has been achieved. In the future, governmental resources and social resources should be effectively integrated by means of information exchange and information sharing to provide users with more completed and efficient information services.

CHAPTER 3 BASIC KNOWLEDGE OF E-NAVIGATION

3.1 Background of proposal of e-Navigation concept

In the 20th century, with the development of navigation technology and modern technology such as GPS, electronic chart, navigational concept and mode have experienced a huge change. OOW use these instruments to get a better understanding in the regional situation of navigation and vessels, at the same time, a new generation of shore-based guide and navigation service constantly emerge and develop, which to a great extent, has changed the original concept of sailing. OOW ability to control the surrounding environment has been greatly improved, and the navigation safety is guaranteed by higher technical means.

The shore of maritime support systems - aid and navigation facilities, also have experienced a big change. Traditional security aid and navigation facilities - lighthouse, buoys, radar transponder and other navigation aid symbols, are unified in the whole world, allocation gradually improves, reliability continuously improves, which form the basic foundation of maritime security. At the same time, some of the new generation shore-based aid based on information technology and navigation technology grows and develops, such as vessel traffic service (VTS), ship automatic identification system (AIS), the position report system, ship tracking and recognition system, which to a large extent, complement and enhance the original aid and navigation systems, and form a better maritime security basis.

However, the following problems make us to think further:

These technological tools are gradually, independently developed in different historical periods. They increased the likelihood of maritime security level and also greatly increased the burden of the OOW, and personnel factor is a very important factor in causing accidents.

Ship is kept fitting more and more equipment, but standards are not unified in terms of onshore infrastructure which leads to incompatible between vessels and vessels shore, difficulty to share information and complexity in operation greatly affect the passion of seafarers and shore administrators to use facilities and equipment.

These technological tools play their respective roles and also provide the foundation platform for other applications, such as:

- ✧ Electronic chart: provide the foundation of other electronic navigation applications;
- ✧ AIS: implement digital communication on shore or on vessels;
- ✧ GPS: provide a benchmark of time and location;
- ✧ ARPA radar: automatic plotting technology can also be applied to the AIS target, etc.

Apart from these technical tools for navigation information, seafarers also want to get some more dynamic real-time information about the port, wharf and waterway. Shore party also wants to inform the ship of some situation in time, or get more information about the concerned other ship.

From the analysis of the above problems, it can be seen that:

a) There are demands to get or exchange information between vessels or vessels shore. This information has a direct impact on the improvement of

ship navigation safety and the improvement of the efficiency of management of ports and waterway;

b) The acquisition of information should be convenient to navigators, which can reduce the current burden for OOW;
c) Integrating the above tools to form an comprehensive navigation system and shore side comprehensive marine management system to form the vessel – shore integrated navigation system is the direction to realize the above two kinds demands;
d) The onboard and shore-based existing technology provides possibility of such integration.

Therefore, a new concept that the integration of existing onboard and shore-based aid and navigation methods can help to exchange navigation information more widely and comprehensively, so as to further improve the management efficiency of navigation between vessels and shore, is gradually formed. In the process, some countries and organizations are consciously or unconsciously conducting researches, and putting forward some preliminary ideas.

3.2 The course of proposing e-Navigation concept

It is because of the advocating of different countries and related organizations, and the concept of "e-Navigation" gradually becomes clearer, and entered into the formal development stage. The concept of e-Navigation has entered in the discussion of the shipping industry since 2005 when the British Ministry of Transportation proposed the earliest concept e-Navigation, which based on the consideration of its beacon infrastructure and awareness of the status of Marine Navigation areas lacking of coordination. E-Navigation again entered into public view is in November 2005 in *IALA Global Ship Tracking Seminar* in Kuala Lumpur.

Since 2006, the general secretary Mr. Efthimios E. Mitropoulos of IMO expressed on many occasions and emphasized a maritime new concept - "e-Navigation", which clearly demonstrates the formally proposal of e-Navigation around the world. In the future, under the guidance of IMO, this concept will gradually become more concrete, and eventually form a new kind of technology and better marine environment, whose purpose is to promote the goal of 'Safer Navigation, Cleaner Ocean, Easier Operation' .

Since 2006, the following situations of IMO are notable:

In the 81th meeting of Maritime Safety Committee (MSC) of IMO in May 2006, Japan, the Marshall Islands, the Netherlands, Norway, Singapore, the United Kingdom and the United States raised a joint proposal to the committee: The Development of e-Navigation Strategy. The committee in the end passed the new project about e-Navigation. From that time onwards, it became a research project of communication working group of the Navigation Safety Subcommittee (NAV) of the International Maritime Organization. Because information transmission depends on the radio, e-Navigation is also incorporated into IMO radio communications and the scope of work of Radio Communications and Search and Rescue Committee (COMSAR). The incorporation is required to be completed before 2008. Then e-Navigation has started to sail.

In May 2006, IALA 16th congress held in Shanghai with "digital world beacon" as the theme of this. The concept of e-Navigation for the first time puts forward: e-Navigation is the way through the electronic collection, integration and display in the ship and shore maritime information, in order to enhance the capacity of ship sailing in the whole process of the berth to berth, enhance the capacity of corresponding Marine service, safety and security, and the Marine environment protection.

In May and July 2006, IMO's Maritime Safety Committee (MSC) and its Navigation Safety Subcommittee (NAV), respectively held meetings, in which the development of e-Navigation were set as a high priority project. On the 52nd meeting of the Navigation Safety Subcommittee of the IMO (NAV) in July 2006, IMO formally put forward the concept of e-Navigation. At the same time, the Navigation Safety Subcommittee (NAV) decided, in accordance with the instruction of the Maritime Safety Committee (MSC), to set up a formal communication working group and start to develop e-Navigation strategy, and proposed corresponding work plans.

In the 53rd session of Navigation Safety Subcommittee of IMO in London, *e-Navigation development strategy* was listed as high priority issues. NAV53 meeting set up an e-Navigation working group to discuss the issue. On NAV53 meeting, subcommittee basically adopted the definition of e-Navigation IALA put forward: e-Navigation is the technology to coordinately collect, integrate, exchange, display and analyze maritime information by electronic way in the vessel and on the shore to enhance the related services of ship voyage from berth to berth, and achieve the purpose of protecting maritime safety, security and marine environment.

The meeting also established the core aim of e-Navigation: considering the basis of the hydrology, meteorology, maritime information and risk, e-Navigation can benefit ships safety and security, the monitoring and management of the vessel traffic; and effectively promote the data exchange from ship to ship, ship to shore, shore to ship, shore to shore, and between the other users. E-Navigation provides opportunities to improve the efficiency of transportation and logistics, and can support emergency response and rescue effective operation. It will establish a safety evaluation system with high accuracy, integration and continuity, and achieve the goal of maximizing the security and minimizing risk through synthesis and display of the information on the ship and shore by artificial interface. It will achieve the goal of managing user workload through synthesis and display of the information on the ship and shore. At the same time, participate actively in user activities and provide decision support.

E-Navigation should satisfy users' demand and facilitate training in the process of development and implementation; it should be beneficial to the global coverage, unified standards, compatible, and convenient operation in equipment, systems, symbols, operation procedures, etc,; it should be beneficial to apply to all potential users.

So far, the concept of e-Navigation has basically achieved consensus in the international shipping industry, as shown in figure 1.

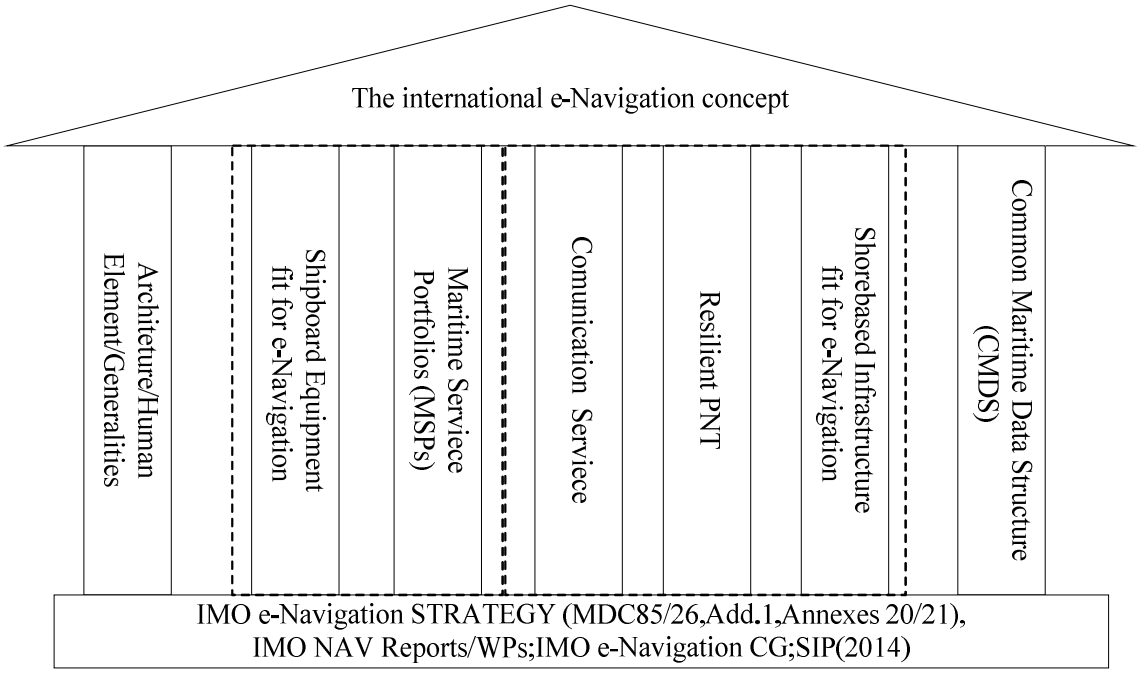

Figure 1 – E-Navigation concept map

Source: IALA, 2014

3.3 Basic framework of e-Navigation

In 2009, e-Nav committee of IALA proposed the framework of e-Navigation; Figure 2 is a diagram of e-Navigation System Structure (Zhang & Zhu, 2012).

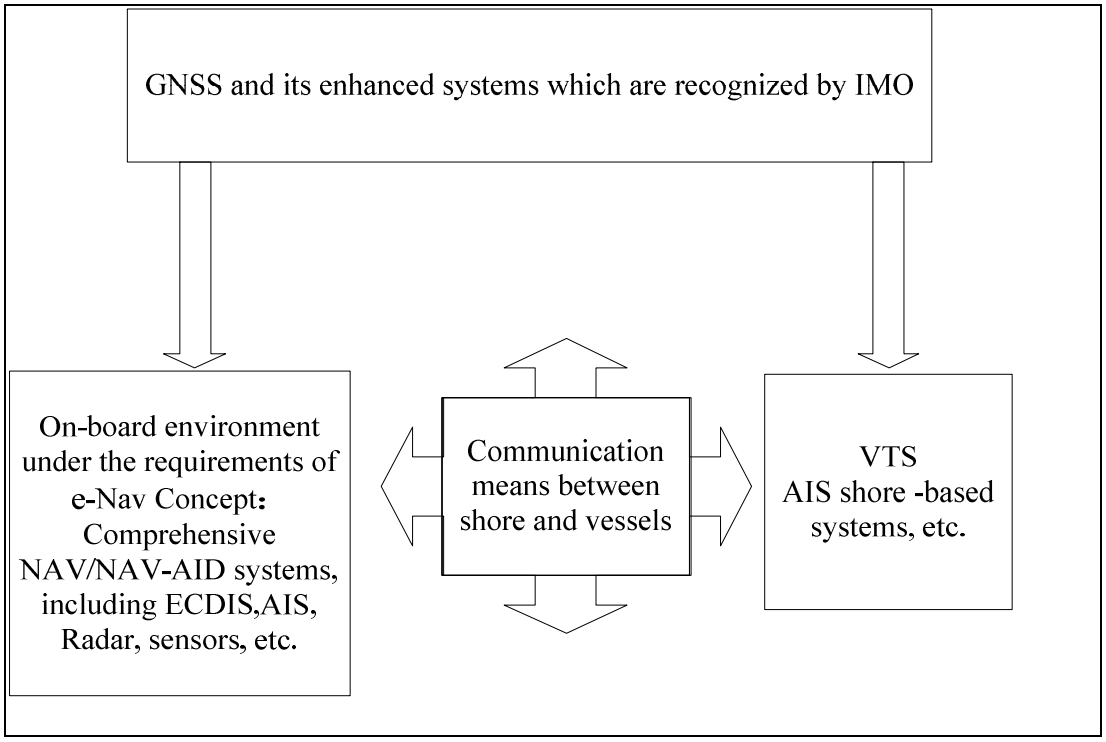

Figure 2 - E-Navigation system structure

Source: Zhang & Zhu, 2012

Currently, guided by IMO, with the joint efforts and collaboration of IALA, IHO, ITU, IEC and other international organizations and countries, the basic framework of e-Navigation has become increasingly clear. From physical framework, e-Navigation can be divided into shore-based and ship-based departments. Overall, it contains three elements (Yang, 2012), namely, the basic infrastructure, communications systems and navigation systems, as shown in Figure 3:

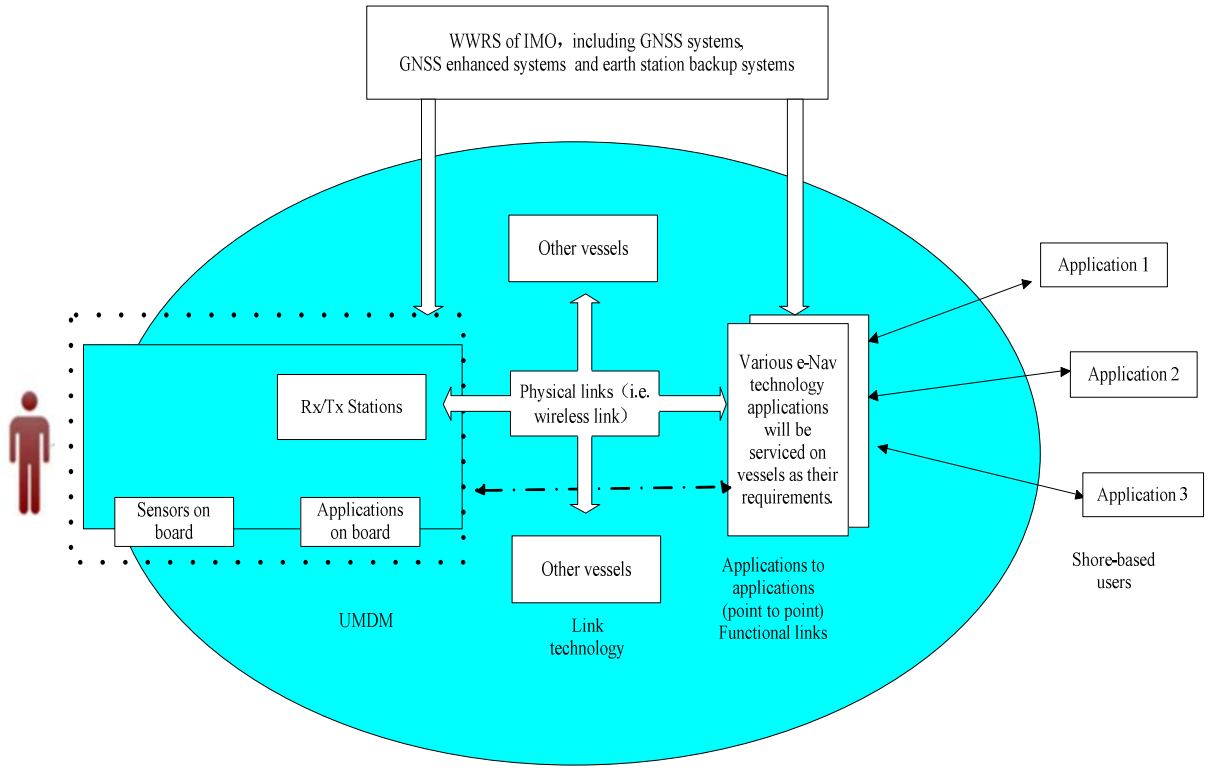

Figure 3 - E-Navigation basic framework

Source: Yang L., 2012

As shown in Figure 3, communication system is mainly responsible for shore-vessel, vessel-shore, and vessel-vessel, shore-shore communication, which is infrastructure of e-Navigation and plays a key role.

E-Navigation Strategy proposed by IALA is: to integrate existing and new navigation equipment via electronic information, especially electronic equipment; to collect, integrate and display maritime information onboard and ashore to enhance maritime services, safety and security capabilities of the berth-berth ship's voyage, and better protect marine environment and improve navigation safety and efficiency.

The "e" in E-Navigation is synthesis of electronic (electronic) and strengthening (enhanced), namely "through electronic (electronic) ways to enhance (enhanced) navigation", and not merely as "electronic". IALA hopes to provide definition of

e-Navigation to relevant international organizations and the shipping industry absorb demands of all parties, to make standard on ship-to-ship, ship-to-shore data, packaging, encryption, data link, check, correction, integrated display.

E-Navigation consists of three parts, namely shipping system, shore-based systems and digital communications links. It is an open system structure based on basic data exchange and information demonstration standards of HMI (Human Machine Interface) (Lou, 2012). Under consideration of benefit of equipment manufacturers, it must be helpful for navigation; adaptability to new technologies and training of users are applicable to all ships (such as SOLAS ships, fishing boats and yachts). There should be a full set of standard communication sentences used by ships to provide aids to navigation for watch-keeping officers, to offer tightly coupled aviation and maritime navigation, applications of search and rescue information. In addition, full benefits of the existing system should be known and understood, especially AIS and different installation requirements of SOLAS for all grades of ships. In order to achieve:

1) Enhance navigation safety, maritime security, environmental protection, national interests and maritime search and rescue.
2) Provide a comprehensive or systematic solution to shore based department and shipping activities.
3) Improve level of human-computer exchange, provide clear information to mariners in order to facilitate safe navigation and reduce collision and grounding.
4) Harmonization and standardization of information, information transmission, the device interface (such as: Plug and Play), function, and maintenance of data, interfaces, openness and transparency, fully accommodation to trends of today's electronic information technology.

5) Technical recommendations for the development of alternate emergency management and system failure, including application of traditional sailing skills, such as lights, beacons, radar plotting and so on.

IALA e-Navigation coordinates information collection, integration, exchange, presentation and analysis onboard and ashore through electronic means to enhance navigation and related services, in order to protect maritime safety, security and protection of marine environment, thus contributing to shipping efficiency and safety at sea. IALA also pointed out that the e-Navigation systems framework building must be guided by user demand and the main components including vessels, offshore systems, and navigation and communications infrastructure.

Shipboard navigation system is the core of ship-based system, the system integrates various sensors onboard (including all bridge, cabin, cabin sensor) to collect information on a variety of ships in real time. Core elements of ship-based systems include: AIS, Radar, VHF/HF/MF, GMDSS, GNSS and terrestrial navigation system/radio navigation system, long-range identification and tracking LRIT, MSI, Navtex, satellite communications systems (INMARSAT, VSAT), mobile cellular communications, ECS / ENC / ECDIS, Visual (ECS), voice recognition, CCTV, portable navigation unit, assisted berthing, virtual navigation mark, hydrological and meteorological sensors to reduce human error on analysis and warning capabilities. Ship-based system should be able to encourage active participation of the crew and prevent the crew from distraction during the course in order to reduce workload of crew.

E-Navigation shore-based system should integrate all the available shore-based vessel traffic management (VTS) systems and related services, so that shore-based operators can understand and use (switching and transmission) a variety of ways to offer information data, in order to ensure navigation safety and improve operational efficiency.

Navigation and communication infrastructure should meet the seamless transition; network should reach areas between ship-ship, ship-shore, competent authorities and other relevant corporate. Users of e-Navigation should concern whether the information obtained meeting their needs, without knowing specific technical subsystem resources or equipment resources; and for e-Navigation system, it requires the user to perform data request service to get data from different technical services subsystems, and it will present the user with information in a standard data format, which is appropriate meet needs of users.

Thus, e-Navigation systems technology stands on the top of information services, with intellectualization as the guiding principle, communications as the cloud of navigation. It integrates all relevant maritime technical service system to transmit data according to a unified business model. And ultimately users' access to data, hidden data sources and security system communications intelligence service can be achieved to complete simple and effective communication between ship-ship, ship-shore, shore-ship and shore-shore and improve the efficiency of maritime transport and management of port risk. It is of help to get the best combination of buoy, and to get understanding of environment onboard and ashore, to expand performance VTS and to reduce information overload without increasing additional workload but the watch keeping officers needs adapt these changes.

In accordance with IMO's consideration, through the implementation of e-Navigation, hoping to achieve the following objectives:

1) Taking into account the hydrographic meteorological, navigational information and risks to promote safety of vessel navigation;
2) From the shore/coastal location suitable facilities, promote vessel traffic observation and management;

3) To facilitate communications, including data exchange, between ship-ship, ship-shore, shore-ship, shore-shore and other users;
4) Provide an opportunity to improve transport efficiency and logistics;
5) Support effective implementation of accident response, and search and rescue services;
6) Demonstrate accuracy integrity and continuity for importance of a security system;
7) Integrate and display the information onboard and ashore via a user-friendly interfaces to maximize the advantages of navigation safety and minimize any risk caused by confusion or misunderstanding of users;
8) Integrate and display the information onboard and ashore to manage the workload of users; at the same time, to stimulate and attract users, and support decision-making;
9) Through the development and implementation process, provide training and familiarization to users;
10) To promote global coverage, consistent standards and arrangements, and mutual compatibility and interoperability of equipment, systems, symbols and procedures in order to avoid potential conflicts between users;
11) Updates facilitate all potential maritime users.

As shown in the target above, e-Navigation is a complicated systematic project, and with continuous development of actual needs, the implementation of e-Navigation needs not only coordination between international organizations and countries, but also a lot of basic infrastructures of communications, navigation, detection, identification and other facilities to support.

3.4 Restrictions and difficulties in implementing e-Navigation

Based on the research of the e-Navigation above, it can be found that technology integration is the key to shipping systems. Five functions of shore-based system: safety, security and emergency response, pollution prevention and coordination of business services are difficulties. Global development of satellite broadband digital communication is the basis of system operation. Constraints and difficulties limited current implementation of e-Navigation mainly include the following points:

A. the existing legal framework. (such as SOLAS ship)
B. the captain remit. (such as provisions that the captain is ultimately responsible for the ship)
C. technological limitation of existing handling capacity and man/machine interface, especially integration for navigation equipment from different periods, different manufacturers and different functions.
D. the lack of requirements on mandatory configuration .
E. electronic chart is not perfect and too expensive.
F. skill level of the crew and VTS operators , work process and training.
G. limited technology (data processing ability)
H. how to win the support and favor from other groups.
I. restrictions on fiscal and policy (e.g., political limits caused by national security problems).
J. market/business restrictions (such as competition, requirement of configuration).
K. radio spectrum resources (e.g., frequency of AIS, global bandwidth limitations).
L. e-Navigation needs further consideration about exchange of business information and information security, and boundary of responsibilities of related organization, which is impossible to isolate.
M. Contact, coordination and cooperation between IALA, IMO and other international organizations (such as IHO, ITU, IEC, etc.)
N. The role of IALA and IMO in e-Navigation strategic planning groups.

3.5 E-Navigation strategic implementation plan

In 2006, IMO accelerated the progress of the development of electronic navigation strategy, decided to increase a priority project to develop electronic navigation. IALA is organizing to make standards on relevant technology of the electronic navigation to accelerate electronization of navigation service.

At the 53rd IMO NAV session in 2007, the meeting classified the development strategy of e-Navigation as a high priority issue, and adopted the definition of e-Navigation put forward by IALA. MSC86 approved the work plan of e-Navigation strategy implementation coordination and make it the joint work task for NAV, COMSAR and STCW subcommittee in the period of 2009-2012.

At the 56th Navigation Safety Conference, e-Navigation working group reviewed the report above, and re-established the communications group led by Norway, in order to complete research on system framework, promote technology, laws and regulations, training, operation and gap analysis, it is required to submit work report to COMSAR15 and NAV57. The conference also requires the working group to prepare IMO information materials about e-Navigation concept and plan for strategic implementation, for the use of member countries and international organizations. According to strategic needs of e-Navigation, identify and describe the data frame to support users' requirements and ensure to promote coordination to the largest degree.

In March 2011, e-Navigation working group discussed work report submitted by Norwegian communication group on the conference of COMSAR. The report covered two modes of future navigation, communication in polar waters, setting up the data access and information service framework, functional requirements of SOLAS IV / 4, prospective study on e-Navigation and GMDSS and preliminary gap analysis report, etc. IALA and IMO will also put forward more effective and practical solutions on the aspects of standards, organization, and funds, etc., aiming

at existing problems. IHO has decided to plan for the future of e-Navigation before decision about e-Navigation made by IMO. First, a new geographical spatial data standard S-100 will be developed, which can realize many functions that can not be offered by S-57 standard. S - 100 will support S - 101 and S-102. S-101 is enhanced ENC, and S-102 really achieves nautical publications information encapsulation. S - 100 will support new or improved functions offered by IALA e-Navigation Committee, in ENC, MSI, tidal, routes, ports and VTS service guide, AIDS to Navigation, meteorological data transfer and etc. to ensure that common protocol is used in data exchange between ship and shore.

CHAPTER 4 RECENT RESEARCH RESULTS OF E-NAVIGATION

4.1 Research on technical structure of e-Navigation

E-Navigation technique structure is the foundation of e-Navigation study. Since e-Nav Committee was established, the Technical Framework Working Group (Working Group 5) continued to carry out related research, determined the basis for e-Navigation on the overall technical framework, and also released *IALA Guidance of e-Navigation shore-based systems on technical framework e-Nav-140*. In 2014, e-Nav committee completed the following work:

4.1.1 Amendment on technical documents of e-Navigation shore-based framework

IALA Guidance of e-Navigation shore-based systems on technical framework e-Nav-140 were *r*eleased (2nd Edition). This edition includes the following elements:

A. Background and concept of e-Navigation;
B. Overall Framework of e-Navigation including the ship, shore and communications systems;
C. The flow of information and unified data structure in e-Navigation technical Framework;
D. The role of maritime services in e-Navigation technical framework;

E. The concept of IALA e-Navigation stack and its position and role in the e-Navigation technical framework;
F. The relationship between IALA e-Navigation Stack and the IHO Registration.

4.1.2 Draft technical documents of CSSA

The duty of IALA is to study and unify shore-based navigation aids system in the world and establish a unified system of shore-based navigational aids for IALA members. In 2013, E-Nav Committee began drafting technical documents about technical framework of unified shore-based systems (Common Shore-based System Architecture-CSSA) on the basis of completing *IALA Guidance of e-Navigation shore-based systems on technical framework e-Nav-140.*

CSSA shore-based systems only concerns land-based systems and it is the further research and discussion of shore-based system in the overall framework of e-Navigation. In September 2013, on its 14th conference of e-Nav Committee, Technical Framework Working Group submitted the framework of *IALA Guidance of e-Navigation shore-based systems on technical framework e-Nav-140*. After the conference, the main tasks of Technical Framework Working Group are to further study and complete the draft of technical document.

4.2 Research on MSP

Since IMO NAV Committee at its 57th meeting (June 2011) adopted the concept of the Maritime Service Part (MSP), the concept of MSP and technology research have

become an important research field of e-Navigation, as well as the focus of research conducted by e-Nav Committee Technical Framework Working Group.

4.2.1 Backgroud of MSP

The implementation of e-Navigation follows a principle that is unified or standardized principles. Unified or standardized principles are reflected in many aspects, such as unified data structure S-100. S-100 is a standard e-Navigation System for lower data structures. On the basis of S-100, e-Navigation technology infrastructure should support the realization of a number of solutions. In fact, it is to achieve a variety of e-Navigation services. These services should reflect the unified or standardized principles in different places of the world.

Only various services of unification or standardization being achieved, technology infrastructures in e-Navigation between ship and shore can be integrated through standardized interface and be connected via a communication link to support implementation of a number of e-Navigation. Based on the discussion above, the concept of Marine Service Set (MSP) came into service.

4.2.2 MSP and understanding

Currently IMO interprets MSP as: MSP refers to a collection of standardized, operational or technical maritime services in a given waters, waterways, ports, or similar areas provided by the shore-based department to crew members.

MSP is established by regions, MSP areas include:

- ✧ Port Area;
- ✧ Coastal or restricted waters;

- ✧ Ocean sailing area;
- ✧ Sea area outside the coast;
- ✧ The Arctic, Antarctic and remote areas.

In e-Navigation technology framework, MSP is at the interface between the shore-based department and communication systems. All e-Navigation services will be unified to the MSP by shore-based department and be accessed to communication systems by MSP between ship and shore, then be submitted to ship users. For MSP understanding can be started from the following four aspects:

A. For concept of e-Navigation itself, MSP is a reflection of e-Navigation from fantasy to specific function;
B. For e-Navigation users, MSP accepts optional packages of e-Navigation services and MSP can be used internationally or regionally;
C. For authority in charge of maritime security: it is their obligation to establish and offer excellent MSP system;
D. For international maritime community: MSP is one of the next key studies in development of e-Navigation.

4.2.3 Summary of MSP from IMO

Currently research on and extraction of MSP is the main duties of IMO and IALA. For instance, description of its name, definition, function, standard research on interfaces, and data structures, etc. promotes the product.

MSP can also be understood to provide standardized services to shore based department. IMO currently has summed up 17 MSP service offerings:

- ➢ MSP1: VTS Information Services (IS);
- ➢ MSP2: VTS navigation aids and services (NAS);
- ➢ MSP3: VTS traffic organization service (TOS);

- MSP4: Local Port Services (LPS);
- MSP5: Maritime Safety Information (MSI) services;
- MSP6: Pilotage Services;
- MSP7: Towage Services;
- MSP8: Ship Reporting;
- MSP9: Ship Telemetry Systems;
- MSP10: Telemedicine Maritime Auxiliary Services (TMAS)
- MSP11: Maritime Auxiliary Services (MAS);
- MSP12: Chart Services;
- MSP13: Nautical Publications Services;
- MSP14: Ice Navigation Services;
- MSP15: Weather Information Service;
- MSP16: Real-time Hydrological and Environmental Information Services;
- MSP17: Search And Rescue (SAR).

4.3 AIS and research on communication

In recognition of AIS system to be main means of communication in the future of e-Navigation environment, e-Nav committee had integrated the AIS working groups and communication groups together to carry out research on e-Navigation communication technology in 2012. E-Nav AIS Committee and communication working groups held its 14th conference to issue a number of technical documents on VDES in September. It explained VDES technology and made recommendations to how to use VDES technology for IALA member states.

4.3.1 Concept of VDES

IALA e-Nav committee proposed the concept of second generation of AIS (AIS2.0) in 2009, and put it into “global radio communication plan” developed by IALA. The second generation provides AIS data communication by expanding frequency of AIS system and increasing AIS channels to make it as dominated means of communication in the future e-Navigation System. Therefore, IALA proposed for spreading AIS program, and submitted its proposal to IMO, ITU and other organizations. In 2012 at the World Radio Conference, ITU basically agreed to the AIS spreading scheme and initiated a revision of Appendix 18 in *World Radio Regulations* to increase the spectrum for AIS.

In May 2013 at the ITU-R WP5B conference, IALA and several member states together introduced the concept of VDES and obtained approval from ITU. VDES, namely VHF data exchange systems (VHF Data Exchange System), ITU sent a memorandum on VDES link to IMO, IALA and other relevant organizations, and planned to expand the focus of research on VDES.

4.3.2 Usages of VDES

Proposing VDES is to solve overload of AIS VHF data link and protect the original channel AIS (AIS1 and AIS2) to realize AIS automatic identification and collision avoidance function. VDES is expected to run as an integrated system (including AIS, special messages (ASM) and VHF data exchange (VDE), completing vessel-vessel and vessel-shore communications, including satellite uplink and downlink). The system will use spectrum resources in Appendix 18 and standards of ITU. ITU WP5B Working Group agreed to provide IMO, IALA and ITU other relevant working groups with working documents to support VDES, and it also agrees to make relevant VDES working documents to submit to the next WP5B conference for discussion in November 2013.

4.3.3 Selection and use of VDES frequencies

On the WP5B conference in May 2013, WP5B provided a description and selection of the following VDES frequency:

VDES system considered both the WRC-15 agenda 1.16 and the WRC-12 modifications to Appendix 18, including usage of roadbed and satellite channel. Through application of AIS and transformation of ASM to other channels, and allocating public communication (VPC) duplex channels for digital modulation signal to protect the integrity of AIS VHF data link. The method above is qualified to describe VDE ITU-R M.1842. VDES integrated AIS, ASM and VDE functions, including desired channels to complete their functions. Table 1 shows available channel arrangement and function of global VDES usage:

Table 1 - Allocation of frequency and channel of VDES

No. of Channels in Appendix 18	Launching frequency(MHz) of stations onboard and ashore	
	stations onboard	Stations ashore
AIS1	161.975	161.975
AIS2	162.025	162.025
75 (AIS of long range)	156.775 (Only launching onboard)	Not available
76 (AIS of long range)	156.825 (Only launching onboard)	Not available
2027(ASM1)	161.950(2027)	161.950(2027)
2018(ASM2)	162.000(2028)	162.000(2028)
24/84/25/85(VDE1)	100kHz Channel (24/84/25/85，Downward used by combination) (vessel-satellite)	100kHz Channel (24/84/25/85，Upward used by combination)
24	157.200（1024）	161.800（2024）
84	157.225（1084）	161.825（2084）
25	157.250（1025）	161.850（2025）
85	157.275（1085）	161.875（2085）
26/86 (SAT1) (VDE2)	50kHz Channel (26/86，Downward used by combination) (vessel-satellite/shore)	50kHz Channel (26/86，upward used by combination) (ashore-vessel/ satellite)
26	157.300（1026）	161.900（2026）
86	157.325（1086）	161.925（2086）

Source: China MSA, 2013

It should also be noted that, according to the rules of the relevant wireless transfer in Appendix 18, more channels can be used in some areas.

4.3.4 Cases of VDES

4.3.4.1 Providing information about staff onboard.

AIS is used in some areas to provide some additional information about the ship, such as personnel information onboard. If there is an accident at sea, authorities can configure the available resources to start rescue. The system has been applied in the Baltic Sea and Netherlands, and the application is used for managing speed boats.

4.3.4.2 Extension of navigational information

In the implementation of Efficien Sea project in the Baltic Sea, the authorities and marine personnel test the functionality of shared aids to navigation information. Route planned onboard can be submitted to the competent bodies and other vessels. Authorities ashore can provide information about navigation infrastructure, weather, water, air, ship turnstiles plan, turnstiles order, suggestions on shipping routes and other information.

4.3.4.3 Route planning

In some areas planning routes by AIS information has been achieved. The combination between AIS information and other information (such as locks, water level information, etc.) can provide necessary information to designated shipping routes planned for the inland shipping between Rotterdam and Antwerp. With the combination between AIS information and lock information, the Captain can better plan the time required by passing the lock, so that the ship can be the most efficient in fuel consumption and save transportation costs. This function can also be applied when ships get into the port at sea.

4.3.4.4 Management for ship queue

In the English Channel, the Bosporus, locks and canals (the Suez Canal, etc.) are restricted by waters, so the ship must be instructed to enter in queue. In this situation, relevant information can be submitted to vessels by application of ASM.

4.3.4.5 Other applications

For CDES system that supports higher data processing capability, shore-based authorities can achieve more applications, such as issuing the latest information about charts, ice charts, tide and current model analysis, calculation and route recommendations based on routes suggestions resulted from the calculation of fuel consumption.

4.3.5 Research results on e-Navigation communication and other research results

The technical document draft about maritime radio communication systems and requirements should be prepared. The document comprehensively reviews each band and related technology in the field of maritime radio communications, and future prospects. E-Nav Committee will continue to revise this document. The document will also be submitted to the relevant working groups of ITU.

4.4 Research on ASM of AIS

Because VDES become the main means of communication of e-Navigation in the future, AIS messages (ASM) will get a lot of applications. E-Nav committee issued a technical document about recommendations on the unified application of ASM at its 13th conference in 2013.

In addition to standard text messages, ASM uses AIS channels to exchange information. ITU-R M.1371-4, Annex 5 provides technical guidance for application of ASM. PCTM ASM is being developed to establish and approve the standards.

IMO document SN.1/Circ.289 using the AIS-specific messages can only provide some additional information about the use of ASM and describe ASM in detail which has been suggested to the global users. The SN.1/Circ.289 is the standard information about ASM. When considering the use of ASM, sub-standard should be taken into account.

The purpose and scope of ASM are described as follow:

AIS was originally used to identify and track ships. It is achieved by sending and receiving ship static. Dynamic voyage related data and transmitting safety-related messages. AIS can also be used to send ASM for limiting communications. ASM can provide information which can not be offered by standard ITU-R M.1371 message.

ASM can both address and broadcast. ASM can process multiple pre-defined data packets, for example, ships can report information to other ships and shore stations; shore based department can publish airfield information, warnings and other information. AIS can ask the other AIS to get a message, and automatically receive information in need. The application of ASM will expand, but not replace the GMDSS and SAR and other standard services.ASM

ASM can use VDL link, through a pre-defined packet to get quick access to important information. Ships can transfer the following important information by ASM: dangerous goods information, information about the number of persons onboard, the expansion of static information, voyage related information, and route information. ASM can also be used by shore based department to issue information about meteorology, water, tides, environment and other information.

ASM will be widely used in e-Navigation environment. As e-Navigation tools, ASM can transfer messages that include vessel and shore-related information. For example, ASM can be used to ask aids to navigation ashore; shore-based department can ask if

the latest version is available for ECDIS onboard.

IMO provides a global ASM, which can be reviewed by a national authority. The competent bodies can regulate some applications that are not developed in regional and International ASM. A competent authority may also use ASM regulated by authorities in other regions.

IALA encourages its member states to cooperate in regional ASM management in order to unify the implementation of regional ASM and it recommends the adoption of the relevant policy in ASM management.

4.5 Data model and relevant research results on S-100

In the Data Model, the focus of present study of e-Nav committee is based on information standard S-100 and the data model. In 2013, it mainly completed the following work:

4.5.1 Draft guidance on formulating IALA S-100 specification

When drafting the guidelines, Data Model Working Group of the Commission fully considered relevant recommendations from seminar of e-Navigation S-100 Product specifications. Working Group and the IHO TSMAD Working Group (working group of data transfer standard and application development) cooperated to serve as the center of data model to carry out research, but research results have not yet been achieved.

4.5.2 Draft of information about specification on products of aids to navigation

E-Nav Committee Data Model Working Group at the 14th conference of the Committee submitted Draft specifications *of S-100 beacon message product*. Working group has studied the draft, and the focus was whether the products meeting required specifications. The Working Group believes that the product specification should be submitted to relevant institutions, and a special working group should be responsible for this, namely Product Specification Development Working Group. IALA 56th Council has agreed to the establishment of the special working group.

4.5.3 Research on IALA management based on standard of IHO S-110 and S-99

E-Nav Committee Data Model Working Group at the 14th conference of the Committee submitted the revised document of *1087 Guidance for IALA Domain Management Program by Registration of IHO Geographic Information*.

4.6 Research on test system of e-Navigation (prototype system)

In 2013, to strengthen guidance in the establishment and operation of e-Navigation test system, e-Nav Committee Working Group was set up to test the system. In 2013, the main research results are as followed (IALA, 2015):

The establishment of e-Navigation test systems and related requirements for research. Test System Working Group studied a number of input files including the test system, the draft Guide, recommendations on difficulty to achieve unified test system from ANM Committee, a number of issues about test systems from VTS Committee and International Workshop report of test systems submitted by Korea. Based on

these documents, the Working Group finalized its *Draft Guidance about Unified Report Results of e-Navigation Test System.*

Related issues about using the website submit the results of test system. At the 14th conference of e-Nav committee, the representative of Sweden introduced the e-Navigation Portal (www. E-Navigation.net).The website is set up and maintained by Danish Maritime Safety Administration. The Working Group discussed the report of the International Symposium e-Navigation Test System (Korea submitted). An important outcome of this meeting is: the possibility of using a common platform for the test system to carry out a feasibility study, and the assembly generally agreed to establish a global common test platform (frame). Members of E-Nav Committee both agreed and disagreed this proposal.

Favorable opinions:

- ✧ Sharing test system solutions in different geographical areas;
- ✧ To promote the rapid development and set up a test system.

Objections:

- ✧ Testing system takes longer time to response and it is difficult to manage;
- ✧ The use of a unified testing system framework would hinder innovative thinking.

The Working Group asked South Korea to continue research on common platform of unified test system, and the results should be timely submitted to the IALA.

CHAPTER 5 COMMUNICATION TECHNOLOGY OF E-NAVIGATION

As shown in Figure 2, in simple terms, the overall structure of e-Navigation can be generally divided into three parts, including the shore part, the physical part of the ship as well as the communication link between ship and shore, which is communication link between vessel-vessel, vessel-shore and shore-shore, and it plays a crucial role in the future of e-Navigation environment. In the future, e-Navigation systems will transmit information via electronic means of communication; share improved navigational aids and related information. It can be said that the future of e-Navigation system is a huge communication system.

Given the importance of wireless communications in the future of e-Navigation systems, it is necessary to analyze the advantages and disadvantages of radio communication technology which is currently available at sea.

5.1 Current methods of communication at Sea

Maritime radio communication is the primary means of communication at sea (Yang, 2009). Global Maritime Distress and Safety System (GMDSS) was passed in November 1988 (1974 Amendment to 1988 SOLAS Convention), and it was fully implemented in the beginning of February 1992. GMDSS mainly concerns satellite communications system composed of INMARSAT and SARSAT, radio communication system on land composed of intermediate frequency (MF), high frequency (HF) and very high frequency (VHF) (DMU, 2011). GMDSS realizes

distress alerts between ship-shore, shore-ship, the ship-ship, as well as search and rescue coordination and on-site communication, position indicating in distress and other major functions. Meanwhile, with the emergence of wireless broadband technology and development of AIS systems and mobile communications technology, mobile cellular communications technologies like Wifi, WiMax, 3G and 4G have been widely used in port approaches and other coastal regions, as shown in Table 2.

Table 2 - Current methods of radio communication at sea

Definition of e-Navigation area	GMDSS waters	wired broad-band (next to wharf)	Wi Fi	WiMax	Mobile communication	AIS	LRIT	INMARSAT	COMSATCOM	MF/HF (including NAVTEX)	NBDP
In the port	A1	●	●	●	●	●	●	●	●	●	
Approach channel	A1			●	●	●	●	●	●	●	
Coastal waters to area covered by mobile phone signal	A1				●	●	●	●	●	●	
Coastal waters to area covered by VHF(about 25 miles)	A1					●	●	●	●	●	
Coastal waters(about 100 miles)	A2						●	●	●	●	●
Open seas	A3						●	●	●	●	●
Polar waters	A4								●	●	●

●：Existing methods

Source: Yang L., 2012

A survey related to maritime broadband communications (including satellite broadband communications, Wifi and mobile phone, etc.) of Canadian Coast Guard shows that: 79% of the participants support broadband maritime communications. As for the three most frequently used communication methods listed in the research between ship-shore, shore-ship and between ship communication, participants prefer to use satellite broadband communications; most of the participants are also inclined to use the phone and Wi-Fi communication. Specific survey results are shown in Figure 3.

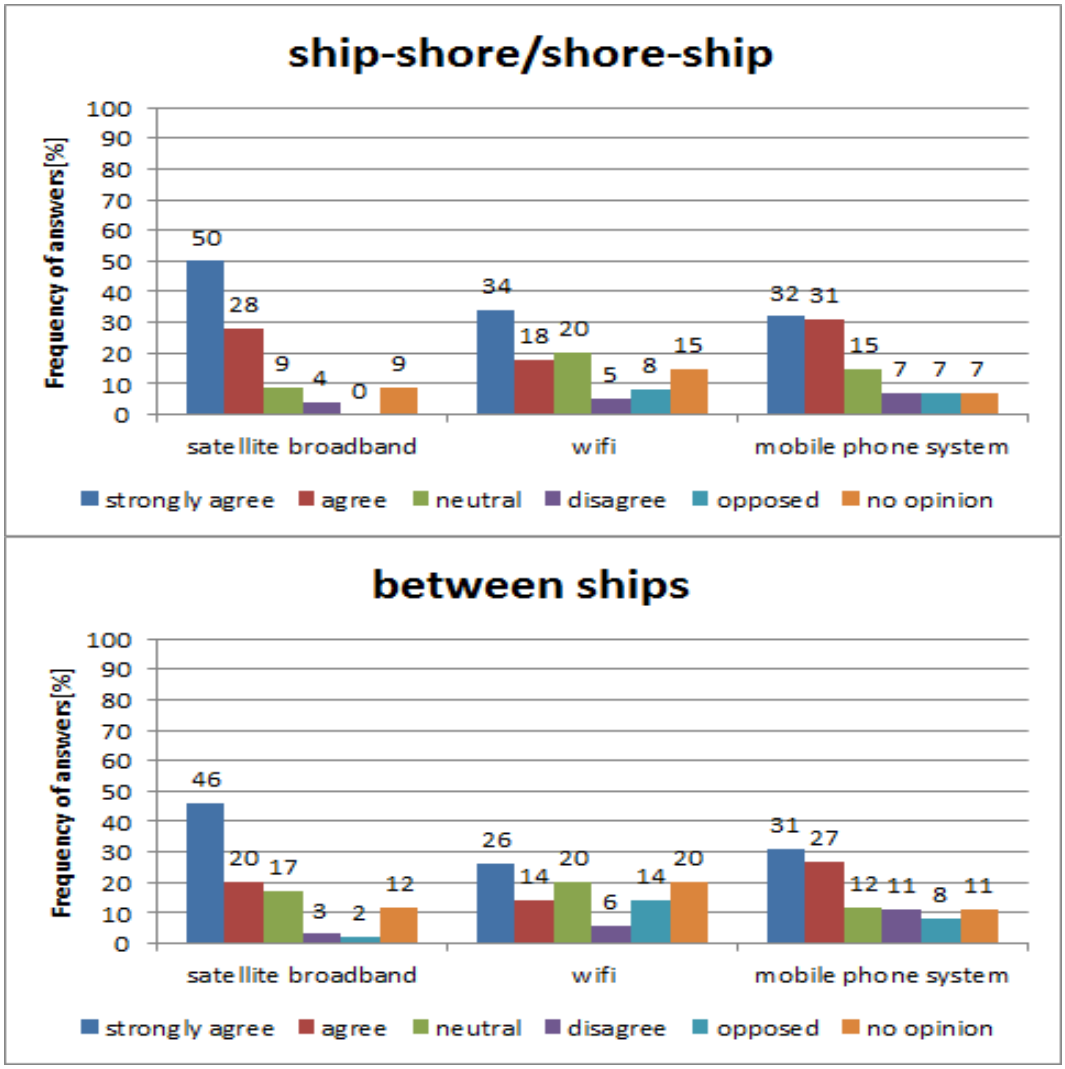

Figure 4 - Survey results of maritime broadband communications
Source: Canadian Coast Guard, 2015 (http://www.ccg-gcc.gc.ca/e-Navigation/Results)

5.2 Communication demand of e-Navigation and gap analysis

Under the framework of e-Navigation, communication system mainly includes voice communications and data communications, and communication range covers areas from the harbor to the open sea, even polar regions and other areas. Due to maritime safety information (MSI) and update of electronic data, dynamic data, digital communications between ship-ship and ship-shore (Zhu, 2011), communication under the framework of e-Navigation is developing toward digitization, high bandwidth, wider coverage and lower cost, in order to support data exchange of e-Navigation.

However, as shown in Table 3, the following three aspects of advantages and disadvantages in maritime radio communication techniques still exist such as digitization, low-cost communication (such as limited broadband, Wifi, WiMax, mobile phone technology, etc.) The biggest drawback is that the coverage is too small; while as for digitized and wide range of communication means (such as INMARSAT satellite), etc. under moderate conditions of bandwidth, the cost of communication is high; capacity of these communication means are low, which is not suitable for future communication requiring large volume of data. Thus, under the framework of E-Navigation, development of new communication system is in need to support development of e-Navigation.

Table 3 - Analysis of radio communication at sea

	Wired broad-band (next to wharf)	WiFi	WiMax	Mobile communication	AIS	LRIT	INMARSAT	COMSATCOM	MF/HF (including NAVTEX)	NBDP
Digitization	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Broad band	High	High	High	High	Low	Low	Moderate	Moderate	Low	Low
Coverage	Small	Small	Small	Middle	Middle	Large	Large	Large	Large	Large
Cost	Low	Low	Low	Low	Low	High	High	High	Low	Low

Source: Yang L., 2012

5.3 Plan for IALA radio communication at sea

IALA Committee of e-Navigation, through years of research, proposed three dominated means of e-Navigation data communications in the future and increased communication frequency requirements as followed in 2011:

In order to solve the gap between the means of communication and the current demand of e-Navigation, after years of research and conference discussion, IALA edited *Maritime Radio Communication Plan*, and proposed a solution. In 2011, they proposed three primary means of future e-Navigation data communications including: 2nd generation AIS (AIS2.0), VHF-based data communication using the frequency band 500 kHz for data communication.

5.3.1 The second generation AIS (AIS2.0)

Development of the second generation of AIS (AIS2.0) increases channels for AIS2.0. AIS2.0 includes four simplex channels and two duplex channels.

AIS1 and AIS2 (both simplex channel) are only used for safe navigation, report and confirmation of important positions and security communications between ship-to-ship and ship to shore;

AIS3 and AIS4 (simplex channel 75 and 76) is used for AIS satellite detection and ships tracking, which can be achieved by 27 AIS messages. These two adjacent frequencies are next channel 16, originally served as protection channel for channel 16. Studies have shown that 27 AIS short messages have a lower frequency of usage, which does not affect the use of distress channel 16;

AIS5 and AIS6 (duplex channels 27 and 28) are used for maritime safety and security related information and communications including meteorological data and AIS binary messages in accordance with IMO document, *Guidance for AIS Message* (S/N Circ.289). AIS2.0 will solve the congestion of AIS1 and AIS2 channel, good AIS satellite signal and effective information about maritime security can be ensured even in heavy traffic waters.

In addition, 70 AIS channel continues to manage AIS channel. AIS2.0 channel arrangement and its specific use are shown in Table 4:

Table 4 - AIS2.0 channel arrangement and functions

AIS channel (simplex or duplex)	AIS1 and AIS2 (simplex) Safe navigation	GMDSS AIS3 and AIS4 (simplex) ship tracking and GMDSS	AIS5 and AIS6 (duplex) Data communication	Channel 70 AIS channel management
Usage	Safe navigation distress and safety communications at sea and inland	Satellite AIS GMDSS	Maritime safety information General information communication	Unified administration of VHF data link according to documentation requirements of ITU - R M. 822-1
Frequency allocation	Assigned as a dedicated channel	A new frequency is in need to be allocated and dedicated as a channel	A new frequency is in need to be allocated, such as common channel	Assigned as a dedicated channel
AIS message type	Ship identification Ship dynamic data Ship static data Aids to navigation information	Satellite AIS Support broadcast of GMDSS message	Binary message of AIS S/N Circ. 289 international AIS binary cables	Cables of TDMA system management, such as cable 20, 22 for coordination of channel shared with other cables
Typical applications	Ship collision avoidance VTS tool Ship tracking GMDSS positioning	Coastal states detect vessels beyond AIS coverage The future of distress alerting	Warnings and advice for navigation Meteorological and hydrological information Vessel traffic management AIS channel management, VHF digital data channel in the future data exchange between vessel and shore	Channel switching FATDMA distribution Channel allocation
Suggested channels	The existing channel to retain	Channel 75 and 76	globally preferable dedicated channel 27 and 28	The existing channel to retain

Source: China MSA, 2013

5.3.2 VHF data communication

VHF data communications will provide high-speed data exchange between ship-ship, and ship-shore. AIS system does not and will not have such high-speed data

exchange capabilities. To solve this problem, VHF data communications should be used.

According to *Appendix 18 of Features of VHF radio systems and equipment in maritime mobile service to exchange data and e-mail* (ITU-R M.1842-1), it requires six consecutive VHF channel 25kHz, the best channels are 24,84,25,85,26 and 86. These channels may be used alone as a data communications channel and can also be combined into a wide band channel. The typical scenario is to use one of the four channels for digital communications in port waters and crowded waters, while the other two channels can be used for digital communication coastal waters between these waters.

With the combination of a plurality of channels 25kHz, a bandwidth of 100kHz is available in typical program, so as to have a larger broadband data communication than a single 25kHz channel.

5.3.3 Data communication by frequency of 500kHz

The band refers to frequency between 495kHz and 505kHz. 500kHz band can be used to broadcast maritime safety and security related information from ship to shore, with transmission distance up to 400 nautical miles and transmission deliberation 25kps. Current 424kHz, 490kHz and 518kHz NAVTEX system can be used together with 500kHz in the future.

5.4 NAVDAT communications

As early as 20th century, 500 kHz band is used for maritime distress calls and communications. However, with the development of GMDSS, the distress alerting

and communication capabilities gradually disappear. In 2007, at the Conference of World Radio, ITU has recovered to 500kHz band. To take full advantage of the larger coverage of 500kHz frequency to solve digital communication problems from shore based department to the ship, ITU made digitized modulation at 500kHz frequency to effectively transmit data, and at the same time, this application is defined as NAVDAT.

According to ITU test reports (ITU, 2010), NAVDAT can use hexadecimal or 64-QAM orthogonal frequency division multiplexing (OFDM). If using 64-QAM, with appropriate antenna height and sufficient transmit power, spectrum channel of 10kHz can achieve transferring rates of 47.4kbps, the coverage can be up to 400 nautical miles; if using 16-QAM, the speed can reach half of the 64-QAM, but it has lower requirements on transmit power, antenna height, with better noise immunity. For the same technique, if the transmission power is 1 kW, the coverage of NAVDAT can reach 320 sea miles; if the transmission power is up to 5kW, the coverage of NAVDAT can be increased to 400 sea miles in coastal waters. Thus, NAVDAT can be used for relatively high bandwidth digital communications.

In addition, since the frequency of NAVDAT is similar to NAVTEX, so for frequency from coastal stations, it only needs to go through a little modification to launch NAVDAT. Though NAVDAT has faster transmission rate and larger coverage, it also has its own shortcomings (IMO, 2012). According to characteristics of the radio transmission, the antenna length should match its wavelength to achieve best results. NAVDAT use medium wave band of 500 kHz, whose wavelength is 600 meters. No fading stable communication usually adopts half-wave antenna, which requires NAVDAT ideal antenna length of 300 meters. As for shore department, it can compromise, such as 1/8 wavelength 1/4 wavelength (75 meters -150 meters) antenna and increasing the transmission power; but for a ship, it is almost impossible to have a long antenna and large transmit power. To save space for installation, ships usually use whip antenna transceiver. Therefore, NAVDAT is the most suitable to

solve data transmission from shore-to-ship, and distance for data transmission between ship to shore, ship-to-ship will be affected by short antenna, low profile, low transmit power and ionospheric propagation limited by time. Namely: longer distance between shore-to-ship and shorter distance between ship to shore.

5.5 Development and prospect of NAVDAT

Since NAVDAT has network characteristic, data services can work across regions, the system can provide messaging, data, fax and other data services for specific users. By using addressing method, information can be sent to a designated receiving vessel. If the vessel is not within the scope of local service land-based system, it can contact shore based department for advertisement through shore-based network. Examples discussed above are simple, once digitized, high bandwidth, wide coverage NAVDAT being put into practice, a variety of shore-based services will continue to provide ship with further support for the development of e-Navigation.

NAVDAT marine terminal can use relevant software radio technology to integrate 490kHz with 518kHz of NAVTEX to achieve DGPS station and multifunctional information terminal. If the GPS are integrated, more accurate positioning information can be output via differential data. With the promotion of the system, NAVDAT terminal manufacturers will introduce more advanced and practical NAVDAT terminal platform.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The e-Navigation system coordinates, collects, integrates, exchanges and displays maritime information. It is to integrate the existing means of ship based and shore-based aids to navigation to achieve comprehensive communication between navigation and aids to navigation and enhance the capacity of the ship during the entire course, the capacity of corresponding marine service, safety and security as well as the ability of marine environmental protection, in order to further improve the management efficiency of navigation between vessel and shore. It is a comprehensive integrated system platform, which is a growing and dynamic concept combining the present and future navigation systems. It will fundamentally solve the independence of existing communication and navigation technology; reduce the burden of watch keeping officers; Reduce the growing configuration of shipboard equipment; unify standards on ship-to-shore equipment; improve the efficiency of the use of users; improve the amount of information exchange between ships and maritime management agencies; continue to diversify marine personnel; put an end to the degradation and other problems of not commonly used skills for crew members; promote harmonization of marine navigation system, to achieve the goals of shore-based service guided by user demand, thus to create a new technical means and a new marine environment, to greatly enhance the operational efficiency and safety of navigation.

At the present stage, the data transmission test of NAVDAT has been completed (CMSA, 2013a). Even NAVDAT only solves one-way digital communications problems between shore - ship, but its high transmission rates and larger coverage range contribute to broad prospect (IALA, 2009). With mandatory carriage of ECDIS, update of electronic chart data is becoming increasingly prominent. If NAVDAT can be used to transmit electronic chart updating data, the ship will get great convenience. Differential GPS data broadcasting can solve single broadcasting and offer a new way to obtain the differential information for the users. There is often some new navigational dynamic information, navigational warnings, and navigation announcement information when ships entering and leaving the port, if NAVDAT can be used to broadcast, vessels can get timely and accurate information. Meteorological and hydrological information offer great help for sailing. If the real-time information can be broadcast, ships in related areas can get better service.

6.2 Recommendations for research on e-Navigation in China

As A-Class member of IMO and leading members of IALA, China hopes to become a great power in the future strategic development of e-Navigation in maritime services. Therefore, China initiates e-Navigation related research independently and combined it into the world e-Navigation system, which is the only way for construction of marine powers. Therefore, recommendations are issued as follows:

6.2.1 Further strengthen research on e-Navigation

At present, as the shore-based system technical structure, Maritime Service Portfolios (MSP), VDES, common data model and other technologies become gradually explicit and EfficenSea, MONALISA, ACCSEA and other e-Navigation test systems successfully implemented, e-Navigation has gradually changed from an

illusory concept to a real scheme of implementation with a clear structure, specific functions and explicit implementation technologies. Now, e-Navigation researches conducted by China Maritime Safety Administration are still in the theoretical level and lack the real development and application of e-Navigation system. There is a big gap between China and other powerful foreign marine countries in the term of e-Navigation research and applications. China MSA should make more efforts on e-Navigation researches and development, put into more human and material resources, strengthen the cooperation with social research institutions outside the maritime system, and establish several e-Navigation test systems in accordance with the concept of e-Navigation so that the study and implementation of comprehensive e-Navigation in China can be achieved, which will also promote the development of maritime security and improve the participation and status of China in the international maritime security affairs.

6.2.2 User demand research on e-Navigation in China waters

IMO, when determining e-Navigation strategy, always follow the user-demand-driven principle, rather than technical-development-driven principle. Based on this viewpoint, IMO, in promoting the early development of e-Navigation, with the support of international organizations such as IALA, completed the world e-Navigation user-demand research report in 2009. Then, they conducted a gap analysis according to users' requirements and put forward a number of e-Navigation solution, and on this basis, promoted the next step of e-Navigation research work. It is because of the scientific users' demand research that e-Navigation related researches can move in the right direction.

China is a country with long coastline and numerous navigable waters. China MSA has established the advanced ship navigation systems, including visual aid system, DGPS system, AIS and VTS, etc. These unique navigation environments will

inevitably lead to a different situation between China maritime and related user demand for China maritime safety services and the world e-Navigation user demand. Therefore, it is of great significance to carry out the comprehensive maritime safety user demand research in China waters in order to complete the gap analysis of navigation safety, to determine the e-Navigation solution, and to formulate e-Navigation development strategies and the development strategy and planning of navigation safety.

6.2.3 Making development strategy on e-Navigation

According to the international e-Navigation research development present situation, China MSA should draw up Chinese e-Navigation research plan and development strategy based on the investigation of the user requirements. Through this strategy, China can further research as a whole strength, determine the research and development in key areas, research progress and targets, to lay a good foundation for e-Navigation development in China.

6.2.4 Establishing e-Navigation test-bed in China

Currently, a number of e-Navigation test-beds have been successfully set up and run in the world, typically including EfficienSea, MONALISA, ACCSEA projects and etc. The successful implementation of the testing beds play an important role in assessing and validating the e-Navigation related research results, testing the system performance, establishing the specific data models, MSP, ASM and submitting relevant registration, and will further improve the navigation security capability in the test-beds waters.

It is advised that China MSA, according to the result of user demand research, choose some waters to establish e-Navigation test-beds, so as to comprehensively promote the implementation of e-Navigation, to ensure the development of navigation security, and timely submit the relevant research results to IALA, IMO and other international organizations in order to improve China's status in the international maritime affairs.

6.2.5 Initiate research on key technology of e-Navigation

Nowadays, international e-Navigation researches dominated by IMO have gradually changed from an illusory concept to a real scheme of implementation with a clear structure, specific functions and explicit implementation technologies. In order to implementing e-Navigation shore-based technology structure, maritime service and (MSP) related technologies, VDES communication technology, the data model based on S-100, etc, it is of great importance for the e-Navigation development whether these key technologies can be successfully developed or applied. It is necessary to integrate related resources, conduct researches on these key technologies, and apply to the actual e-Navigation test-beds, so as to lay a solid foundation for the further development of e-Navigation.

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