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A study on the effects of e-navigation on reducing vessel accidents

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A STUDY ON THE EFFECTS OF E-NAVIGATION ON REDUCING VESSEL ACCIDENTS

By

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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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ABSTRACT

Title of Dissertation: **A Study on the Effects of e-Navigation on Reducing Vessel Accidents**

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The dissertation aims to evaluate how and to what extent e-navigation contributes to reducing accidents for SOLAS ships as well as non-SOLAS ships, hoping that the results are referred to IMO Member States when they are implementing e-navigation along with the maritime sectors such as shipping companies, crews on board ships and manufactures developing e-navigation related systems.

The study focuses on the potential effects of e-navigation based on tool kits of the IMO e-navigation for SOLAS ships and services of SMART-navigation, which is the Korean approach to implementing the e-navigation concept for both SOLAS ships and non-SOLAS ships. The processes and the methodologies that are used by the IMO to assess the effects of e-navigation are investigated. The vessel accidents for all ships in Korean waters and all Korean-flagged ships worldwide during the 5 years from 2009 to 2013 are analyzed. The formula is proposed to calculate the effects of e-navigation on reducing accidents, which can also be used by other Member States of the IMO when they implement e-navigation in their waters. The direct causes of accidents, which are reducible by the risk control options (RCOs), and the RCOs, which are applicable to non-SOLAS ships, are identified.

Additionally, an expert questionnaire survey is carried out with a view to supporting the validity of identifying the RCOs and the direct causes. The results are collated and evaluated for the potential effects of e-navigation on reducing accidents, in relation to type of accidents as well as type of ships, for comparison with the results obtained by the IMO and for reference of other Member States.

The concluding chapter examines the results of analysis of e-navigation's tool kits and methodologies to assess their effects on reducing accidents, and discusses the potential rate of accident reduction through e-navigation. A number of recommendations are made concerning the need for further investigation in quantifying the coefficient applied to the proposed formula for evaluating the effects of e-navigation.

KEY WORDS : Bayesian Network, Human Error, E-navigation, Maritime Service Portfolios, Navigational Accidents, Rate of Risk Reduction, Risk Control Options, Safety of Navigation, SMART-navigation, Strategic Implementation Plan

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LIST OF ABBREVIATIONS

The following abbreviations are used in the dissertation:

ABS	American Bureau of Shipping
AIS	Automatic Identification System
AtoN	Aids to Navigation
BN	Bayesian Network
CG	Correspondence Group
CMDS	Common Maritime Data Structure
COMSAR	Radio-Communications and Search and Rescue Sub-Committee
DMA	Danish Maritime Authority
DNV	Det Norske Veritas
EC	European Commission
ECDIS	Electronic Chart Display and Information System
EU	European Union
FSA	Formal Safety Assessment
GL	Germanischer Lloyd
HEAP	Human Element Analyzing Process
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IFSPA	International Forum on Shipping, Ports and Airports
IHO	International Hydrographic Organization
IHS Fairplay	Database Provided by Information Handling Service Enterprize
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
ITU-R	International Telecommunication Union Recommendation
KMST	Korea Maritime Safety Tribunal
LTE M	Long Term Evaluation - Maritime Communication Network
MOF	Ministry of Oceans and Fisheries, Republic of Korea
MSC	Maritime Safety Committee of IMO
MSP	Maritime Service Portfolio
NAV	Sub-Committee on Safety of Navigation of IMO
NCSR	Sub-Committee on Navigation, Communications and Search
NMA	Norwegian Maritime Authority
NTSB	National Transportation Safety Board
PLL	Potential Loss of Life
PNT	Data Position, Navigation and Time date
RDANH	Royal Danish Administration of Navigation and Hydrography
TRANSNAV	International Journal on Marine Navigation and Safety of Sea

	Transportation
RCO	Risk Control Option
SAR	International Convention on Maritime Search and Rescue (SAR)
SIP	Strategic Implementation Plan
SMART-Navigation	Korean Approach of Implementing the e-Navigation Concept
SOLAS	International Convention for the Safety of Life at Sea,1974
STW	Standards of Training and Watch-keeping Sub-Committee
VDE	VHF Date Exchange
VTS	Vessel Traffic Service
WG	Working Group
WWRNS	World Wide Radio Navigation System

1. INTRODUCTION

1.1 Background

The International Maritime Organization (IMO), ever since it was established, has focused on preventing vessel accidents by enacting minimum safety standards for ships and crews on board. As a result, there are now very few accidents caused by technical or machinery problems in the ship structure itself.

However, accidents still happen mainly due to human error, which is one of the most important issues concerning global maritime communities. For example, Rothblum (2012) demonstrated that more than 75 % to 96 % of maritime accidents are caused by human error. Barsan, Surugiu and Dragomir also demonstrated that more than 80% of maritime accidents are caused by human error (TRANSNAV, 2012). Further, these accidents indicate a rising trend as examined in paragraph 2.2.2 of this dissertation.

Human error is mainly rooted in fatigue, the lack of situational awareness and the safety culture of crews on board ship (Carter-Trahan, 2002)[1]. There have been limitations to prevent human error in terms of quantity and quality of information, complexity, lack of providing decision making support to help avoid dangerous navigational situations, and lack of response to emergency situations in a timely and adequate manner. One of the reasons of these limitations might be the quantitative limitation of the current analog-

[1] The author, Alicia C, shows examples of human errors in his dissertations, An examination of the human factors attitudes and knowledge of surface warfare officers (Chapter 4, page 10-14)

based maritime communication network and the different types of information used in each piece of navigational equipment on board ships as well as between ships and shore-based stations. This assumption is clearly supported by the user needs, which reflect the concerns that they experience most often during their work, according to a survey on e-navigation as shown in the IMO document NAV 55/INF. 9.

With regard to human error, the other point that the author would like to recall is Reason's SWISS Cheese Model which visualizes a number of barriers between existing hazards and a potential accident. However, the question why accidents occur - even though many layers of safety barriers, including assistance and decision support systems, might be installed - remains. Of course, there are holes in each of the layers that, if aligned, can allow an accident to occur (Hollnagel, Schröder-Hinrichs & Baldauf, 2012). Obviously, it can be interpreted that an accident could be prevented if one of the holes among the defense layers was blocked.

For example, this is clearly supported by Wagenaar W.A and Groeneweg J (1987)[2], introducing that most accidents are caused by multiple reasons that are combined together, ranging up to 58 types of reasons. They demonstrated that more than 96 % of accidents involve human error, and more than 93 % of accidents involve the combination of a number of human errors. The important point from the findings above is that each human error in an accident acts as one of the conditions to cause the accident, which means that an accident caused by combined multiple human errors might be preventable if one of the errors had been eliminated in advance and the chain had been blocked (Rothblum, 2012).

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2 With regard to this, for detail information, see paragraph 4(p. 594) and Table 4, "*Classification of human errors in 100 accidents at sea, according to Feggetter' s classification system*" (p. 595) of the article, "*Accidents at sea: Multiple causes and impossible consequences*" (Wagenaar W.A and Groeneweg J., 1987)

With regard to this, IMO has also been making efforts to reduce human error (Etman & Halawa, 2006)[3]. As one of its latest efforts, IMO has been preparing for the introduction of e-navigation. This initiative began in 2006, and IMO finally adopted the Strategic Implementation Plan (SIP) for implementing e-navigation into the maritime sectors[4]. The concept of e-navigation is defined, in Annex 20 of MSC 85/26 Add.1 (para. 1.1), as follows:

> *The harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of marine environment.*

This might mean that one of the global aims of e-navigation is to digitalize the current analog-based navigational equipment on board ships in order to reduce human error by providing much more safety information and reducing the burden on crews with regard to handling paper work regardless of the safety of navigation. In addition, it may solve the complexity[5] of navigational equipment and the lack of decision making by supporting crew members to avoid the dangerous situation on the ship's bridge.

In more detail, e-navigation is to enhance the safety of navigation by reducing these

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[3] They explained as "*IMO gave attention to the human element of daily ship operation and ship management*" (para. 4), and, as examples for that, listed the human error-related documents developed by IMO in their paper, "*Safety culture, the cure for human error : A critique*" (para. 4), such as Res. A.850 (20), A.947 (23) and A.900 (21) as well as the STCW Convention, the ISM Code and the IMO Casualty Investigation Code (para. 4)

[4] With regard to maritime sectors, it might include the potential e-navigation users in Table 1 of this dissertation. The users were identified and defined in the IMO document, MSC 85/26 Add.1 Annex 20.

[5] With regard to this, the e-navigation solutions, which were identified based on user needs, for example, solution 1 (improved, harmonized and user-friendly bridge design), solution 2 (means for standardized and automated reporting), and solution 4 (integration and presentation of available information in graphical displays) might contribute to solve this complexity. (See Table 4 in para. 2.2.3 for details).

kinds of human errors, or avoiding them in advance through its tool kits such as 7 kinds of Risk Control Options (RCOs) and 16 kinds of Maritime Service Portfolio (MSPs). With these tool kits of e-navigation on board ship or support from the shore-based station, a dangerous situation, which might potentially lead to an accident, could be prevented or corrected in advance by monitoring a ship's routing, informing the ship of much more safety information, and warning of dangerous situations.

In addition, because of the evolution in the communication network between ships and the shore side, e-navigation could greatly improve the efficiency[6] of maritime activities. For example, the more modernized and standardized information and communication technology of e-navigation such as the globally standardized and automated ship-shore reporting system[7] and the seamless transmission of electronic information and data between ship and shore, would allow the IMO to address the efficiency of maritime related business as well as the safety of navigation. Thus, IMO is able to talk about the safety and efficiency of navigation at the same time, which was generally not possible in the past.

The effect of modernized and standardized communication technology as a tool to increase efficiency is clearly supported by the European Commission's (EC) e-maritime project. The project was initiated in order to increase the efficiency of using the resources and to promote the competitiveness of maritime sectors (e-maritime, 2012) by

[6] The IALA (2011) introduces "*the higher efficiency and reduced costs enabled is one of the main broad benefits of e-navigation*" (para. 6, p. 3, e-Navigation Frequently Asked, 2011) .

[7] With regard to this, NAV 59/6 Annex 1 comments "*An investigation undertaken by the MarNIS project of 15 European ports found that around 25 documents had to be sent from the ship, or the ship's agent, in conjunction with a port call* " (p. 25, para. 7.2.4

the DIRECTIVE 2010/65/EU, and the DIRECTIVE emphasized[8] smooth and effective communication as the key element of the project.

Then, how and to what extent could e-navigation reduce such human error that causes accidents? This would be an important question to the stake-holders involved in the implementation of e-navigation such as Governments, shipping companies, shipyards and the relevant equipment manufacturers, and even crews on board ships. It could also contribute to maximizing the benefits of e-navigation in terms of effectiveness and efficiency when it is introduced and applied to the existing business processes of the maritime sector.

With regard to this, IMO's formal safety assessment (FSA) was carried out by Det Norske Veritas (DNV, Norway) and Germanischer Lloyd (GL, Germany) for the e-navigation SIP before it was approved by the Maritime Safety Committee (MSC) at its 95th session in 2014, including the risk and cost-benefit analysis, as set out in the IMO documents, NAV 59/6. Annex 1 (2013) and NCSR 1/28 (2014). Annex 7. According to these documents, more than 65 % of the direct causes of ships' navigational accidents, including collisions and groundings, caused by human error (p15) could be reduced by 7 kinds of risk control options (RCOs) of e-navigation.

However, even though the IMO document NAV 56/9. Annex 1 and NCSR 1/28. Annex 7 provide the feasibility of introducing e-navigation in terms of the cost-benefit as well as the effect on reduction of navigational accidents for SOLAS ships by up to 52.7%[9],

8 With regard to this, the DIRECTIVE 2010/65/EU described as "*The full benefits of electronic data transmission can only be achieved where there is smooth and effective communication between SafeSeaNet, e-Customs and the electronic systems for entering or calling up data*" (para. 12).

9 65 % means the rate to reduce the percentage of each detailed direct cause, which is reducible by 7 kinds of risk control options (RCOs), involving navigational accidents, while 52.7% is the actual rate

which is 22.8% among total accidents including other accidents as well as navigational accidents, the author assumes that the practices to introduce e-navigation would be different among different countries in terms of their priorities, levels and methods of applying it in their water areas. This is because the situation of each country's maritime safety would be different. Further, non-SOLAS ships might be important factors needed to be taken into account implementation of e-navigation because SOLAS ships are always interfaced with non-SOLAS ships in real maritime practices.

Therefore, it is important for a country to analyze its own specific data of vessel accidents for all ships in its waters and its flagged vessels worldwide, and assess the effects of e-navigation in terms of accident types and ship types, including non-SOLAS ships as well as SOLAS ships. This would lead the country to maximize the benefits of implementing e-navigation in its water areas by establishing an effective and efficient National SIP.

For this reason, the author analyzes the vessel accident data for all ships in Korean water areas and all Korean-flagged ships worldwide over the period 2009 to 2013, and develops a formula to evaluate the effect of e-navigation, which can be also used by other Member States of the IMO.

Then, the author evaluates the potential effects of SMART-navigation, which is the Korean approach to implementing the e-navigation concept, on reducing accidents by applying the formula with various approaches such as SOLAS ships and non-SOLAS ships, fishing vessels and non-fishing vessels, and navigational accidents and non-navigational accidents. The results could be an example to evaluate the effects of e-navigation by other countries when they are introducing e-navigation to their waters.

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to be reduced among navigational accidents, by implementing e-navigation tool kit application, the 7 kind of RCOs. See paragraph 5.1 for detailed calculation method.

1.2 Objectives

This dissertation researches the potential effects of e-navigation on reducing vessel accidents. It mainly includes studies and discussion on how and to what extent e-navigation could possibly reduce vessel accidents.

It is hoped that the result of this study might be referred to the maritime safety policies of the Member States of IMO when they are introducing e-navigation, as well as to the practices of the private maritime sectors such as shipping companies, crews on board ships and the manufacturers of e-navigation related systems. Therefore, this dissertation:

- Identifies what kinds of tool kits the IMO e-navigation has, by examining the SIP set out in NCSR 1/28 and NAV 59/6, as means to reduce accidents.
- Examines related IMO documents over the period from 2006 to 2015 in order to determine methodologies to evaluate the effect of e-navigation.
- Develops a formula, which is applicable to other Member States of IMO as well as the Republic of Korea, as a tool to calculate the effect of e-navigation on reducing accidents in terms of both SOLAS ships and non-SOLAS ships
- Analyzes the vessel accident data for all ships in Korean water areas and all Korean-flagged ships worldwide, during the 5 years from 2009 to 2013.
- Reviews the concept and the service scope of SMART-navigation, which is the Korean approach to implementing e-navigation, in order to identify the RCOs that might be applicable to both SOLAS and non-SOLAS ships.
- Verifies the validity of methodologies to be used in the dissertation through an expert questionnaire.
- Discusses the potential effect of SMART-navigation on reducing accidents, and provides the results as an example for other countries to evaluate the effects of e-navigation when they are introducing it into their waters.

1.3 Scope of the Study

This dissertation includes 6 Chapters. Chapter 1 shows the background, objectives, scope and methodologies of this paper.

Chapter 2 overviews the development of e-navigation, through examining and reviewing its related documents developed by the IMO so as to identify what kinds of tool kits the IMO's e-navigation has as a means to prevent vessel accidents and how such tool kits have been developed and finalized.

Chapter 3 determines the methodology to be used in this dissertation for determining the effects of e-navigation, and especially the effects of SMART-navigation on reducing accidents for all ships in Korean water areas and all Korean-flagged ships worldwide in terms of non-SOLAS ships as well as SOLAS ships. To determine the methodologies, this chapter reviews the risk and cost-benefit analysis that the FSA team carried out as set out in the IMO document, NAV 59/6. Annex 1 and NCSR 1/28. Annex 7, in addition to other e-navigation related documents developed by the relevant Sub-Committees of IMO.

Chapter 4 shows the result of analyzing accident data for all ships in Korean water areas and all Korean-flagged ships worldwide during the 5 years from 2009 to 2013. The analysis is focused mainly on identifying the accident types in terms of navigational accidents and others, the accident ship types in terms of SOLAS and non-SOLAS ships, and the detailed direct causes of accidents in terms of human error, technical failures and external factors, which are expected to be preventable by e-navigation.

The methods and formats analyzing the data were followed in the same manner as carried out in the document, NAV 59/6. Annex 1 and NCSR 1/28. Annex 7, in order to harmonize the level of the rate of risk reduction of accidents. However, the author analyzes all kinds of accident data, including SOLAS and non-SOLAS, as well as non-fishing and fishing vessels, whilst the document NAV 59/6. Annex 1 and NCSR 1/28. Annex 7 analyzed only SOLAS ships except non-SOLAS ships and fishing vessels.

Chapter 5 discusses the effect of the SMART-navigation on reducing accidents based on the result of analyzing accident data in chapter 3. To compare and identify differences to results obtained by the IMO, the chapter reviews the concept and services of SMART-navigation, and defines the scope of the RCOs that are considered to have an effect on reducing accidents for the non-SOLAS ships including fishing vessels. In addition, the chapter develops a formula to calculate the effect of e-navigation, which can be used by the other Member States of the IMO not only by the Republic of Korea. Then, the chapter provides the results of evaluating the effects of SMART-navigation on the rate of accident reduction as an example to be used by other Member States to assess the effects of e-navigation when they introduce it to their waters.

Finally, Chapter 6 gives a summary of this dissertation and concludes the effects of e-navigation on reducing vessel accidents.

1.4 Methodology and Sources of Information

The research question of this paper is "What percentage of vessel accidents could be reduced by the introducing e-navigation?". To answer this question, this paper uses two methodologies, namely qualitative and the quantitative analysis.

For the qualitative analysis, an examination and review of the e-navigation related documents developed by IMO and other related research papers are carried out in order to define the analysis tools to calculate the rate of risk reduction of accidents, and identify the tool kits of e-navigation that have an effect on reducing accidents. All of these documents were collected from the IMO website, internet and WMU library.

An overview of SMART-navigation is also conducted by qualitative analysis through examining and reviewing its components as described in the preliminary feasibility study on SMART-navigation and the study of systems to prevent safety accidents in maritime sectors, which were carried out by the Ministry of Oceans and Fisheries (MOF).

On the other hand, the quantitative methodology focuses on calculating the rate of the effects of e-navigation on reducing accidents. The calculation is carried out by the formula developed by the author based on the methodology used in Annex 1 of NAV 59/6 (May 31, 2013). The detailed direct causes of vessel accidents and the RCOs, which are applicable to non-SOLAS ships, are also identified by quantitative analysis based on the statistics and law data-base that have been accumulated by the Korea Maritime Safety Tribunal (KMST).

In addition, the expert questionnaire survey is carried out as one of the quantitative analysis items in order to verify the validity of methodologies which were used in calculating the rate of reducing accidents for non-SOLAS ships.

2. TOOL KITS OF IMO E-NAVIGATION TO REDUCE ACCIDENTS

The IMO document, NAV 59/6. Annex 1, demonstrates that e-navigation could reduce, by more than 65 %, the detailed direct causes of ships' collisions and groundings. What kinds of main tool kits of e-navigation function as the tools to reduce such accidents, and how? To answer these questions, the chapter is to examine in detail the process by which those e-navigation tool kits were developed, and what these respective e-navigation tool kits are. In addition, the chapter is to examine the user needs of e-navigation and the detailed direct causes of navigational accidents, including collisions and groundings, in terms of human errors, technical failures and external factors. It is because that user needs and detailed direct causes are to be used as the basis to identify the tool kits.

In this chapter, the term "tool kits" cover all kinds of functional and technical, legal "systems" and "services" related to e-navigation, for example, such as its solutions, risk control options (RCOs) and maritime service portfolios (MSPs).

2.1 Overview of IMO e-navigation

2.1.1 History of developing e-navigation

E-navigation was initiated by a joint proposal, including Japan, the Marshall Islands, the Netherlands, Norway, Singapore, the UK and the USA, to the MSC of IMO at its eight-first session in 2006 (MSC 81/23/10). Those States suggested that :

E-navigation would contribute to reduce navigational accidents, errors and failures by developing standards for an accurate and cost effective system that would make a major contribution to the IMO's agenda of safe, secure and efficient shipping on clean oceans (page 1, executive summary, MSC 81/23/10).

Following this proposal, the NAV Sub-Committee developed a "*Strategy for the development and implementation of e-navigation (NAV 54/25 Annex 12)*" and "*Time frame for implementation of the proposed e-navigation strategy (NAV 54/25 Annex 13)*", in co-operation with the COMSAR Sub-Committee and with the relevant input provided by other relevant organizations such as IALA and IHO, over a period of two years (2006 to 2008). The strategy and the time frame were submitted to the MSC of IMO at its eight-fifth session (2009) and were approved by the Committee as set out in MSC 85/26 Add 1 (Annex 20) and MSC 85/26. Add.1 (Annex 21), respectively. The MSC 85/26 Add 1 (Annex 20) explains the core objectives of e-navigation as follows:

(1) facilitate safe and secure navigation of vessels having regard to hydrographic, meteorological and navigational information and risks; (2) facilitate vessel traffic observation and management from shore facilities; (3) facilitate communications, including data exchange, among users; (4) provide opportunities for improving the efficiency of transport and logistics; (5) support the effective operation of contingency response, and SAR services; (6) demonstrate defined levels of accuracy, integrity and continuity appropriate to a safety-critical system; (7) integrate and present information on board and ashore through a human-machine interface which maximizes navigational safety benefits and minimizes any risks of confusion[10] *or misinterpretation on the part*

[10] With regard to this, according to the report of e-navigation underway conference 2014, John Murray (2014) emphasized that "*the fault by watch-keepers causing accidents are mainly due to the distraction or confusion, emphasizing the need to retain the skills of watch-keepers while simplifying displays" (page 8).*

of the user; (8) integrate and present information onboard and ashore to manage the workload of the users, while also motivating the user and supporting decision-making; (9) incorporate training and familiarization requirements for the users throughout the development and implementation process; (10) facilitate global coverage, consistent standards and arrangements, and mutual compatibility and interoperability of equipment, systems, symbology and operational procedures, so as to avoid potential conflicts between users; and (11) support scalability, to facilitate use by all potential maritime users (p. 3).

The approved strategy, even though there were some points that were somewhat overwhelming and included many issues to be solved (para. 11.19, MSC 85/26), became the stepping stone for the MSC to move forward to further development of the strategy for e-navigation. After this, the joint work done by COMSAR, NAV and STW (Standards of Training and Watchkeeping) Sub-Committees were undertaken to develop a coordinated approach to implement the approved e-navigation strategy according to the time framework as set out in MSC 85/26. Add. 1 as shown in Table 1 below.

Table 1 *Time framework for implementing SIP (MSC 85/26)*

2009	2010	2011	2012
Identifying user needs in details			
Developing an architecture & Carrying out gap analysis			
Cost- benefit analysis & a risk analysis			
			Upon formulating the implementation plan, beginning implementation

Source: Developed by the author by using data given on page 1 of MSC 85/26. Add.1. Annex 21. This figure is to show the time framework more clearly.

The above tasks had been undertaken by 2012 and their results were submitted to the MSC of IMO at its ninetieth session. However, the MSC of IMO at its ninety-first session extended the target date for completing the SIP of e-navigation until 2014 because the Committee noted that the results needed further revision and finalization of the work.

Then, the MSC, in its ninetieth and ninety-first sessions, instructed both STW 43 and NAV 58 to progress further work by re-establishing the Correspondence Group (CG) and endorsed the joint plan of work on e-navigation for the COMSAR, NAV and STW Sub-Committees for the period 2012-2014.

Finally, based on the report submitted by the CG (NAV 59/6), the MSC of IMO at its ninety-forth session on November 26, 2014, approved the e-navigation SIP, as set out in document NCSR 1/28, Annex 7. According to the SIP, the e-navigation is expected to be fully operational from 2020 if five prioritized e-navigation solutions as well as 18 kinds of tasks are implemented over the period 2014 to 2019 according to the time framework as shown in Table 2.

According to Hagen (2015), who is the chair of the Correspondence Group (CG) on IMO e-navigation, the approved SIP would be continuously developed and supported with IMO in the leading role, and included[11] in the IMO High-level Action Plans for 2016-2019.

[11] In line with this, interested Member States may submit proposals to the Committee for the inclusion of new planned or unplanned outputs in the High-level Action Plan of the Organization based on the identified tasks contained in this SIP (MSC 95/21, p 78, paragraph 21.2.17, MSC 95/22, p 88, paragraph 22.2.10, MSC 95/22, p72, paragraph 19.12.6).

Table 2 *Time framework for eighteen tasks to implement SIP*

	2014	2015	2016	2017	2018	2019	2020
T1							
T2							
T3							
T4							
T5(a)							
T5(b)							
T6							
T7(a)							
T7(b)							
T8							
T9							
T10(a)							
T10(b)							
T11							
T12							
T13							
T14(a)							
T14(b)							
T15							
T16							
T17							
T18							

Source: p. 18, Annex 7 of NCSR 1/28. "T" means "Task to be done" (For details, see p. 13-16 Annex 7 of NCSR 1/28).

2.1.2 Strategic Implementation Plan (SIP) of IMO

As examined in the history of developing e-navigation, for the time being, the SIP is a master for the implementation of e-navigation, which was approved by MSC 94 in 2014, as set out in the Annex 20 of NCSR 1/28. That is, the SIP could be said to include all aspects with regard to the implementation of e-navigation. Therefore, it is necessary to examine in detail the components of the SIP in order to understand what kind of e-navigation tool kits reduce accidents and how.

The SIP was developed based on user needs according to 5 main steps from the beginning stage as follows: (1) identifying user needs; (2) identifying the key elements to meet them; (3) gap analysis between the key elements and the current technologies; (4) identifying the tool kits of e-navigation to meet user needs, and (5) carrying out the risk and cost-benefit analysis against the tool kits.

The steps from (1) to (4) above had been continuously conducted, reviewed and finalized mainly by the NAV and COMSAR Sub-Committees and the MSC, including the series of CGs and Working Groups (WGs) established by each committee, from 2006 when e-navigation was proposed jointly by several Member States until 2013.

All of these outputs were assessed and verified through the FSA (NAV 59/6, summary) as shown in the Figure 1. The FSA[12] is the standard risk assessment tool to be used for the development of new rules and regulations of IMO as described in the Annex of MSC 83/INF.2, "*Consolidated text of the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making (MSC/Circ.1023−MEPC/Circ.392)*" (p. 3).

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[12] Hermanski, G. & Daley, C. (2005) summarized the case of applying the FSA and commented that: "*Since IMO published its interim guidelines on FSA (MSC/Circ.829-MEPC/Circ.335) in 1997 many FSA studies were conducted. Member governments, non-governmental observer organizations, International Association of Classification Societies (IACS) and individual class societies carried out variety of FSA studies*" (p. 8)

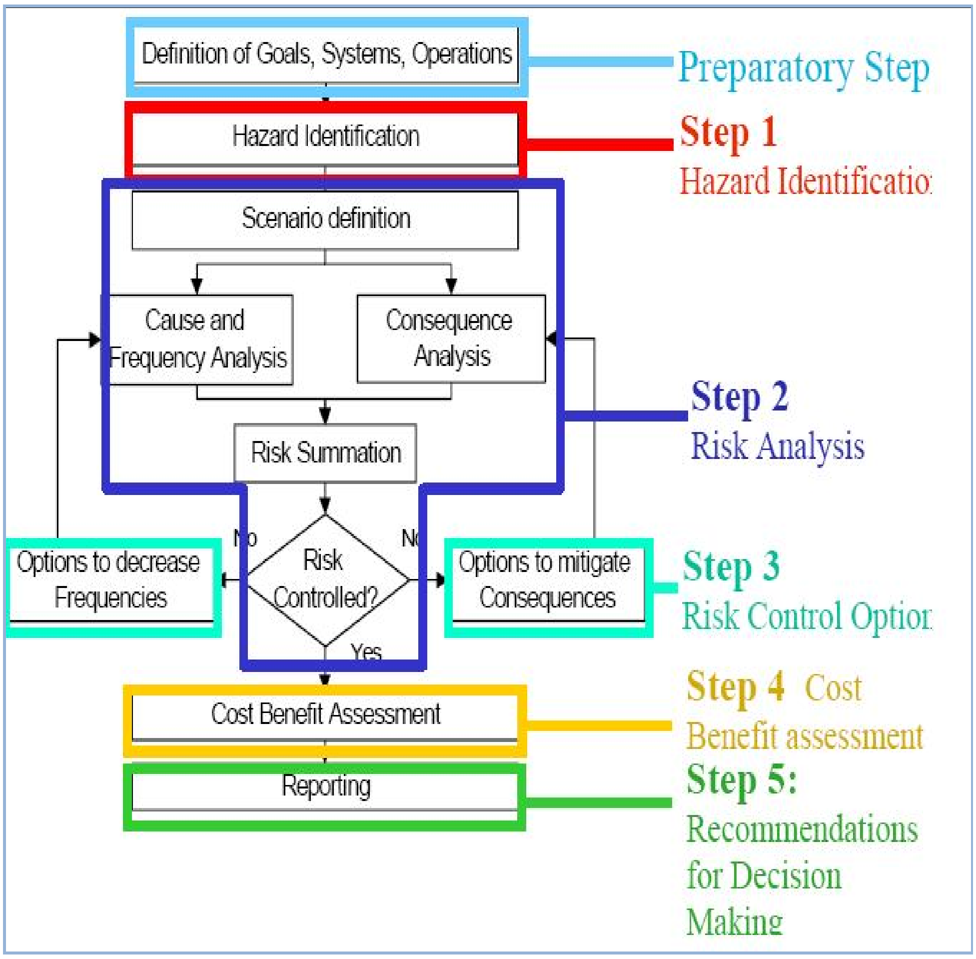

Figure 1 *Steps of FSA used in developing the SIP*

Source: NAV 56/8 (page 17)

Through the processes above, the SIP was finally developed. The SIP is mainly composed of 3 kinds of components with regard to the e-navigation tool kits as set out in Annex 7 of NCSR 1/28 (p. 2-3, p27-34) as follows:

- The five prioritized solutions, including S1, S2, S3, S4 and S9,
- The seven RCOs with the sub-solutions related to, and
- The sixteen MSPs for 6 areas.

The SIP contains other components, which are to be undertaken in order to prepare and provide these 3 kinds of tool kits from 2014 to 2019, as set out in Annex 7 of NCSR 1/28, as follows:

(1) *18 Tasks with expected deliverables, transition arrangements and implementation schedule* (p. 13-16),
(2) *Examples of key enablers of e-navigation* (p. 18, Annex 7 of NCSR 1/28),
(3) *Examples of key messages to promote the benefits of e-navigation through each solutions according to the stakeholders* (p. 37-40),
(4) *Identification of communication systems for e-navigation; Communications are a key for e-navigation. Any communications systems used must be able to the deliver appropriate MSPs in the 6 areas defined, as per S9, as well as delivering reliable ship reporting as identified in S2* (p. 19), and
(5) *Ship and shore architecture for solutions*[13] *as shown in Figure 2* (p. 18-19).

[13] With regard to the architecture, Annex 7 of NCSR 1/28 explains that :

> *The Figure 2 shows the principle of an information and data flow in the e-navigation architecture. The figure shows the complete overarching e-navigation architecture, and defines two additional important features: the CMDS that spans the whole of the horizontal axis; and the World Wide Radio Navigation System (WWRNS)* (page 18).

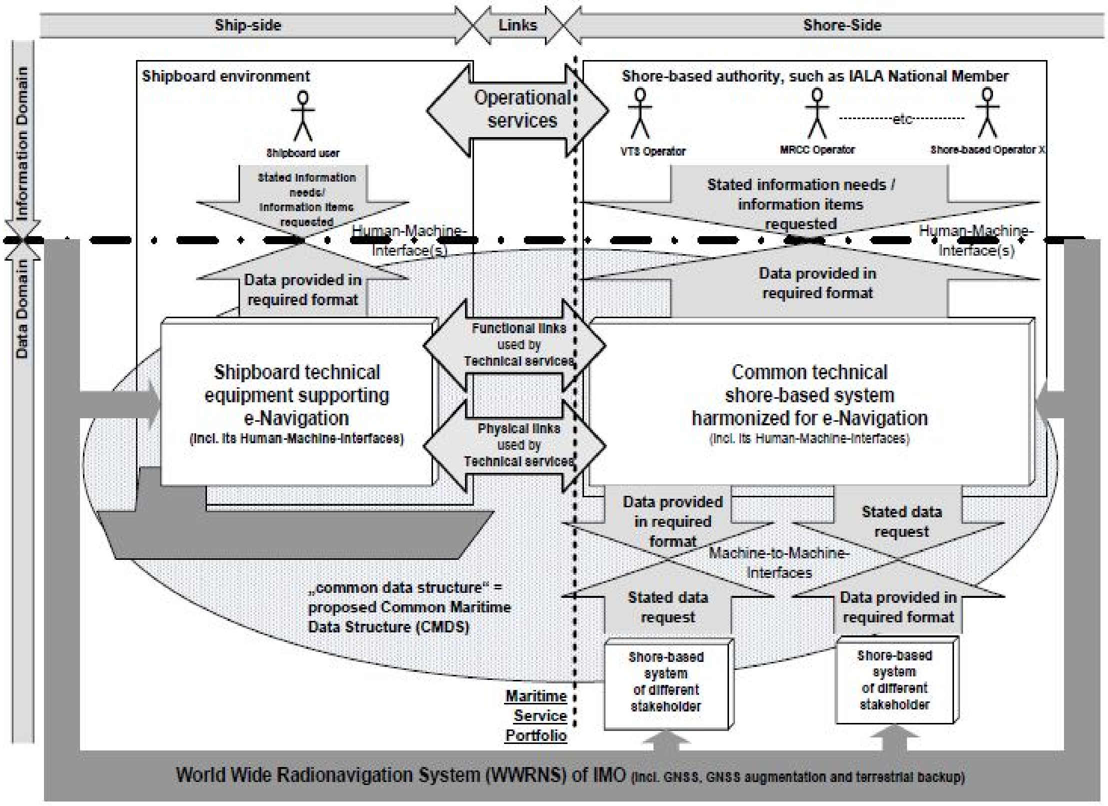

Figure 2 *Overarching e-navigation architecture*

Source: Annex 7 of NCSR 1/28 (page 18)

2.1.3 Identifying user needs

Following the decision by both the Sub-Committees of NAV 53 and COMSAR 11 that the e-navigation strategy should be user-driven rather than technology driven, the work to identity the user needs was undertaken by the intersessional CG and the results included in MSC 85/26 Add.1. Annex 20, "*Strategy for the development and implementation of e-navigation*".

The basic concept of user needs of e-navigation is to avoid system failures causing delays because the ship is now deemed unseaworthy, loss of basic good seamanship by crews, inappropriate substitution of the human element by technology and degradation of bridge resource management and best practices by the crew (paragraph 7, page 5, MSC 85/26 Add.1. Annex 20)

The documents MSC 85/26 Add.1 Annex 20 emphasized the importance of applying ergonomic principles to the electronic systems of e-navigation, including the presentation of information for users, so as to reduce single person errors and enhance team operations (paragraph 8.2.5, p7). Further to this, the document also recommended the concept of user needs in more detail as shown in Table 3 below.

Table 3 *Potential e-navigation users*

No	Shipborne users	Shore-based users
1	Generic SOLAS ships	Ship owners/operators, safety managers
2	Commercial tourism craft	VTM organizations
3	High-speed craft	VTS centres
4	Mobile VTS assets	Pilot organizations
5	Pilot vessels	Coastguard organizations
6	Coastguard vessels	Law enforcement organizations
7	SAR vessels	National administrations
8	Law enforcement vessels (police, customs, etc)	Coastal administrations
9	Nautical assistance vessels (tugs, salvage, tenders)	Port authorities
10	Counter pollution vessels	Security organizations
11	Military vessels	Port State control authorities
12	Fishing vessels	Incident managers
13	Leisure craft	Counter pollution organizations
14	Ferries	Military organizations
15	Dredgers	Fairway maintenance organizations
16	A to N service vessels	A to N organizations
17	Ice patrol/breakers	Meteorological organizations
18	Offshore energy vessel (supply, lay barges, survey)	Hydrographic Offices/Agencies
19	Hydrographic & Oceanographic research vessels	Ship owners/operator, logistics managers
20		News organizations
21		Coastal management authorities
22		Marine accident investigators
23		Health and safety organizations

24		Insurance and financial organizations
25		National, regional and local governments
26		Port authorities (strategic) Ministries
27		Marine environment managers
28		Fisheries management
29		Tourism agencies (logistics)
30		Energy providers
31		Ocean research institutes
32		Training organizations
33		Equipment and system manufacturers
sum	**18**	**33**

Source: MSC 85/26/Add.1. Annex 20 (p. 14-15)

The document MSC 85/26 Add.1 Annex 20 also identified 8 kinds of user needs as follows: *"(1) Common maritime information/data structure; (2) Automated and standardized reporting functions; (3) Effective and robust communications; (4) Human centred presentation needs; (5) Human machine interface; (6) Data and system integrity; (7) Analysis; and (8) Implementation issues"* (p. 15).

However, the identified user needs in the strategy were somewhat overwhelming (para. 11.18, p. 79, MSC 85/26) and based only on feedback from the high-level generic users such as Member States, other maritime organizations, and interested parties, and limited to the typical SOLAS ship and a generic shore authority (para. 8.2, p5, MSC 85/26/Add.1 Annex 20).

Therefore, the user needs needed to be identified in more detail and the identification was undertaken again by the consecutively established CG and the WG over a period of from 2008 to 2010. During this period, in the document NAV 55/ INF. 9, the user needs were identified through a questionnaire with 353 persons responding in total, whose average experience as a mariner was 16.6 years (p. 2). This document was further developed by the CG and WG of the NAV Sub-Committee, which was chaired by Mr.

John Erik Hagen, as set out in the document NAV 56/WP.5/Rev.1 and NAV 56/20. These two documents completed the comprehensive works related to the implementation of e-navigation, including indentified tool kits and services to support user needs in a harmonized and holistic manner (para. 8.3, p. 20, NAV 56/20).

Based on these results above, e-navigation user needs were finalized as set out in the document COMSAR 15/11, including Annex 1(INITIAL GAP ANALYSIS – shipboard users), Annex 2 (INITIAL GAP ANALYSIS – shore-based users) and Annex 3 (INITIAL GAP ANALYSIS – Search and Rescue).

2.1.4 Analyzing human errors that cause accidents

The objective of the FSA was to identify relevant hazards pertaining to navigation, to quantify related safety risks, and to identify and prioritize a set of RCOs deemed to reduce said risks. The result was submitted to NAV 59 (NAV 59/6), showing, in conclusion, that e-navigation has effects on reducing by more than 65 %, the risk of vessels' collisions and groundings through providing the seven RCOs.

To achieve the objective, the FSA team applied the casualty database of the IHS Fairplay[14] for the period from 2001 to 2010, but also used it together with accident data from the Norwegian Maritime Authority (NMA). For the purpose of analyzing the direct causes of navigational accidents, the FSA team first classified the initial accidents, and then identified the direct causes of accidents according to the structure given in Figure 3.

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[14] IHS Fairplay, which is belonging to the IHS (Information Handling Service) enterprise founded in 1959, provides maritime databases, evolved from the Lloyd's Register of Ships books, such as ship, vessel movement, casualty, ownership and port database. The enterprise has two headquarters; a global headquarter based at Englewood, U.S.A, and a regional headquarter based at Bracknell, U.K.

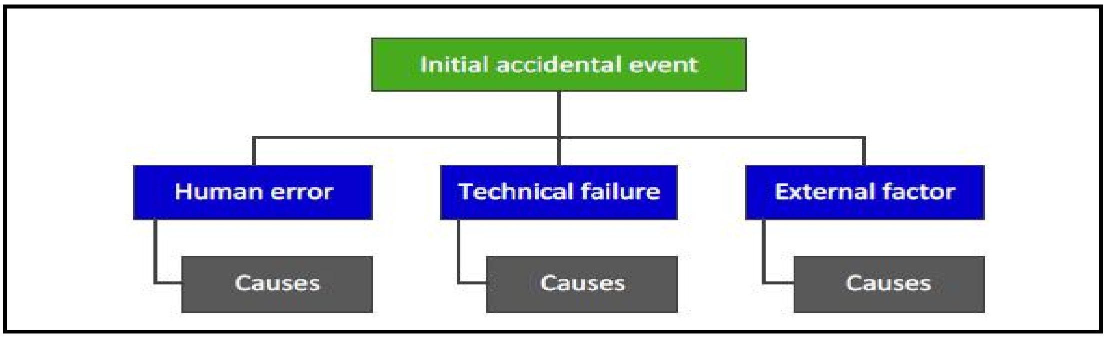

Figure 3 *Methodology to identify the direct causes of accidents*

Source: Annex 1 of NAV 56/6 (p. 12)

Table 4 shows the statistics analyzed by the FSA team for accidents involving the selected ship types over the time-span from 2001 to 2010, and Table 5 shows that more than 43.2 % were navigational accidents, including 21.6% of collisions and 21.6% of groundings, among the total 12,819 accidents and more than 21.9 % of losses of life among the total 6,262 happened in navigational accidents.

Table 4 *Number of events and loss of life*

Ship type	Accident category	Accidental events	Loss of life
Cargo ship (including tanker for oil) (351,741 ship-years, 55%)	Collision	2336	238
	Grounding	2286	200
	Σ (Navigational accident)	**4622**	**438**
	Other accidents	5133	1563
	Σ (All accident)	**9755**	**2001**
Passenger ship (67,254 ship-years, 10%)	Collision	245	53
	Grounding	321	836
	Σ (Navigational accident)	**566**	**889**
	Other accidents	1543	3166
	Σ (All accident)	**2109**	**4055**
Work ship (224.429 ship-years, 35%)	Collision	194	41
	Grounding	162	4
	Σ (Navigational accident)	**356**	**45**
	Other accidents	599	163
	Σ (All accident)	**955**	**208**

Source: Annex 1 of NAV 56/6 (page 9)

Table 5 *Composition of events and loss of life*

Ship Type	Accidents Type				Loss of Life			
	Navigational			Non-Nav	Navigational			Non-Nav
	collision	Grounding	sum		collision	Grounding	sum	
Cargo ship	2336 (18.2%)	2286 (17.8%)	4621 (36.1%)	5133 (40.0%)	238 (3.8%)	200 (3.2%)	438 (7.0%)	1563 (25.0%)
Pass-enger	245 (1.9%)	321 (2.5A%)	566 (4.4%)	1543 (12.0%)	53 (0.8%)	836 (13.3%%)	889(14.2%)	3166 (50.5%)
Others	194 (1.5%)	162 (1.3%)	356 (2.8%)	599 (4.7%)	41 (0.7%)	4 (0.1%)	45 (0.7%)	163 (2.6%)
Sub-Total	**2775 (21.6%)**	**2768 (21.6%)**	**5543 (43.2%)**	7275 (56.8%)	332 (5.3%)	1040 (16.6%)	**1372 (21.9%)**	4892 (78.1%)
Total				12819				6264

Source: The author developed this to show data more clearly, by reassembling data given in Table 4.

The outcome of this analysis is that more than 65 % of all navigational accidents were caused by human error, while 18% are caused by technical failure and 17% by external factors (para. 5.1, Annex 1 of NAV 59/6). Figures 4, 5 and 6 show the detailed causes of navigational accidents in terms of human error, technical failures and external factors.

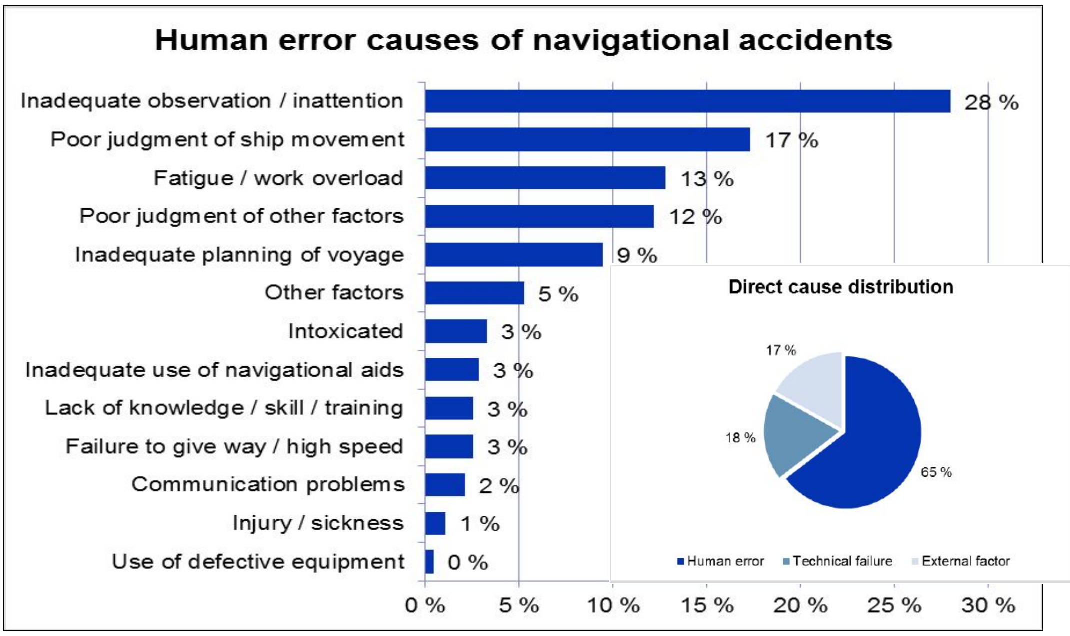

Figure 4 *Human error cause distribution*

Source: Annex 1 of NAV 56/6 (page 13-14)

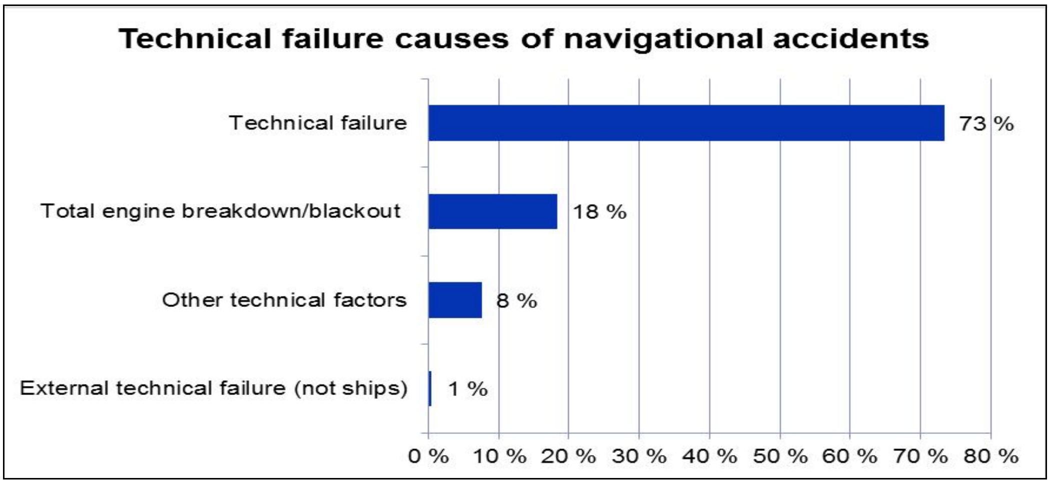

Figure 5 *Technical failure cause distribution*

Source: Annex 1 of NAV 56/6 (page 15).

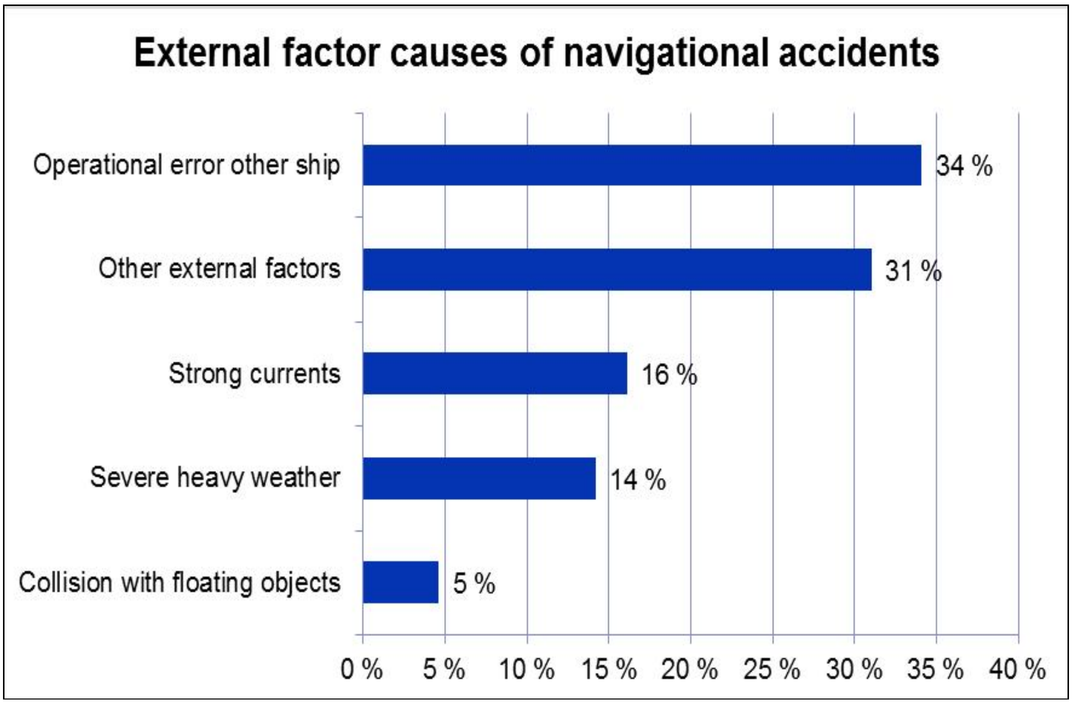

Figure 6 *External factor cause distribution*

Source: Annex 1 of NAV 56/6 (page 15)

2.2 Main tool kits of IMO e-navigation

Up to now, the author has summarized the development of IMO's e-navigation and its SIP, and found that it has mainly 3 kinds of tool kits, including the five prioritized e-navigation solutions, the seven RCOs and the sixteen MSPs in paragraph 2.1.2. There are several reasons [15] for IMO to introduce e-navigation. With regard to this, the document MSC 85/26/Add.1 emphasized that:

> *If e-navigation could assist in improving the reliability of the decision-making process, both by well-designed onboard systems and closer cooperation with vessel traffic management (VTM) instruments and systems, the risk of navigational accidents and their inherent liabilities could be dramatically reduced* (p. 2).

These tool kits might contribute to improve the reliability of the relevant decision-making process, and reduce accidents as a result of that. The chapter examines the tool kits of IMO's e-navigation in more detail, involving its solutions, RCOs and MSPs.

2.2.1 The e-navigation solutions

Based on the identified user needs and analysis of accidents, the NAV 57 decided to carry out a gap analysis in order to identify e-Navigation solutions to meet user needs, taking into account the Human Element Analyzing Process (HEAP), and the document NAV 58/6 was submitted as the result of gap analysis.

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[15] The document MSC 85/26/Add.1 summarized the reasons as follows: *"the rising trends of navigational accidents; the numerous examples of such accidents might have been avoided if there had been suitable input to the navigation decision-making process; and the fact that 60% of collisions and groundings are caused by human error"* (para. 3.2)

Annex of the NAV 58/6 provides a list of practical e-navigation solutions in terms of 4 aspects; (1) the operational (procedural / automation), (2) the human element, the technical (H/W, S/W, equipment), (3) the regulatory (regulation, standard), and (4) the training (human element). Table 6 summarizes and describes the IMO agreed and prioritized solutions and their sub-solutions.

Table 6 *Description of Solution and its Sub-Solutions*

Solutions and Sub-Solution		**Description**
S1 improved, harmonized and user-friendly bridge design	**S1.1**	Ergonomically improved and harmonized bridge and workstation layout.
	S1.2	Extended use of standardized and unified symbology for relevant bridge equipment.
	S1.3	Standardized manuals for operations and familiarization to be provided in electronic format for relevant equipment
	S1.4	Standard default settings, save/recall settings, and S-mode functionalities on relevant equipment.
	S1.5	All bridge equipment to follow IMO Bridge Alert Management
	S1.6	Information accuracy/reliability indication functionality for relevant equipment.
	S1.6.1	Graphical or numerical presentation of levels of reliability together with the provided information.
	S1.7	Integrated bridge display system (INS) for improved access to shipboard information.
	S1.8	GMDSS equipment integration – one common interface.
S2 means for standardized and automated reporting;	**S2.1**	Single-entry of reportable information in single-window solution.
	S2.2	Automated collection of internal ship data for reporting.
	S2.3	Automated or semi-automated digital distribution/communication of required reportable information, including both "static" documentation and "dynamic" information.
	S2.4	All national reporting requirements to apply standardized digital reporting formats based on recognized internationally harmonized standards, such as IMO FAL Forms or SN.1/Circ.289.
S3 improved reliability, resilience and integrity of bridge equipment and navigation information;	**S3.1**	Standardized self-check/built-in integrity test (BIIT) with interface for relevant equipment (e.g. bridge equipment).
	S3.2	Standard endurance, quality and integrity verification testing for relevant bridge equipment, including software.
	S3.3	Perform information integrity tests based on integration of navigational equipment – application of INS integrity monitoring concept.
	S3.4	Improved reliability and resilience of onboard PNT information and other critical navigation data by integration with and backup of by integration with external and internal systems.

S4 integration and presentation of available information in graphical displays received via communication equipment	**S4.1**	Integration and presentation of available information in graphical displays (including MSI, AIS, charts, radar, etc.) received via communication equipment.
	S4.1.1	Implement a Common Maritime Data Structure and include parameters for priority, source, and ownership of information.
	S4.1.2	Standardized interfaces for data exchange should be developed to support transfer of information from communication equipment to navigational systems (INS).
	S4.1.3	Provide mapping of specific services (information available) to specific regions (e.g. maritime service portfolios) with status and access requirements.
	S4.1.4	Provision of system for automatic source and channel management on board for the selection of most appropriate communication means (equipment) according to criteria as, band width, content, integrity, costs.
	S4.1.5	Routing and filtering of information on board (weather, intended route, etc.).
	S4.1.6	Provide quality assurance process to ensure that all data is reliable and is based on a consistent common reference system (CCRS) or converted to such before integration and display.
	S4.1.7	Implement harmonized presentation concept of information exchanged via communication equipment including standard symbology and text support taking into account human element and ergonomics design principles to ensure useful presentation and prevent overload.
	S4.1.8	Develop a holistic presentation library as required to support accurate presentation across displays.
	S4.1.9	Provide Alert functionality of INS concepts to information received by communication equipment and integrated into INS.
	S4.1.10	Harmonization of conventions and regulations for navigation and communication equipment.
S9 improved Communication of VTS Service Portfolio	**S9**	Improved communication of VTS service portfolio (not limited to VTS stations)

Source: Solutions (para. 15, p. 5, NAV 59/6), Sub-Solution (Tables 1 to 5, Annex 7 of NCSR 1/28)

These five solutions shown in Table 6 above were finalized with a goal-based approach based on the risk and cost-benefit analysis according to the FSA process and the methodology of the HEAP (para. 19, p. 5, NAV 59/6). In addition, these solutions were used as the basis for creating the SIP and the RCOs as well as for the further implementation of e-navigation.

2.2.2 Risk Control Options (RCOs)

In order to identify the tangible and manageable RCOs, the FSA team used the process as depicted in Figure 7, by merging the results of user needs, gaps analysis and prioritized solutions with the accident data analysis. Through this process, the seven RCOs with sub-solutions were decided as the RCOs to provide cost-effective risk reductions in a cost-effective manner (p. 6, para. 24-26, NAV 59/6) as follows:

- RCO 1: Integration of navigation information and equipment including improved software quality assurance (related to sub-solutions: S1.6, S1.7, S3.1, S3.2, S3.3, S4.1.2, and S4.1.6);
- RCO 2: Bridge alert management (S1.5);
- RCO 3: Standardized mode(s) for navigation equipment (S1.4);
- RCO 4: Automated/standardized ship-shore reporting (S2.1, S2.2, S2.3, S2.4);
- RCO 5: Improved reliability and resilience of onboard PNT systems (S3.4);
- RCO 6: Improved shore-based services (S4.1.3 and solution S9);
- RCO 7: Bridge and workstation layout standardization (S1.1).

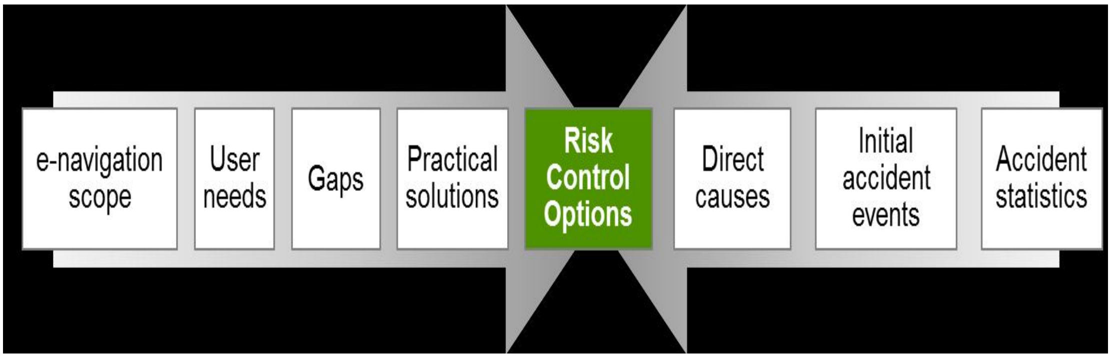

Figure 7 *RCO identification process*

Source: Annex 1 of NAV 59/6 (p. 20)

2.2.3 Maritime Service Portfolios (MSPs)

The concept of MSPs was first introduced at the fifty-seventh session of NAV Sub-Committee (para. 23-26, NAV 57/6). MSP is a part of the improved provision of services to vessels through e-navigation (NCSR 1/28 Annex 7, paragraph 17), and defined and described as the set of operational and technical services and their level of service, with the need for information and communication services, provided by a stakeholder in a given area[16] (para. 23, NAV 57/6).

The MSPs were finalized as in Table 7 below by the CG on e-navigation established by NAV 58. The CG proposed 17 kinds of MSPs, in the document NAV 59/6. Annex 3 with detailed descriptions. However, through the discussion of the Working Group established by NAV 59, one of them, "Remote monitoring of ships systems" was deleted[17]

Table 7 *List of the Maritime Service Portfolios (MSPs)*

MSPs	Services	Responsible Service Provider
MSP1	VTS Information Service (IS)	VTS Authority
MSP2	Navigational Assistance Service (NAS)	National Competent VTS Authority/Coastal or Port Authority
MSP3	Traffic Organization Service (TOS)	National Competent VTS Authority/Coastal or Port Authority
MSP4	Local Port Service (LPS)	Local Port/Harbour Operator

[16] With regard to this, the SIP defines 6 areas : *"(1) port areas and approaches; (2) coastal waters and confined or restricted areas; (3) open sea and open areas; (4) areas with offshore and/or infrastructure developments; (5) polar areas; and (6) other remote areas"* (para. 18, p. 11, Annex 7 of NCSR 1/28).

[17] During the discussion, this MSP was severely argued between delegations and deleted according to the opinion, especially the strong suggestion by the representative from ICC, that it is not directly related to the safety of navigation. The author participated in the Working Group as the delegation of the Republic of Korea.

MSP5	Maritime Safety Information Service (MSI	National Competent Authority
MSP6	Pilotage service	Pilot Authority/Pilot Organization
MSP7	Tugs Service	Tug Authority
MSP8	Vessel Shore Reporting	National Competent Authority, Shipowner/Operator/Master
MSP9	Telemedical Assistance Service (TMAS)	National Health Organization/dedicated Health Organization
MSP10	Maritime Assistance Service (MAS)	Coastal/Port Authority/Organization
MSP11	Nautical Chart Service	National Hydrographic Authority/ Organization
MSP12	Nautical Publications Service	National Hydrographic Authority/ Organization
MSP13	Ice Navigation Service	National Competent Authority Organization
MSP14	Meteorological Information Service	National Meteorological Authority/WMO/ Public Institutions
MSP15	Rea-time Hydrographic and Environmental Information Service	National Hydrographic and Meteorological Authorities
MSP16	Search and Rescue Service	SAR Authorities

Source : Annex 7 of NCSR 1/28

2.3 Conclusion of the tool kits of e-navigation

Up to now, the author has examined the tool kits of e-navigation, and their developed processes and functions. As a result, the author has identified three kinds of main tool kits of IMO e-navigation, including the five solutions, seven RCOs and sixteen MSPs. They were finalized through a goal-based approach based on the cost-benefit and risk analysis by the FSA team (para. 19, p. 5, NAV 59/6).

In brief, e-navigation, using these tool kits, might be able to enhance the capability of shore-based stations to manage and assist the safety of navigation in an efficient and timely manner. It also supports the decision making process and provides safety information to crews on board ships, which might lead the crews to avoid or detect human error in advance. This is clearly supported by the current definition and concept of e-navigation. The concept of e-navigation was finally defined in Annex 20 of MSC 85/26 Add. 1, "*Strategy for the development and implementation of e-navigation*", which was submitted by the NAV Sub-Committee in 2009, as follows:

> *The harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of marine environment (para. 1.1, p. 1).*

This might mean that e-navigation is to enhance the safety of navigation and increase the efficiency of maritime-related businesses by implementing its three kinds of tool kits. The words *"to enhance"* here might mean to increase the quantity and quality of managing safety of navigation by improving the maritime communication network, the structure of information and services, and the relevant systems and equipment on board ship and ashore. This is clearly supported by the vision of e-navigation, involving the elements of communication, on board ship and ashore, as described in the MSC 85/26. Annex 20 (para. 4.1, p. 2)

In other words, as the author mentioned in the background, the more modernized information and communication technology of e-navigation such as the globally standardized and automated ship-shore reporting system and the seamless transmission of electronic information and data between ship and shore might provide crews on board ship with more decision-making support and also to minimize their work-loads, enabling them to focus on the safety of navigation. In addition, these electronic technologies of e-navigation might increase the efficiency of the maritime-related businesses, as well. One of the reasons why the IMO's e-navigation strategy has been driven based on its user needs is because of this.

In conclusion, the author concluded, based on the examination done in this Chapter, that the tool kits of e-navigation reducing vessel collisions and groundings by 65% are the five prioritized solutions, the sixteen MPSs, and especially the seven RCOs, and summarized the relationships between these tool kits as shown in Table 8.

Table 8 *Relation between Tool kits of e-navigation to reduce accidents*

RCOs	Functions and MSPs	Relevant Solutions
(**RCO 1**) Integration of navigation information and equipment including improved software quality assurance	to provide **integrated and augmented functions to the navigator, i.e. an improved basis for navigational decision-making,** taken from the INS standard, as follows; ● **Route planning and monitoring :** the route check against hazards based on the planned minimum under keel clearance as specified by the mariner; overlaying radar video data on the chart to indicate navigational objects, restraints and hazards to own ship in order to allow position monitoring evaluation and object identification; determination of deviations between set values and actual values ● **Supporting decision making of collision avoidance** ● **Providing navigation control data :** under keel clearance (UKC), STW, SOG, COG, position, heading, ROT (measured or derived from change of heading), rudder angle, propulsion data; set and drift, wind direction and speed (true and/or relative selectable by the operator); the active mode of steering or speed control; time and distance to wheel-over or to the next waypoint; safety related messages e.g. AIS safety-related and binary messages, NAVTEX, SafetyNet or other GMDSS information. ● **Status and data display** : ship's static, dynamic and voyage-related AIS data ; safety related messages, such as AIS safety-related and binary messages, Navtex, SafetyNet or other GMDSS information; ● **Function editing AIS** own ship's data and information to be transmitted by AIS messages. ● **Redundancy of important equipment and Software testing**	S1.6 S1.7 S3.1 S3.2 S3.3 S4.1.2 S4.1.6

(**RCO 2**) Bridge alert management	To **provide alert management** in order to enable the bridge team to devote full attention to the safe navigation of the ship and to immediately identify any abnormal situation requiring action to maintain the safe ● Danger of collision, Danger of grounding	S1.5
(**RCO 3**) Standardized mode(s) for navigation equipment	Safe navigation relies on the ability **of key personnel to easily operate navigational equipment as well as comprehend the information** that is presented to them. Lack of familiarity with bridge equipment and/or slow response due to not finding correct information/control/alarm is thus considered to adversely affect safe navigation. Standard modes are to provide a standardized and common display familiar to all stakeholders, reducing the need for personnel to familiarize themselves with variations of HMIs in order to safely navigate. ● Offer default display configurations for the ECDIS and the radar to provide the bridge team and pilot with a standardized display and a simple operator action. ● Provide operational modes for a set of predefined operational areas such as open sea, coastal, confined waters (pilotage, harbour berthing, and anchorage).	S1.4
(**RCO 4**) Automated and standardized ship-shore reporting	Forms are usually manually filled out and sent individually to each authority requesting the information. Compliance with IMO FAL forms normally takes about two hours to fill. For example, around 25 documents had to be sent from the ship, or the ship's agent, in conjunction with a port call. The data requested in many of these documents are fully or almost identical. Documents are also often in paper or other non-computer-compatible formats, which is a time-consuming and costly affair. The S-mode provides followings in order to **reduce workload due to filling out and delivering reportable information** is identified. ● The system would integrate relevant onboard systems enabling collection and edition of information and data needed for reporting. ● The system should allow for automated digital distribution of required reportable information **(single window solution**), including both static, dynamic, voyage related and SAR information to authorized authorities, with the least possible intervention required by the ship during and/or before navigation.	S2.1, S2.2, S2.3 and S2.4

(**RCO 5**) Improved reliability and resilience of onboard PNT systems	Ensuring reliable and resilient PNT data, providing ship's position, velocity, and time data (PVT) for navigators and navigational functions, is important for safe navigation. However, for the time being, due to insufficient redundancy within single sensors and unsupported exploitation of multi-sensor based redundancy the classic approach is considered unable to meet e-navigation user needs such as improvement of availability, reliability and indication of integrity based on monitored and assessed data and system integrity. In order to improve reliability and resilience of position, navigation, and timing data (PNT) an integrated and harmonized utilization of PNT related systems and services is envisioned.	S3.4
(**RCO 6**) Improved shore-based services	VTSs and other shore-based stakeholders gather and hold a lot of information regarding navigational warnings, incidents, operations, tide, AIS, traffic regulations, chart corrections, meteorological conditions, ice conditions, etc., which often is referred to as the Maritime Service Portfolio. As per today this information is mostly communicated via voice VHF and paper documents. Information transfer via voice communication can be time-consuming and distractive as navigators may need to make notes of information received and possibly consult various written documentation on the bridge. The voice communication procedure also holds a potential for incorrect transfer and misinterpretation of information. • Implementation of system for automatic and digital distribution of shore support services would make information more available, updated and applicable for navigators. • Maritime Safety Information (MSI) received by the ship should be applicable to the ship's specific voyage, i.e. it should not contain information related to other areas which is not relevant to that ship, and be presented on one location, the ENC/ECDIS or AIS/RADAR display. • Notices to mariners, ENC updates and corrections to all nautical publications should be received electronically without any delays in the delivery. • All MSI to be sent out digitally and using a standard such as the IHO S-100 data framework standard enabling better visualization on board, for example, Virtual Aids to Navigation (AtoN) for warning of new	S4.1.3 and solution S9

	navigational hazards, such as wrecks, obstructions or floating debris, displaying on AIS/ECDIS ● In addition automatic updating and correction of nautical charts via satellite is envisioned	
(**RCO 7**) Bridge and workstation layout standardization	Cumbersome equipment layout on the bridge adversely influences the mariner's ability to optimally perform navigational duties. Therefore, regulation, based on existing guidelines and standards, regarding the physical layout of all bridge equipment regarded as essential for safe and efficient navigation, is envisaged to Workstation for navigating and maneuvering including; ● radar/radar plotting ● ECDIS ● information of AIS ● Indications of: rudder angle, rate-of-turn, speed, gyro compass heading, compass heading and other relevant information ● VHF point with channel selector	S1.1

Source: Summarized pages 20 to 31 of NAV 59/6 Annex 1

3. METHODOLOGY TO EVALUATE THE EFFECTS OF E-NAVIGATION

3.1 Introduction

This Chapter is to identify the methodology to quantitatively evaluate the effects of SMART-navigation on reducing accidents for all ships in Korean waters and all Korean-flagged ships worldwide during the 5 years from 2009 to 2013.

With regard to this quantitative analysis, the author intends to apply same methodology used by the FSA team for the IMO e-navigation strategy in order to increase the objectivity of the study results. For that purpose, the methodology used by the FSA team is to be examined as to how it was developed and how the rate of reducing navigational accidents, "65 %", was calculated.

3.2 Methodology used in the FSA for IMO e-navigation

According to Annex 1 of NAV 59/6, the FSA team put several conditions in its methodology to estimate the risks and analyze the causes as follows:

- to define a generic risk model (paragraph 3, page 4)
- to select the ship types, excluding non-SOLAS ships (paragraph 3.3, page 5),
- to limit accident categories of collision and grounding (paragraph 3.3, page 5).

As the first step to quantify the rate of risk reduction of navigational accidents, the FSA team calculated the frequencies for the accident categories as well as the potential loss of lives (PLL) as shown in Table 9 below, by combining the numbers of accidental events and losses of lives with the number of ship years for each ship category. The calculation was based on the direct cause distribution of accidents, including human errors, technical failures and external factors, as shown in Figures 4, 5 and 6, respectively (para. 2.2.2).

As a result, for example, for a generic ship, the distribution of accident types in terms of frequency per ship-year is 44 % for collisions and groundings, and 56 % for other accidents among all accidents per ship year as shown in Table 9 below.

Table 9 *Accident frequencies*

Ship type	Accident category	Initial accident frequency per ship year	%
Cargo ship (including tanker for oil) (351,741 ship-years - 55%)	Collision	6.6E-03	24%
	Grounding	6.5E-03	23%
	∑ (Navigational accident)	**1.3E-02**	**47%**
	Other accidents	1.5E-02	53%
	∑ (All accident)	**2.8E-02**	**100%**
Passenger ship (67,254 ship-years – 10%)	Collision	3.6E-03	12%
	Grounding	4.8E-03	15%
	∑ (Navigational accident)	**8.4E-03**	**27%**
	Other accidents	2.3E-02	73%
	∑ (All accident)	**3.1E-02**	**100%**
Work ship (224.429 ship-years – 35%)	Collision	8.6E-04	20%
	Grounding	7.2E-04	17%
	∑ (Navigational accident)	**1.6E-03**	**37%**
	Other accidents	2.7E-02	63%
	∑ (All accident)	**4.3E-03**	**100%**
Generic ship (weighted average of ship types above)	Collision	4.3E-03	22%
	Grounding	4.3E-03	22%
	∑ (Navigational accident)	**8.6E-03**	**44%**
	Other accidents	1.1E-02	56%
	∑ (All accident)	**2.0E-02**	**100%**

Source: Annex 1 of NAV 59/6 (page 10)

According to the document NAV 59/6, the risks are summarized to estimate the individual risk and societal risks to crew members resulting from the operation of a generic ship, and the FSA team extracted the total potential loss of lives (PLL) as the risks by using a risk model "the frequency and consequence modeling" (para. 6.2, p. 16, Annex 1).

The results of the risk estimation are presented in Table 10 below. For example, for a generic ship, the risk distribution of accident types in terms of the PLL is 22% per ship year for navigational accidents, including collisions and groundings, and 78 % for other accidents among all accidents.

Table 10 *Risk estimations*

Ship type	Accident category	Potential Loss of Life for crew and passengers (per ship year)	%
Cargo ship (including tanker for oil) (351,741 ship-years - 55%)	Collision	6.8E-04	12%
	Grounding	5.7E-04	10%
	∑ (Navigational accident)	**1.2E-03**	**22%**
	Other accidents	4.4E-03	78%
	∑ (All accident)	**5.7E-03**	**100%**
Passenger ship (67,254 ship-years – 10%)	Collision	7.9E-04	1%
	Grounding	1.2E-02	21%
	∑ (Navigational accident)	**1.3E-02**	**22%**
	Other accidents	4.7E-02	78%
	∑ (All accident)	**6.0E-02**	**100%**
Work ship (224.429 ship-years – 35%)	Collision	1.8E-04	20%
	Grounding	1.8E-05	2%
	∑ (Navigational accident)	**2.0E-04**	**22%**
	Other accidents	7.3E-04	78%
	∑ (All accident)	**9.3E-04**	**100%**
Generic ship (weighted average of ship types above)	Collision	5.2E-04	5%
	Grounding	1.6E-03	17%
	∑ (Navigational accident)	**2.1E-03**	**22%**
	Other accidents	7.6E-03	78%
	∑ (All accident)	**9.7E-03**	**100%**

Source: Annex 1 of NAV 59/6 (p. 16)

For the purpose of producing an improved picture of where the highest risks originate, the FSA team distributed the above estimated risks among the probable accident causes as shown in Table 11 below, by applying findings from the hazard identification study (para. 6.3, p. 17, Annex 1 of NAV 59/6).

Table 11 *Total generic risk distributed among accident causes*

#	Description	% of category	PLL per ship year	% total
1	Inadequate observation/inattention	28%	3.8E-04	24%
2	Poor judgment of ship movement	17%	2.3E-04	15%
3	Fatigue/work overload	13%	1.7E-04	11%
4	Poor judgment of other factors	12%	1.7E-04	10%
5	Inadequate planning of voyage	9%	1.3E-04	8%
6	Operational error other ship	34%	1.2E-04	8%
7	Other factors	5%	7.2E-05	4%
8	Strong currents	16%	5.7E-05	4%
9	Severe heavy weather	14%	5.0E-05	3%
10	Intoxicated	3%	4.5E-05	3%
11	Inadequate use of navigational aids	3%	3.9E-05	2%
12	Failure to give way/high speed	3%	3.5E-05	2%
13	Lack of knowledge/skill/training	3%	3.5E-05	2%
14	Communication problems	2%	2.9E-05	2%
15	Collision with floating objects	5%	1.6E-05	1%
16	Injury/sickness	1%	1.4E-05	1%
17	Use of defective equipment	0%	6.1E-06	0%

Source: Annex 1 of NAV 59/6 (p. 18)

Based on the results above, the rate of risk reduction, according to each direct cause of navigational accidents, by each RCO was estimated through a workshop composed of 5 experts from the USA, Netherlands, Denmark and Norway, who had a total of over 190 years of maritime experience (para. 8.3, p. 36, Annex 1 of NAV 59/6). The experts estimated the potential rate of risk reduction against the detailed direct causes reducible by RCOs, which are extracted among each direct cause, including human error, technical failure and external factor. The estimation was revised through panel discussion and refined by inputting the ideas of additional 4 experts after the workshop. Table 12 below shows the rate of risk reduction of navigational accidents by each RCO, according to each direct cause.

Table 12 *Risk reducing potential*

	RCO 1	RCO 2	RCO 3	RCO 4	RCO 5	RCO 6	RCO 7
Human error							
Inadequate observation/ inattention	16%	23%	14%	18%	10%	11%	32%
Poor judgment of ship movement	21%	8%	11%	4%	20%	3%	20%
Fatigue/work overload	20%	26%	11%	33%	5%	17%	24%
Poor judgment of other factors	11%	12%	10%	11%	11%	12%	19%
Inadequate planning of voyage	26%	3%	8%	1%	0%	15%	4%
Intoxicated	1%	1%	0%	0%	0%	0%	0%
Failure to use navigational aids	18%	8%	17%	9%	5%	13%	21%
Failure to give way/high speed	18%	11%	12%	9%	9%	5%	27%
Lack of knowledge/skill/training	3%	7%	18%	7%	6%	1%	10%
Communication problems	8%	5%	9%	19%	3%	11%	15%
Injury/sickness	0%	1%	0%	0%	0%	0%	0%
Use of defective equipment	11%	18%	3%	1%	18%	0%	8%
Technical failure							
Technical failure not related to main engine	6%	9%	1%	1%	10%	1%	2%
External factor							
Strong currents	9%	1%	2%	0%	11%	14%	7%
Severe heavy weather	2%	0%	1%	0%	6%	23%	7%

Source: Annex 1 of NAV 59/6 (page 37)

As the next step, the FSA team estimated the potential reduction of PLL frequency by implementing each RCO as shown in Table 13 below. It was estimated by combining the PLL frequency of 2.1E-03 presented in Table 11 and the percentages of risk reductions given in Table 12 based on the cause distributions presented in Figures 4, 5 and 6.

Table 13 *Estimated reduction potential of PLL per ship*

	RCO 1	**RCO 2**	**RCO 3**	**RCO 4**	**RCO 5**	**RCO 6**	**RCO 7**
Human error							
Inadequate observation/ inattention	4.4E-05	6.3E-05	4.0E-05	5.1E-05	2.8E-05	3.1E-05	8.9E-05
Poor judgment of ship movement	3.6E-05	1.3E-05	1.8E-05	6.5E-06	3.5E-05	4.3E-06	3.5E-05
Fatigue/work overload	2.6E-05	3.3E-05	1.4E-05	4.2E-05	6.4E-06	2.2E-05	3.1E-05
Poor judgment of other factors	1.3E-05	1.4E-05	1.2E-05	1.3E-05	1.4E-05	1.4E-05	2.4E-05
Inadequate planning of voyage	2.4E-05	2.4E-06	7.7E-06	1.2E-06	Negligible	1.4E-05	4.1E-06
Intoxicated	2.1E-07	4.1E-07	Negligible	Negligible	Negligible	Negligible	Negligible
Failure to use navigational aids	5.0E-06	2.1E-06	4.8E-06	2.5E-06	1.4E-06	3.6E-06	6.1E-06
Failure to give way /high speed	4.5E-06	2.9E-06	3.0E-06	2.4E-06	2.4E-06	1.3E-06	6.9E-06
Lack of knowledge/skill/ training	6.4E-07	1.8E-06	4.6E-06	1.8E-06	1.4E-06	3.2E-07	2.6E-06
Communication problems	1.6E-06	1.1E-06	2.0E-06	4.1E-06	5.3E-07	2.4E-06	3.2E-06
Injury/sickness	Negligible	1.3E-07	Negligible	Negligible	Negligible	Negligible	Negligible
Use of defective equipment	5.1E-07	7.9E-07	1.1E-07	2.8E-08	8.2E-07	Negligible	3.7E-07
Technical failure (not related to main engine)							
Technical failure	1.3E-05	2.0E-05	2.6E-06	1.3E-06	2.1E-05	1.3E-06	3.9E-06
External factor							
Strong currents	3.7E-06	2.6E-07	7.9E-07	Negligible	4.7E-06	5.8E-06	2.9E-06
Severe heavy weather	6.9E-07	Negligible	2.3E-07	Negligible	2.1E-06	8.3E-06	2.5E-06
Sum	**1.7E-04**	**1.5E-04**	**1.1E-04**	**1.3E-04**	**1.2E-04**	**1.1E-04**	**2.1E-04**

Source: Annex 1 of NAV 59/6 (p. 38)

Lastly, based on Table 13 above, the RCOs were ranked by their respective rate of risk reduction in terms of PLL reduction as shown in Table 14, and the rate of risk reduction is estimated as 65% in total.

The FSA carried out cost-benefit (CB) analysis based on the above findings, resulting[18] in the conclusion that RCO 1, RCO 2, RCO 3, RCO 5, RCO 6 and RCO 7 are all beneficial in themselves in terms of economics; the costs of implementing the RCOs are less than the economic benefits of implementing them.

Table 14 *RCOs ranked by PLL*

Rank	RCOs		PLL reduction	PLL reduction of total
1	RCO 7	Bridge and workstation layout standardization	2.1E-04	14%
2	RCO 1	Integration of navigation information and equipment including improved software quality assurance	1.7E-04	11%
3	RCO 2	Bridge alert management	1.5E-04	10%
4	RCO 4	Automated and standardized ship-shore reporting	1.3E-04	8%
5	RCO 5	Improved reliability and resilience of on board PNT systems	1.2E-04	8%
6	RCO 3	Standardized mode	1.1E-04	7%
7	RCO 6	Improved shore-based services	1.1E-04	7%
Total				**65%**

Source: Annex 1 of NAV 59/6 (p. 37)

3.3 Methodology to be used in the dissertation

3.3.1 Conclusion of the methodology

The author examined, in Chapter 2, IMO e-navigation tool kits functioning to reduce navigational accidents. As a result, the five e-navigation solutions, the seven RCOs and the 16 MSPs were identified as the tool kits. Based on the result, this chapter examined

[18] For details, see the document NAV 59/6. Annex 1 (page 42)

the methodology that the FSA team used to assess the effects of e-navigation on reducing accidents. Table 15 shows the results, summarizing the process of developing the methodology. As shown in Table 15, the rate of reducing accidents by each RCO is developed in the 4th step, whilst the other steps from the 1st step to the 3rd-2 step are to identify factors necessary for carrying out the cost-benefit analysis.

With regard to rate of risk reduction, 65% in total, estimated by the FSA team as shown in Table 14, even though there is a limitation in the methodology to quantify the rate in a quantitative way, the author concluded that the rate is reasonable and feasible. It is because the rate has been developed based on reliable factors such as user needs, gap analysis, three kinds of tool kits of e-navigation, the analysis of navigational accidents, results of a generic risk model and verification by the competent experts through a workshop as shown in Table 15. The next paragraph 3.3.3 examines the limitations in more detail.

Thus, based on the examination up to now, the author decided to use the rate of risk reduction by seven RCOs, 65%, which was estimated by the FSA team, as the coefficient to develop a formula for evaluating the effects of SMART-navigation on reducing accidents in Chapter 5.

Table 15 *Calculation process of risk reduction rate by the FSA team*

Steps	**Founding**	**Methods, Sources**
(1st) Identifying problems in terms of safety of navigation	User Needs Direct Cause of Accidents, including human errors, technical failures and external factors	Survey Analyze Statistics
↓	↓	
(2nd) Identifying tool kits	Five e-Navigation Solutions Seven RCOs, and	Experts opinions based on user needs and direct

of e-navigation to reduce risk	Sixteen MSPs	cause of accidents
↓	↓	
(3rd - 1) Analyzing accidents Statistics	Accident Trend (Table 4) Accident Types (Collision, Grounding, and Others) according to the ship's type Direct Cause (human error, technical failures and external factors); Figures 4,5 and 6	IHS Statistics NMA Statistics
↓	↓	
(3rd - 2) Estimating Risks of Collisions and Groundings	Accident frequency, PLL per ship year (Table 9) ↓ Risk estimations in terms of PLL (Table 10) ↓ Total generic risk distributed among accident causes (Table 11) ↓ Risk reducing potential (Table 12) ↓ Estimated reduction potential of PLL per ship year (Table 13) ↓ RCOs ranked by PLL reduction per ship year (Table 14)	Based on the results of analyzing accident statistics In terms of PLL A generic risk model Frequency and consequence modeling
↓	↓	
(4th) Estimating the effect of reducing risks	Rate of reduction of accident by each RCO (Total : 65 % for SOLAS ships)	Experts opinions & Frequency and consequence modeling

Source: The author summarized process based on the examination results in paragraph 3.2

3.3.2 Limitation in the methodology and Bayesian Network (BN)

The document NAV 59/6. Annex 1 (p. 47) and MSC 83/INF.2. Annex (p. 4) defines "risk" as "the combination of the frequency and the severity of the consequence", "frequency" as "the number of occurrences per unit time", and "consequence" as "the outcome of an accident". These definitions are similar to those of the American Bureau of Shipping (ABS). The ABS (2000) defines "risk" as "*the product of the frequency with* *which an event is anticipated to occur and the consequence of the event's outcome: Risk = Frequency × Consequence".*

Therefore, the rate of risk reduction of accidents by implementing e-navigation might be the same as the rate of reducing frequency or probability. For example, Dr. Jens Schröder-Hinrichs, who is a professor of the World Maritime University (WMU), explained "risk" as the product of the probability with which an event is anticipated to occur and the consequence of the event's outcome; Risk = Probability × Consequence, and "probability" as the average number of events, divided by time unit or other adequate basis, during his lecture about risk equations in the common reliability engineering approaches (class notes, February 6, 2015).

However, it is not easy to actually measure this rate because of the limitation of taking into account the same situation with and without the tool kits of e-navigation. For example, the Danish Maritime Authority (DMA) and the Royal Danish Administration of Navigation and Hydrography (RDANH) carried out a risk analysis of navigational safety in Danish waters in 2002. The report commented that "*the risk reduction factor as the effects of implementing the selected RCOs, including VTS, AIS and ECDIS, by the expected number of spills after implementation of the RCOs, divided by the number of expected spills before implementation of the RCOs*" (p. 8, DMA & RDANH, 2002).

Like the above case, because of similar limitations, the coefficient as the rate of risk reduction, which was estimated by the FSA team, was quantified in a qualitative way by experts through a workshop as described in paragraph 3.2. With regard to this, the IMO document MSC 83/INF.2. Annex also guides that "*Quantification makes use of accident and failure data and other sources of information as appropriate to the level of analysis. Where data is unavailable, calculation, simulation or the use of recognized techniques for expert judgement may be used*" (para. 6.2.2).

However, even though it is difficult to quantify the coefficient, it should be noted that the coefficient acts as the most important factor to quantitatively evaluate the effects of e-navigation on reducing accidents according to each detailed direct cause of the vessel accident.

Therefore, further investigation in quantifying the coefficient by a quantitative methodology might be necessary in order to provide a more reliable rate of reducing accidents by implementing e-navigation. In other words, the coefficient needs to be quantified based on a more quantitative relationship between accident types and detailed direct causes as well as the relationship between the RCOs and their rate of risk reduction. With regard to this, the Bayesian Network (BN) might be a tool to quantify the coefficient.

For example, Li, Yin, Yang and Wang (2011)[19] introduced the BN, in their research "*The Effect of Shipowners' Effort in Vessels Accident: A Bayesian Network Approach*", as "*By taking into account different actors (i.e. age, size, etc.) and their mutual influences, maritime risk assessment using the BN enables to identify the factors that have the greatest impact on the accident occurrence" (p. 352, Chapter 5)*.

Besides the above case, there have recently been many cases to apply the use of BN as a tool for modeling and analyzing vessel accidents, for example, *"Analysis of Loss of Position Incidents for Dynamically Operated Vessels"* (Stenvågnes Hauff, 2014), and "*An Analysis on Incident Cases of Dynamic Positioning Vessels"* (Chae & Jung, 2015). Further, the FSA guideline, MSC 83/INF.2. Annex, also recommends BN as one of the methods that could be used, if appropriate (p. 9).

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19 With regard to calculation of the probability of accident, Li et al. (2011) criticized that "*Traditional and the most common way to estimate the prior probability of accidents is by expert estimation. There are some typical problems associated with using the subjective probability, provided by expert, as a measure of uncertainty in risk analysis" (p.337, Abstract)*.

4. ANALYSIS OF KOREAN-RELATED ACCIDENTS (2009-2013)

4.1 Introduction

This chapter analyzes the Korean investigation statistical accidents data[20] for all ships in Korean water areas and all Korean-flagged ships worldwide over the period of 2009 to 2013; this data having been collected from the KMST. The analysis is based on the following:

- The trend of accident' volume according to the accident types
- The types of accidents with direct causes according to each ship's category; SOLAS ships and non-SOLAS, non-fishing vessels and fishing vessels
  - Accident types : collisions and groundings, and others
- The direct causes ; human errors, technical failures and external factors
- The statistics are analyzed by number of vessels, not in number of events.

[20] There have been two kinds of statistics related to marine accidents; one of them is the statistics provided by the KMST that are mainly based on vessel accidents, and the other one is the statistics provided by the Korean Coast Guard that are mainly based on their rescue activities. Because of the difference in the scope and purpose of producing the statistics between these two organizations, there have been differences in the figures of their statistics respectively, causing some confusion to the public in Korea because both statistics are seemed to be very similar each other to the common people. Because of this, KMST had began to produce the incorporated statistics combining the both statistics of from 2008 since 2014, while the former statistics that KMST had been producing until 2013 were kept left. For the purpose of focusing on the vessel accident oriented data, this paper is to analyze the statistics produced by KMST, which were produced based on the marine accident investigation code of IMO.

With regard to the scope of a ship's type, unlike the ones used by the FSA team, the author includes all kinds of ships involved in accidents in Korean waters and all Korean-flagged ships worldwide. It is because the scope of SMART -navigation services includes non-SOLAS ships that are engaged in domestic coastal areas, and fishing vessels as well as SOLAS ships.

Thus, the author analyzes the effect of SMART-navigation on reducing all kinds of accidents, unlike the IMO's e-navigation analysis, which is limited to navigational accidents, including collisions and groundings, of SOLAS ships. With regard to the ship's type, as shown in Table 16 below, the author categorized all ships into 2 groups, non-fishing vessels and fishing vessels, and 6 sub-groups under the 2 groups. The group of non-fishing vessels includes cargo ships, tankers, passenger ships, towing ships, and others.

Table 16 *Ship types included in the dataset*

Group of Ship Type		**Sub-Group of Ship Type**	
		Ship's Type included	**Size**
Non-fishing vessels	**Cargo ships**	All ships, which are not included in the ships below, including general cargo carrying ships, semi-container ships, coal carrying ships, car carriers, refrigerated cargo ships, chilled carriers, etc	All ships regardless of size, including SOLAS and not-SOLAS ships
	Tanker	Dangerous cargo carriers, LPG and LNG carriers, Chemical Tankers, Product Oil carriers, etc.	
	Passenger ships	Car-ferries, Cargo-Passenger carriers, and other ferries and passenger ships	
	Towing ships	All kinds of tugs and towing ships	
	Other ships	Barges, dredging ships, leisure boats, yachts, etc	
Fishing vessels		All kinds of fishing vessels	

Source: Categorized based on the descriptions of KMST investigation statistics (2014)

4.2 Analyzing accidents

4.2.1 Historical trends of accident volume

Figure 8 and Table 17 below show the historical trends of vessel accidents based on the KMST investigation statistics during the last 5 years from 2009 to 2013. The total number of annual accidents during the last 5 years shows a rising trend until 2011, but decreasing trend after that as shown in Figure 8. However, over the period from 2009 to 2013, non-fishing vessel accidents have a rising trend in general, while fishing vessel accidents have a decreasing trend in general even though there was a fluctuation in 2011 due to the rapid rise in collisions as shown in Table 18.

Table 17 *Historical trend of accidents by ship's type*

Ship Type		2009	2010	2011	2012	2013	Sum
Non-Fishing vessel	Cargo	89	105	99	89	88	470 (9.6%)
	Tanker	20	42	37	43	44	186 (3.8%)
	Passenger	9	18	19	26	20	92 (1.9%)
	Towing	61	117	126	122	80	506 (10.4%)
	Others	20	13	38	35	30	136 (2.8%)
	Total	199	295	319	315	262	1390 (28.5%)
Fishing		742	680	890	647	522	3481 (71.5%)
Total		941	975	1209	962	784	4871 (100%)

Source: KMST investigation statistics and data base (2014)

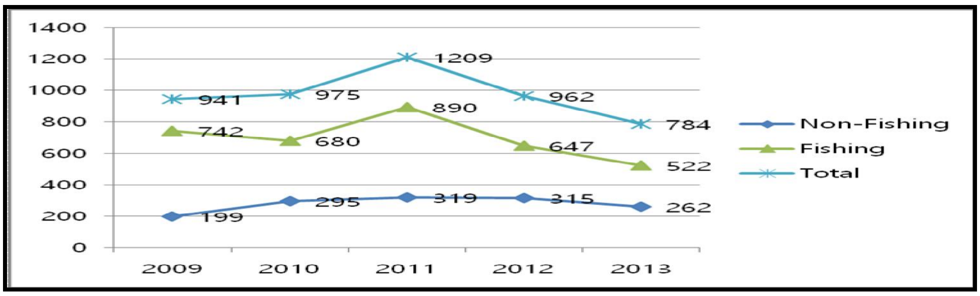

Figure 8 *Historical trend of accidents by ship's type*

Source: KMST investigation statistics and data base (2014)

4.2.2 Historical trend of accident types

Table 18 and Figure 9 show the ratio of categorized types of accidents according to ship type by percentage, for all ships in Korean water areas and all Korean-flagged ships worldwide from 2009 to 2013. 64.1% of non-fishing vessel accidents involved navigational accidents, including collisions and groundings. In more detail, 37.2% of SOLAS ship accidents and 26.9% of non-SOLAS ship accidents were navigational accidents. The figure for SOLAS ship navigational accidents, 37.2%, is 6% lower than NMA's statistics, 43.2%.

However, in the case of calculating all accidents by both SOAS and non-SOLAS ships, more than 43.5 % were involved in navigational accidents, including 18.3% for non-fishing vessels and 25.1% for fishing vessels. This figure is similar to the statistic, 43.2% that the FSA team obtained based on IHS Fairplay.

Table 18 *Accident type distribution*

Accident	Ship Type	2009	2010	2011	2012	2013	Sum
Collision	Non-Fishing	122	172	173	168	121	756 (15.5%)
	Fishing	224	205	**269**	174	168	1040 (21.4%)
	Subtotal	346	377	442	342	289	1796 (36.9%)
Grounding	Non-Fishing	21	33	26	24	31	135 (2.8%)
	Fishing	27	36	**46**	38	40	187 (3.8%)
	Subtotal	48	69	72	62	71	322 (6.6%)
Navigational Accidents	Non-Fishing	143	205	199	192	152	**891 (18.3%)**
	Fishing	251	241	**315**	212	208	**1227 (25.2%)**
	Subtotal	394	446	**514**	404	360	**2118 (43.5%)**
Other	Non-Fishing	56	90	120	123	110	499

							(10.2%)
	Fishing	491	439	**575**	435	314	2254 (42.3%)
	Subtotal	547	529	695	558	424	2753 (56.5%)
Total	Non-Fishing	199	295	319	315	262	**1390** (28.5%)
	Fishing	742	680	890	647	522	**3481 (71.5%)**
	Total	941	957	1209	962	784	**4871 (100%)**

Source: KMST investigation statistics and data base (2014)

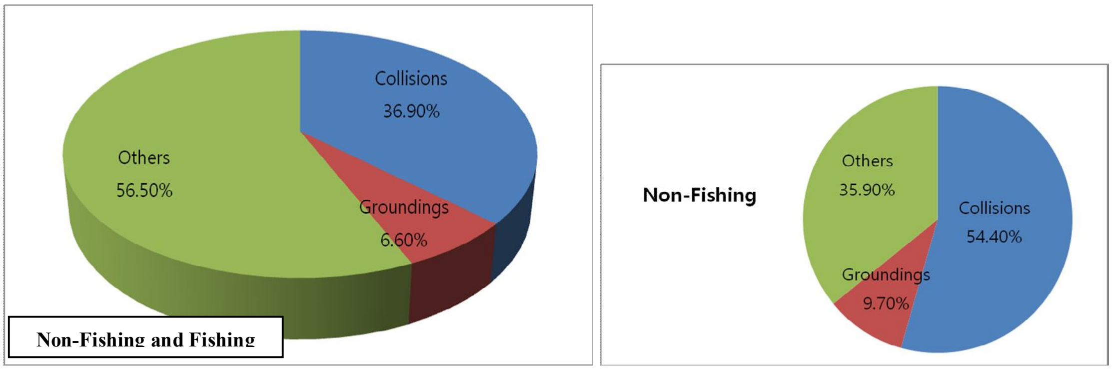

Figure 9 *Accident type distribution (2009-2013)*

Source: KMST investigation statistics and data base (2014)

4.2.3 Direct causes of accidents

This study analyzed the distribution of accident causes based on the methodology performed by KMST as shown in Figure 10: (1) the accidents are listed; (2) the direct causes are identified; and (3) the root causes are identified.

The KMST statistics classify the accident causes into five groups, including human error, technical failure, external factors, inadequate handling of machinery and cargo, and others as shown in Table 19.

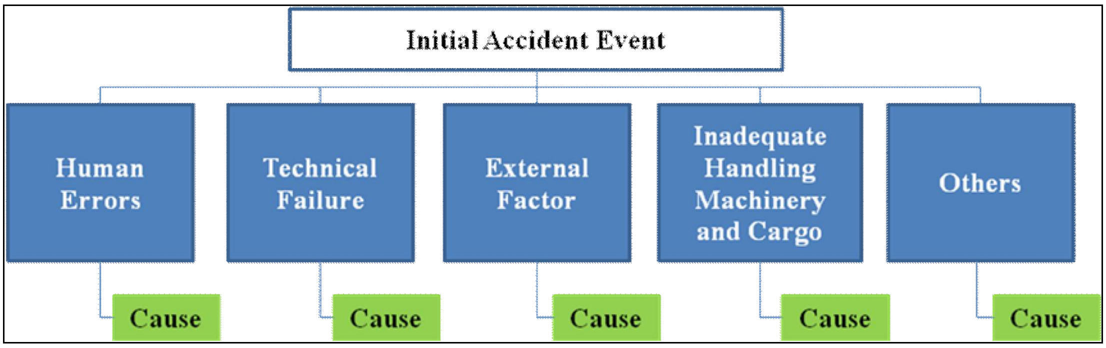

Figure 10 *Methodology to identify the direct causes of accidents*

Source: KMST investigation statistics and data base (2014)

Table 19 and Figure 11 demonstrate that most of the navigational accidents were caused by human error: 90.7 % of all navigational accidents (collisions and groundings) were caused by human error, and also 35.1 % of other accidents were caused by human error. The percentage for navigational accidents is greater than the one from NMA statistics, 65%, meaning that there would be more possibilities to reduce accidents caused by human error in the case of Korea.

Table 19 *Direct cause distribution by accident type*

Direct Causes	Navigational Accidents			Others	Sum
	Grounding	Collision	Sum		
Human Errors	273 (84.8%)	1647 (91.7%)	1920 (90.7%)	965 (35.1%)	2885 (59.2%)
Inadequate Handling machineries or cargos	4	7	11	1236	1247 (25.6%)
Technical Failures	1	2	3	175	178 (3.7%)
External Factors		41	41	19	60 (1.2%)
Others	44	113	157	355	512 (10.5%)
Total	322 (100%)	1796 (100%)	2118 (100%)	2753 (100%)	4871 (100%)

Source: KMST investigation statistics and data base (2014)

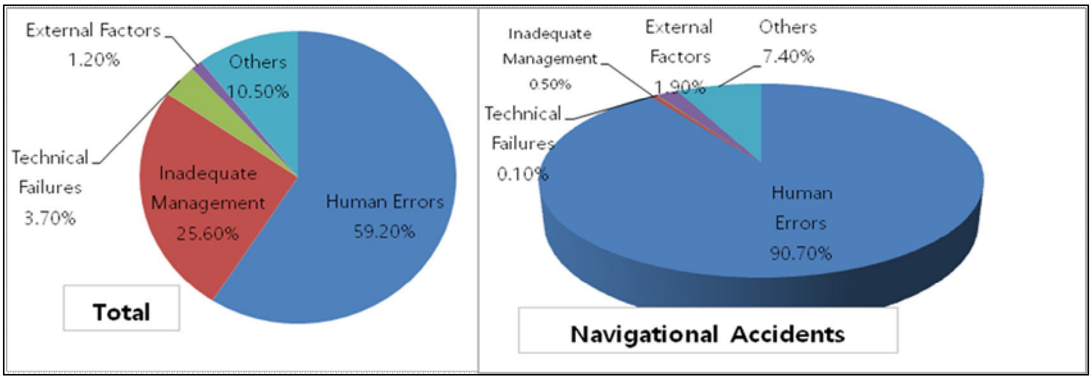

Figure 11 *Direct cause distribution by accident type (2009-2013)*

Source: KMST investigation statistics and data base (2014)

Table 20 shows the distribution of direct causes in more detail: 88.1% among the navigational accidents of non-fishing vessels and 92.0% of fishing vessel accidetns were caused by human error. These figures are higher than the one from NMA statistics, 65%[21]. However, in the case of calculating all kinds of accidents, including navigational accidents and others involving all kinds of ship types, 59.2% were caused by human error. This figure is more similar to the statistic, 65% that the FSA team obtained based on IHS Fairplay.

Table 20 *Direct cause distribution*

Direct Cause	Non-Fishing					Fishing Vessels					Total
	Navigational Accident			Non-Nav.	Sub-Total	Navigational Accident			Non-Navi	Sub-Total	
	Coll	Gro	Sum			Grou	Colli	Sum			
Human Error	681 (90.1)	104 (77.0)	785 (88.1)	255 (51.1)	1040 (74.8)	169 (90.4)	966 (92.9)	1135 (92)	710 (31.8)	1845 (53)	2885 (59.2)
Technical Failure	**2**		2	43	45	1		1	132	133	178
Inadequate Handling	**3**	3	6	114	120	1	4	5	1122 (49.8)	1127	1247
External Factors	**25**		25	7	32		16	16	12	28	60
Others	**45**	28	72	80	152	16	60	76	272	348	501
Total	**756 (100)**	135 (100)	891 (100)	499 (100)	1390 (100)	187 (100)	1040 (100)	1227 (100)	2254 (100)	3481 (100)	4871 (100)

Source: KMST investigation statistics and data base (2014)

[21] see Annex 1 of NAV 59/6 (p. 14)

Table 21, and Figures 12 and 13 show the distribution of detailed causes of human errors in the case of navigational accidents. Among them, "Inadequate observation" (70.4%), "Inadequate ship maneuvering" (8.0%), "Inadequate actions to avoid collision" (8.0%), and "Inadequate positioning" (5.2%) are shown as the most significant causes for human errors.

Table 21 *Human error cause distribution*

Human error	Non-Fishing Vessel					Fishing Vessel					Total
	Navigational Accident			Non-Navi	Sub-Total	Navigational Accident			Non-Navi	Sub-Total	
	Collision	Grounding	Sum			Collision	Grounding	Sum			
Inadequate observation	531 (78.0)	22 (21.5)	553 (70.4)	42 (16.5)	595 (57.2)	815 (84.4)	49 (29.0)	864 (76.1)	357 (50.3)	1221 (66.2)	1816 (62.9)
Over loading				1	1				3	3	4
Failure to equipments									3	3	3
Other Navigational failure	19 (2.8)	5 (4.8)	24 (3.1)	38 (14.9)	62 (6.0)	10 (1.0)	11 (6.5)	21 (1.9)	165 (23.2)	186 (10.1)	248 (8.6)
Negligence of duty	4 (0.6)	5 (4.8)	9 (1.1)	2 (1.3)	11 (1.1)	7 (0.7)	4 (2.4)	11 (1.0)	1 (0.1)	12 (0.7)	23 (0.8)
Pilot error/violations	5		5 (0.6)	7	12						12
Inadequate Anchoring	1	2	3 (0.4)	1	4				3	3	7
Inadequate safety management	1	1	2 (0.3)	1	3				4	4	7
Not observing safety manual on board	1 (0.1)		1 (0.2)	70 (27.5)	71 (6.8)		1 (0.6)	1 (0.1)	93 (13.1)	94 (5.1)	165 (5.7)
Inadequate positioning		41 (39.4)	41 (5.2)	16	57 (5.5)	1 (0.1)	90 (53.5)	91 (8.0)	15 (2.1)	106 (5.7)	163 (5.6)
Inadequate Maneuvering	52 (7.6)	11 (10.6)	63 (8.0)	45 (17.6)	108 (10.4)	17 (1.8)	4 (2.4)	21 (1.9)	34 (4.8)	55 (3.0)	163 (5.6)
Inadequate departure preparing				2	2				1	1	3

Inadequate actions to avoid collision	63 (9.3)		63 (8.0)		63 (6.1)	96 (9.9)		96 (8.5)		96 (5.2)	159 (5.5)
Inadequate Course plan and keeping	2 (0.3)	1 (1.0)	3 (0.4)	3 (1.2)	6 (0.6)	1 (0.1)	1 (0.6)	2 (0.2)	1 (0.1)	3 (0.2)	9 (0.3)
Violation of COREG						7	1	8 (0.7)		8	8 (0.3)
Lack of sailing plan		2	2 (0.3)	1	3		1	1 (0.1)	1	2	5 (0.2)
Lack of preparing heavy weather	2 (0.3)	13 (12,5)	15 (1.9)	19 (7.5)	34 (3.4)	6 (0.6)	7 (4.1)	13 (1.1)	29 (4.1)	42 (2.3)	76 (2.6)
Inadequate Management		1	1 (0.2)	7	8	6		6 (0.5)		6	14 (0.5)
Total	681	104	785	255	1040	966	169	1135	710	1845	2885

Source: KMST investigation statistics and data base (2014)

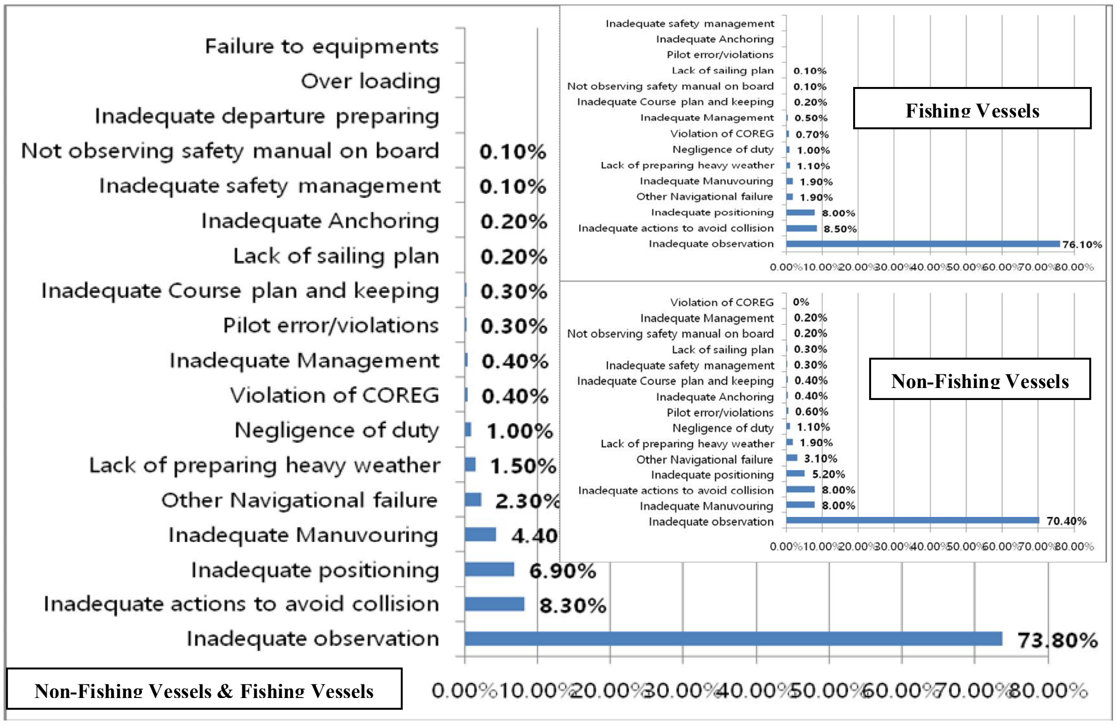

Figure 12 *Human error cause distribution of navigational accidents*

Source: KMST investigation statistics and data base (2014)

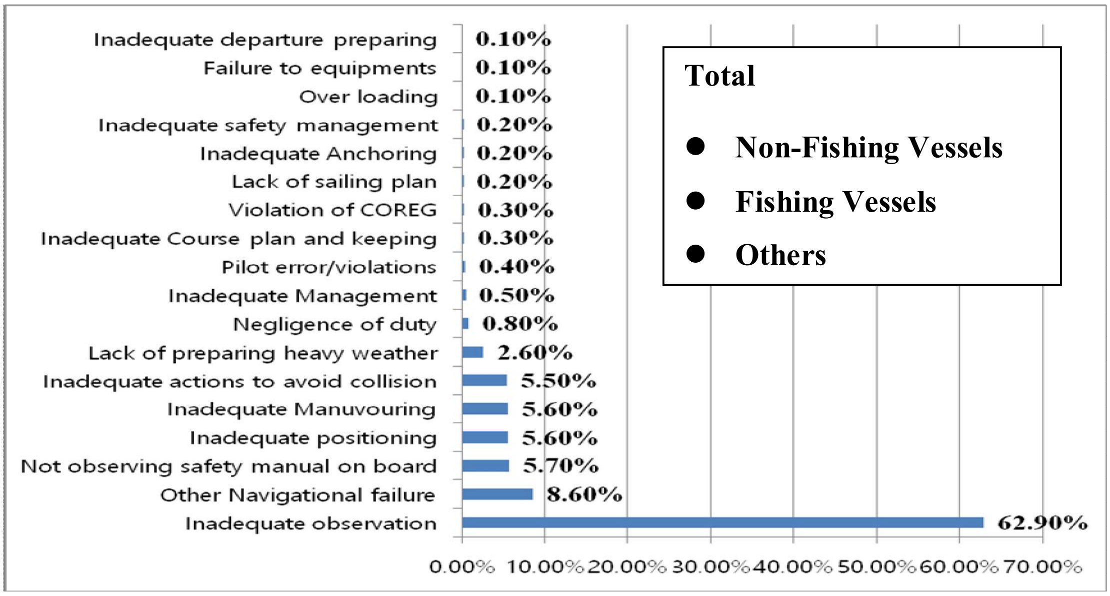

Figure 13 *Human error cause distribution of all accidents*

Source: KMST investigation statistics and data base (2014)

Table 22 and Figure 14 show the distribution of detailed causes of technical failures, showing that few navigational accidents are caused by these causes; 1.1% for non-fishing vessels and 0.6% for fishing vessels. Totally, for all kinds of ships and accidents, "Electronic facility deficiency" (38.8%), "Other machinery deficiency" (14.5%), "Main Engine trouble" (14.0%), and "Deficiency in closing" (5.2%) are shown as the most significant causes of technical failures.

Table 22 *Technical failure cause distribution*

Technical Failures	Non-Fishing Vessels					Fishing Vessel					Total (%)
	Navigational Accident			Non-Navi.	Sub-Total	Navigational Accident			Non-Navi.	Sub-Total	
	Col	Gro	sum			Col	Gro	sum			
Other machinery deficiency				8	8				18	18	26 (14.5)
Fatigue of Hull				12	12				10	10	22 (12.4)
Electronic facility				8	8				61	61	69

deficiency											(38.8)
Steering gear related deficiency									4	4	4 (2.2)
Auxiliary machinery deficiency				1	1				7	7	8 (4.5)
Main Engine trouble	2		2	2	4				21	21	25 (14.0)
Deficiency in closing				10	10				10	10	20 (11.2)
Loading/Unloading facility deficiency				2	2						2 (1.1)
Deficiency of Nav. equipments							1	1	1	2	2 (1.1)
Total	2		2 (1.1)	43 (24.1)	45 (25.2)		1 (0.6)	1 (0.6)	132 (74.2)	133 (74.7)	178 (100)

Source: KMST investigation statistics and data base (2014). Unit of figures in blank: %

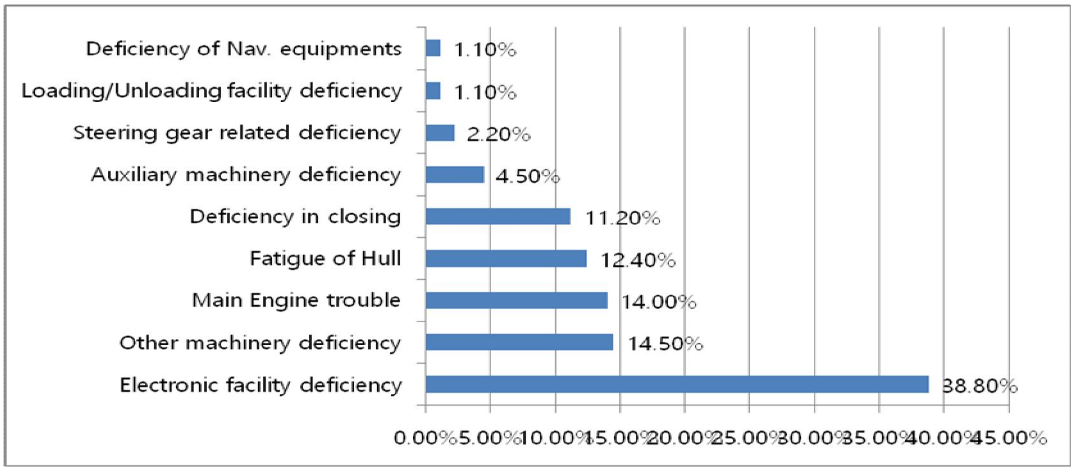

Figure 14 *Technical failure cause distribution*

Source: KMST investigation statistics and data base (2014)

Table 23 and Figure 15 show the distribution of detailed causes of external factors, revealing that "Other ship's errors" (85%) is the most significant cause. This cause was accounted for 100% of navigational accidents among non-fishing vessels, and 68.3% of navigational accidents among total accidents.

With regard to external factors, the cause "Other ship's errors" could be argued as being a human error cause. Adding it to the human error category brings the share of human error up to 90.9% for navigational accidents of non-fishing vessels, 93.3% for navigational accidents involving fishing vessels, and 60.2% for all kinds of accidents involving both types of vessels.

Table 23 *External factors distribution*

External Factors	Non-Fishing Vessels					Fishing Vessels					Total
	Navigational Accident			Non - Nav	Sub-Total	Navigational Accident			Non - Nav	Sub-Total	
	Col	Gro	sum			Col	Gro	sum			
Other ship's errors	25		25		25	16		16	10	26	51 (85%)
Deficiency of shore facilities				7	7				1	1	8 (13.3%)
Deficiency of AtoN facility									1	1	1 (1.7%)
Total	25		25	7	32	16		16	12	28	60

Source: KMST investigation statistics and data base (2014)

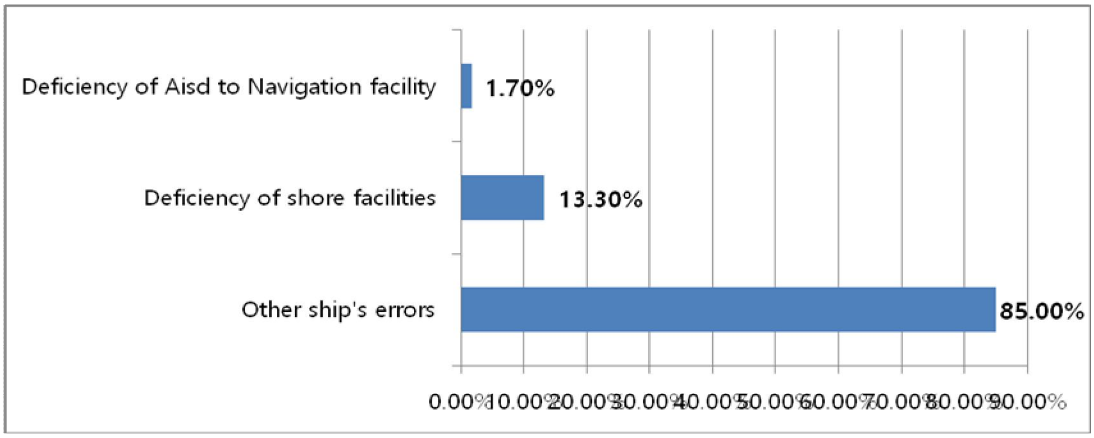

Figure 15 *External factors distribution*

Source: KMST investigation statistics and data base (2014)

Table 24 and Figure 16 show the distribution of detailed causes for the inadequate handling of machinery or cargo, showing that "Lack of Engine Maintenance" (83.4%) is the most significant cause. In more detail, the cause distribution of "Lack of Engine Maintenance" was 63.1% among navigational accidents involving non-fishing vessels and 80% among navigational accident involving fishing vessels.

Other significant causes in this category were "Lack of Maintenance of steering/navigational gears" (8.4%), "Inadequate Fire machinery" (3.7%) and "Lack of checking fuel oil, lubrication oil" (2.0%).

Table 24 *Inadequate handling machinery or cargo cause distribution*

Inadequate Handling	Non-Fishing Vessels					Fishing Vessels					Total
	Navigational Accident			Non-Nav	Sub-Total	Navigational Accident		Non-Nav		Sub-Total	
	Col	Gra	sum	Other		Col	Gra	Sum	Other		
Lack of Eng. Maintenance	3 (100)	3 (100)	6 (100)	72 (63.1)	78 (65)	3 (75)	1 (100)	4 (80)	958 (85.4)	962 (85.4)	1040 (83.4)
Lack of checking fuel oil, lubrication oil				7	7	1		1	17	18	25 (2.0)
Inadequate handling dangerous cargo				3	3				1	1	4
Self-ignition				1	1				4	4	5
Inadequate Handling cargo				3	3				5	5	8
Lack of Maintenance of steering/nav.gears				9	9				96	96	105 (8.4)
Inadequate Fire machinery				9	9				37	37	46 (3.7)
Inadequate Loading Cargo				5	5				2	2	7
Explosion of cargo				4	4						4
Cargo shifted				1	1				2	2	3
Total	3 (100)	3 (100)	6 (100)	114 (100)	120 (100)	4 (100)	1 (100)	5 (100)	1122 (100)	1127 (100)	1247 (100)

Source: KMST investigation statistics and data base (2014)

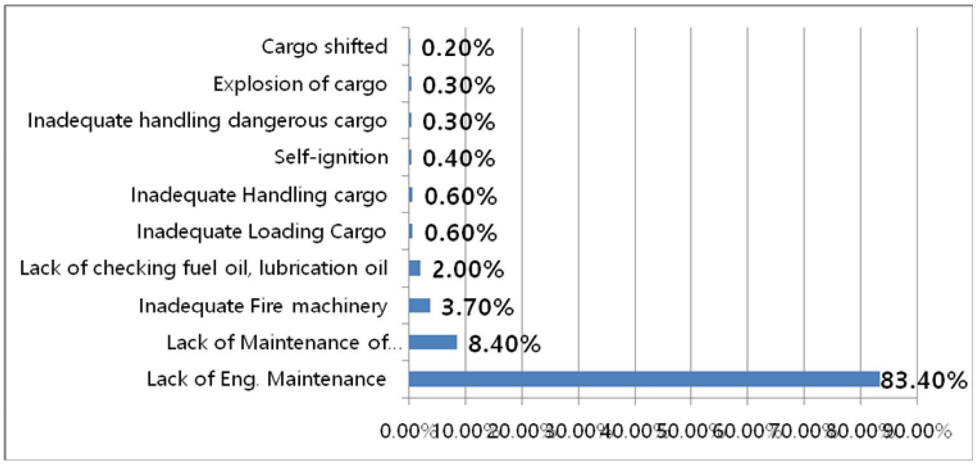

Figure 16 *Inadequate handling machinery or cargo cause distribution*

Source: KMST investigation statistics and data base (2014)

Table 25 shows the distribution of detailed causes for other factors, showing two kinds of causes: 75.4 % of irresistible causes such as natural disasters and typhoons, and 24.6% of the unknown and others. The "unknown" and "others" are 7.8% among the total number of accidents. The direct cause "others" could also be argued as being a human error because it is composed of inadequate management of a ship's operation and inadequate loading of cargo or passengers according to the KMST's descriptions.

Table 25 *Other Factors Distribution (Korea related)*

Others	Non-Fishing Vessels					Fishing Vessels					Total
	Navi. Accident			Other	sum	Navi. Accident			Other	sum	
	Col	Gro	sum			Col	Gro	sum			
Other	14 (31.1)	5 (17.9)	19 (26.0)	46 (57.5)	65 (42.5)	18 (30)	3 (18.8)	21 (27.6)	123 (45.2)	144 (41.4)	209 (41.7)
Unknown	25 (55.6)	5 (17.9)	30 (41.1)	18 (22.5)	48 (31.4)	41 (68.3)	1 (6.3)	42 (55.3)	79 (29.0)	121 (34.8)	169 (33.7)
irresistible natural disasters		6 (21.4)	6 (8.2)	4 (5.0)	10 (6.5)		7 (43.8)	7 (9.2)	47 (17.3)	54 (15.5)	64 (12.8)
typhoon	6 (13.1)	12 (42.9)	18 (24.7)	12 (15.0)	30 (19.6)	1 (1.7)	5 (31.3)	6 (7.9)	23 (8.5)	29 (8.3)	59 (11.8)
Total	45 (100)	28 (100)	73 (100)	80 (100)	153 (100)	60 (100)	16 (100)	76 (100)	272 (100)	348 (100)	501 (100)

Source: KMST investigation statistics and data base

5. DISCUSSION OF THE EFFECTS OF E-NAVIGATION

5.1 Development of the formula to evaluate the effects of e-navigation

The author, in Chapters 2 and 3, examined the IMO's e-navigation related documents, and especially the SIP set out in NCSR 1/28. Annex 7 in order to determine the methodology to discuss the effects of SMART-navigation on reducing accidents. As a result, the author determined the rate of risk reduction of "65%" that the FSA team calculated through a generic risk model and an expert workshop, as the coefficient to calculate the effects of SMART-navigation as described in Chapter 3.

However, the rate of the risk reduction of "65%" does not mean the rate to reduce the volume of accidents, but the rate to reduce the percentage of each detailed direct cause reducible by RCOs, which is extracted from each direct cause, in terms of the potential loss of lives (PLL) as described in Tables 13 and 14 in Chapter 3.

This means that the rate of "65%" should be converted into the actual rate of risk reduction by RCOs for each direct cause as well as the total actual rate of risk reduction to be reduced by RCOs for all direct cause in order to calculate the actual volume of selected accidents to be reduced by RCOs in terms of percentage among total accidents.

Thus, the author developed the following formulas in order to calculate the effects of SMART-navigation on reducing accidents in terms of the actual volume of the relevant accidents by RCOs:

$$
\begin{aligned}
AVSA &= \sum(RSAD \times ARDC_{HF/TF/EF}) \\
&= \sum(RSAD \times c \times \sum RDDC_{HF/TF/EF}) \\
&= c \times \sum(RSAD \times \sum RDDC_{HF/TF/EF})
\end{aligned}
$$

where is :

c	= Coefficient (65% for SOLAS ships, 55% for non-SOLAS ships)
AVSA	= Actual Volume of selected accidents to be reduced in terms of percentage among total accidents
RSAD	= Rate of selected accident distribution
ARDC	= Actual Rate of risk reduction of each direct cause to be reduced
$RDDC_{HE}$	= Rate of risk reduction of detailed direct cause of Human Error to be reduced
$RDDC_{TF}$	= Rate of risk reduction of each detailed direct cause of Technical Failure to be reduced
$RDDC_{EF}$	= Rate of risk reduction of each detailed direct cause of External Factor to be reduced

In more detail, the above formulas are explained as follows :

- the actual rate of risk reduction to be reduced by RCOs for each direct cause (ARDC) = the coefficient (65%) × ∑(each percentage of the detailed direct causes of relevant direct cause to be reduced by RCOs)

- the total actual rate of risk reduction to be reduced by RCOs for all direct cause (Total ARDC) = ∑(the percentage of each direct cause among total direct cause × each actual rate of risk reduction to be reduced by RCOs for relevant direct cause) = ∑(the percentage of each direct cause among total direct cause × ((the coefficient (65%)) × ∑(each percentage of the detailed direct causes of relevant direct cause)))

- the actual volume of selected accidents to be reduced by RCOs in terms of percentage among total accidents
 = the percentage distribution of the selected accidents among total accidents × total actual rate of risk reduction to be reduced by RCOs for all direct cause

= the percentage distribution of the selected accidents among total accidents × ∑(the percentage[22] of each direct cause among total direct cause × ((the coefficient (65%)) × ∑[23](each percentage of the detailed direct causes of each direct cause)))

For example, in the case of the NMA investigation statistics that were used in the FSA, the actual volume of navigational accidents, including collisions and groundings, to be reduced by RCOs in terms of percentage among total accidents is calculated as 22.8% by applying the above formula as follows:

- 43.2%[24] (the percentage distribution of navigational accidents among total accidents) × ∑(65% (the percentage of **human error**) × 61.1% ((the coefficient (65%) × ∑(the percentage of the detailed direct causes of the human error to be reduced by RCOs)) + 18% (the percentage of **technical failures**) × 53.3% ((the coefficient (65%) × ∑(the percentage of the detailed direct causes of the technical failures to be reduced by RCOs)) + 17% (the percentage of **external factors**) × 19.5% ((the coefficient (65%) × ∑(the percentage of the detailed direct causes of the external factors to be reduced by RCOs))) = 43.2% × ∑((65% × 61.1%)+(18% × 53.3%)+(17% × 19.5%)) = 43.2% × 52.6% = **22.8%**

[22] The percentage of each direct cause among total direct cause : 65% for the human error, 18% for the technical failures and 17% for the external factors, respectively (see Table 29 in paragraph 5.3.4.1).

[23] Each percentage of the detailed direct causes of each direct cause to be reduced by RCOs is 94% for the human error, 82% for the technical failures and 30% for the external factors, respectively (see Table 29 in paragraph 5.3.4.1).

[24] see Table 3 in the paragraph 2.2.2

For the purpose of applying the above formula to non-SOLAS ships, this chapter overviews SMART-navigation, which focuses on the services for non-SOLAS ships as well as SOLAS ships as mentioned in the paragraph 1.1. The RCOs that are applicable to non-SOLAS ships, including fishing vessels, are to be identified. Further, the author discusses the effects of SMART-navigation on reducing accidents based on the results of calculations by applying the above formula.

5.2 The SMART-navigation concept

5.2.1 Background of SMART-navigation

The Ministry of Oceans and Fisheries (MOF) established the SMART-navigation strategy to implement IMO's e-navigation concept in 2013, and finished the feasibility study on developing necessary core technologies and infrastructures to implement the strategy in 2014. The project to implement the strategy has been undertaken sparsely.

SMART-navigation is the Korean approach to implementing the IMO e-navigation concept in both Korean waters and Korean-related ships. Beside the scope of IMO e-navigation, SMART-navigation even includes services for non-SOLAS ships, including fishing vessels as well as non-fishing vessels engaging in domestic coastal areas.

The strategic implementation plan for SMART-navigation was basically composed of 16 kinds of MSPs as adopted in the IMO's SIP. Non-SOLAS ship are more vulnerable[25] to accidents than SOLAS ships. This is, among others, because of lack of capacity of navigational equipment, higher workload on board and less safety information provided

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[25] According to the preliminary feasibility study to implement the IMO e-Navigation (MOF, 2014), 89.04% among all accidents for all ships in Korean waters and all Korean-flagged ships during last 5 years from 2009 to 2013 happened to non-SOLAS ships, while 10.06% were SOLAS ships (p. 5-44)

by shore based stations. Consequently, SMART-navigation concept even provides the much more enhanced services for non-SOLAS ships.

5.2.2 Components of the SMART-navigation

5.2.2.1 Main services of the SMART-navigation

According to the preliminary feasibility study on implementing IMO's e-navigation (MOF, 2014), the strategy of this project was developed through the following steps: (1) identifying the user needs of all stake-holders; (2) a gap analysis; (3) analyzing the direct causes of accidents; (4) identifying target services based on the results of the former steps; and (5) a risk and cost-benefit analysis. In addition to the study, the MOF conducted "A fundamental study on maritime accident prevention systems" and completed the definition of the main services of the SMART-navigation as summarized in Table 26:

Table 26 *Main services of the SMART-navigation*

Service Groups and its concept	Main Functions	Relevant MSPs
<Intelligent traffic coordination> The Services to increase the safety and efficiency of vessel traffics by using safety information, which is based on CMDS, to the vessel traffic management and coordination	● Providing VTS information to ship : other ships' position, destination, and intention of movement; any changes in safety information of the VTS areas ● Monitoring the ship's routing plan ● Supporting navigation decision-making ● Organizing vessel traffic ● Providing port information : local port; pilot-age, berthing and un-berthing	- MSP 1 - MSP 2 - MSP 3
<Automation of maritime information> Serve to increase the efficiency of maritime related businesses as well as the safety of navigation by	● Maritime safety information (MSI) service ● Safety fishing related information service ● Pilot-age information service ● Single window service for automatic reporting to shore for decreasing crews' unnecessary work burden and making them	- MSP 4 - MSP 5 - MSP 6 - MSP 7 - MSP 8 - MSP11

improving their efficiencies through automation of creating, delivering, utilizing and inter-connecting the maritime information.	focus on safety of navigation ● Transferring nautical charts and nautical publications for supporting automatic up-dating them electronically ● Meteorological information service for safety navigation and fishing activities ● Real-time hydrographic and environmental information service	- MSP12 - MSP14 - MSP15
<Pro-active management of the maritime safety> Service to prevent the potential accident causes in advance by proactively managing the ships and areas, which are identified as being vulnerable to accidents based on utilizing the real time of relevant statistics and local situation data	● Managing ships and areas, which are identified as being vulnerable to accident, in timely manner, based on real-time statistics and information ● Supporting safety navigation decision-making for their proactive responding to avoid accidents ● Analyzing maritime safety factors based on Big-data ● Providing safety information to ships, which are vulnerable to accidents, and supporting their safety decision-making ● Providing service of streaming electronic navigational charts (ENCs) to ships of medium and small size ● Remote supporting and managing safety training crews	Korean version of special services for non-SOLAS ships
<Remote/rapid emergency assistance > Service to minimize loss of lives and properties from accidents and variable emergencies happened in remote water areas by prompt and comprehensive responding to them	● Remote telemedical assistance in order to prevent delaying in remedial treatment ● Assisting ships' emergency responding ● Supporting SAR operation ● Supporting maritime affairs, regarding MAS ● Assisting remote crews' training to increase their competences	- MSP9 - MSP10 - MSP16
<Maritime domain awareness> Service to increase maritime security by real-time monitoring and managing all maritime domains in Korean water areas	● Comprehensive recognizing and responding to all maritime domains over all Korean water areas ● Providing information regarding the illegal unreported unregulated fishing activities ● Providing information regarding oil spill ● Supporting activities preventing illegal discharge of wastes/pollutants from ships ● Supporting the other activities related to maritime security	Korean version of service

Source: A fundamental study on maritime accident prevention systems (pages 162-163, MOF, 2015)

5.2.2.2 SMART-navigation Services for non-SOLAS ships

According to Table 26, SMART-navigation will introduce more enhanced special services[26] for non-SOLAS ships, which are designed as SMART-phone like services for examples: (1) the service supporting ship's routing for ships vulnerable to accidents such as coastal ferries and dangerous cargo carriers as shown in Figure 17; (2) the service supporting the safety of fishing vessels; (3) the electronic navigation chart (ENC) streaming service for small coastal ships; (4) and the single window service.

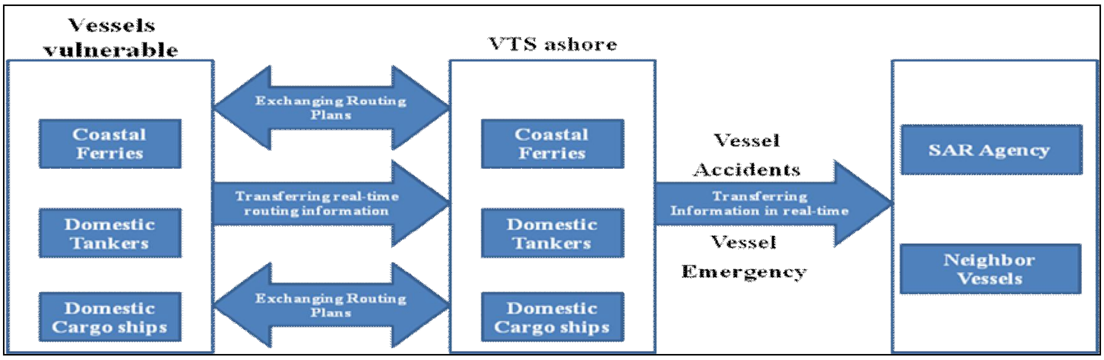

Figure 17 *Concept of service for non-SOLASe ships*

Source : A fundamental study on maritime accident prevention systems (page 176, MOF, 2015)

5.2.3 Architecture of SMART-navigation

One of the most important prerequisites to implement e-navigation is the system architecture for information exchange, so that, the SMART-navigation services can be established as shown in Figure 18. The architecture was designed according to IMO e-navigation philosophy, enabling the ship-borne and shore-based users to exchange

26 For detailed information on each special services for non-SOLAS ships, see page 175 to 179, A fundamental study on maritime accident prevention systems (MOF, 2015)

information using S-100[27] format and based on the maritime cloud service concept via various communication networks.

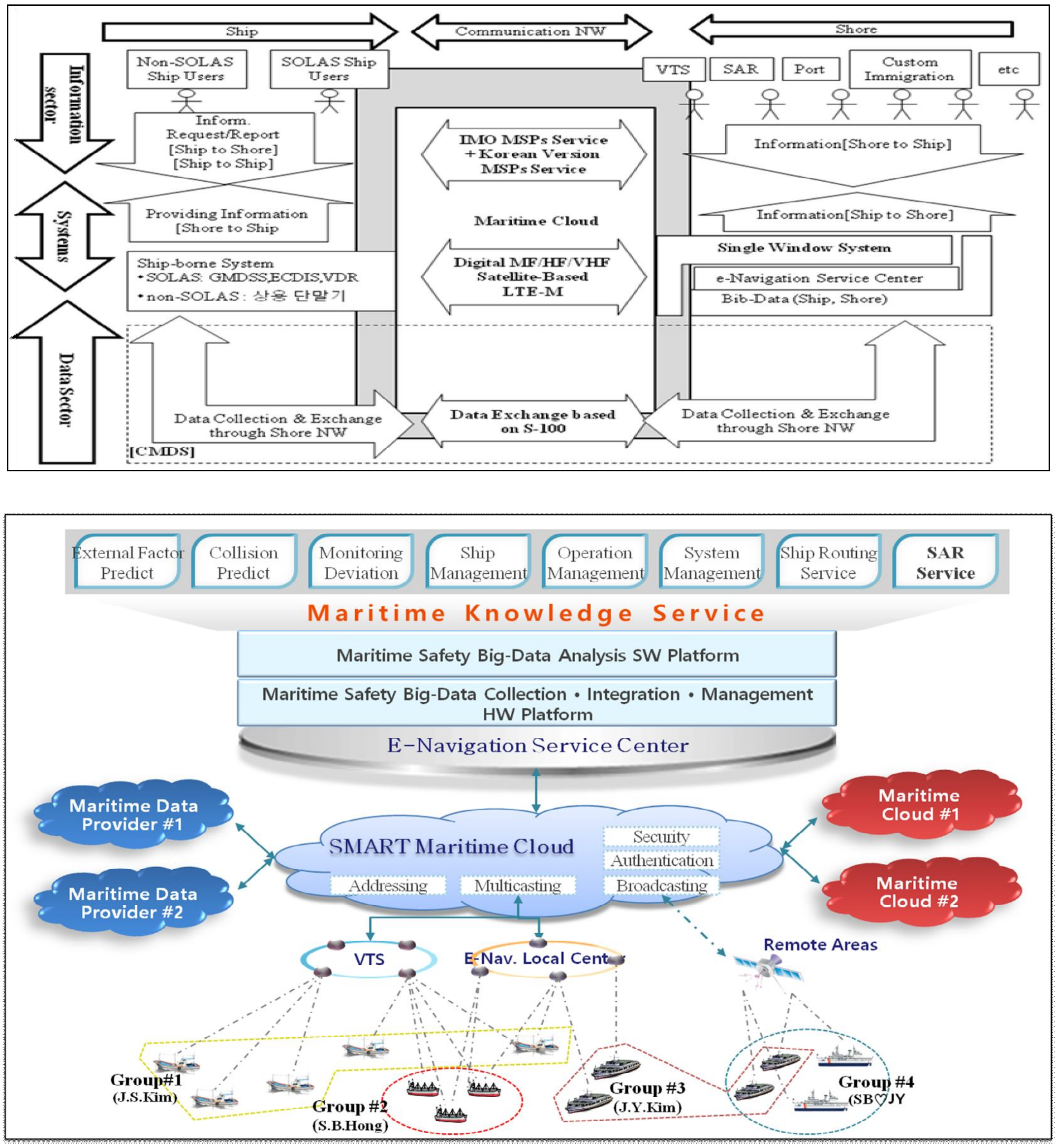

Figure 18 *Overall architecture of the SMART-navigation (MOF,2015)*

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27 It has been designated as the common maritime data structure (CMDS) for e-navigation as described in the IMO e-navigation SIP.

The communications network might be the most important factor in realizing the aims of e-navigation. There are a number of limitations in the current maritime communication network, as shown in Table 27 below, which are based on analog communications with the minimum capacity for essential communication and with regard to safety of navigation and emergency situations.

Further, even Korean fishing vessels of less than 5 tons, which represent the majority, at more than 87%, among all Korean fishing vessels, have yet to be equipped with navigational or emergency communication equipment.

Table 27 *Communication networks around the Korean coastal water areas*

Network	AIS	VHF	TRS	Satellite
Frequency	156 MHz- 162MHz	30 MHz- 300MHz	Tx : 851 MHz Rx:806 MHz	Inmarsat, Orbcom, Argos, Globalstar
Distance reachable	100 km	100 km	70 km	LEO : 5,000 km HEO : A3 areas
Outputs	1 W - 12.5 W	10 W	Unit : 0.6 W Base Station : 70 W	-
Data Speed	9,600 bps	4,096 bps	22,000 bps	9,600 bps

Source: A fundamental study on maritime accident prevention systems (MOF, 2015, page 36)

With regard to this, SMART-navigation is to provide the LTE-Maritime communication network[28] as a platform for non-SOLAS ships in order to implement the necessary e-navigation services.

[28] For LTE-Maritime service, MOF had been allocated the necessary digital communication frequency by the Ministry of Science, ICT and Future Planning (MSIP) in 2014. According to the media, MOF launched the project to establish LTE-M communication network in 2015, which is carried out by SKT telecom (SK Telecom, 2015, August 2).

In addition, the relevant communication networks for e-navigation services are to be provided with a data structure based on the CMDS[29], including the VHF Date Exchange (VDE), digital HF/MF and satellite-based communication, configuring their concept as shown in Figure 19 below (MOF, 2015).

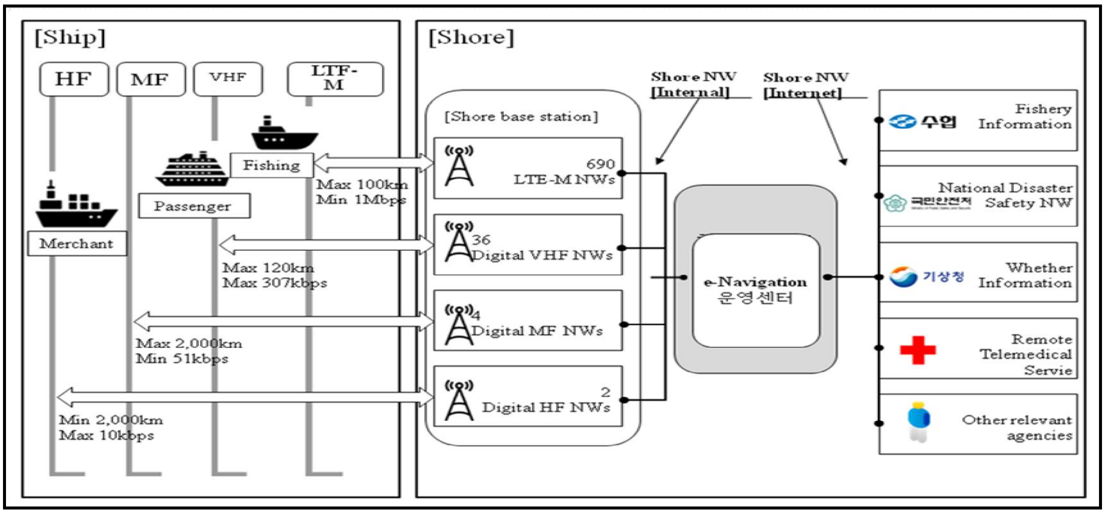

Figure 19 *Communication architecture for the SMART-navigation*

Source: A fundamental study on maritime accident prevention systems (MOF,2015,page 228)

5.3 Accident reducing effects of SMART-navigation

5.3.1 Discussion of detailed direct causes reducible by RCOs

The list of the detailed direct causes categorized in this dissertation and the NMA statistics are different from each other as examined in Chapters 3 and 4. For example, among human error, NMA statistics include detailed direct causes such as

[29] M. Jonas and J.H. Oltmann (2013) regarded the CMDS as the most important pillar for e-navigation, providing the "cement" to the other pillars, including (1) the overarching architecture of e-navigation and generalities, (2) shipboard equipment fit for e-navigation, (3) MSPs, (4) communication technologies, (5) resilient PNT, and (6) shore-based infrastructure.

"injury/sickness", "intoxicated" and "Fatigue/work overload", while KMST statistics do not. Such causes are underlying factors rather than direct causes.

However, this does not mean that the accidents caused by these underlying factors were excluded in the KMST investigation statistics. The KMST statistics were produced based on the direct causes only, not based on the underlying factors. That is why the author could not analyze and insert such causes in the detailed direct cause lists. In contrast, there are many more detailed direct causes with different names that the KMST statistics contain and the NMA statistics do not, and vice versa.

With regard to this, the author has identified the detailed direct causes of KMST, as shown in Table 28, based on the description given in the instructions for the KMST investigation statistics, in order to make conditions similar to the category of the NMA statistics that the FSA team identified and used for the risk and cost-benefit analysis.

For example, the author includes some detailed direct causes, which have different names but are considered to be reducible by RCOs, into the relevant group of the direct cause as follows:

- among the detailed direct causes of the inadequate handling of machinery or cargo, "Lack of checking fuel oil, lubrication oil", "Lack of Maintenance of steering/navigational gears" and "Inadequate Fire machinery" are included in the list of detailed direct causes under technical failures; and

- among the detailed direct causes of the external factors, "Other ship's errors" and "Deficiency of Aids to Navigation facility External Factors" are included in the list of the detailed direct causes under external factors.

In addition, the author excludes some of the detailed direct causes, which are not considered to be reduced by RCOs as shown in Table 28. For example, "Loading/Unloading facility deficiency", "Main Engine trouble" of the technical failures, and "Deficiency of shore facilities" of the external Factors were excluded.

As a result, the author extracted 3,366 accident vessels, which involved the detailed direct causes preventable by the RCOs of e-navigation, from the total 4,871 accident vessels.

Table 28 *Identified detailed direct causes*

List of Direct Causes by NMA		Shuffled Direct Cause of KMST to match with NMA	
Human Errors	Inadequate observation/ inattention Poor judgment of ship movement Fatigue/work overload Poor judgment of other factors Inadequate planning of voyage Intoxicated Failure to use navigational aids Failure to give way /high speed Lack of knowledge/skill/ training Communication problems Injury/sickness Use of defective equipment	Human Errors	(1) Inadequate observation (2) Over loading (3) Failure to equipments (4) Other Navigational failure (5) Negligence of duty (6) Pilot error/violations (7) Inadequate Anchoring (8) Inadequate safety management (9) Not observing safety manual (10) Inadequate positioning (11) Inadequate Maneuvering (12) Inadequate departure preparing (13) Inadequate actions to avoid collision (14) Inadequate Course plan and keeping (15) Violation of COREG (16) Lack of sailing plan (17) Lack of preparing heavy weather (18) Inadequate Management
Technical Failures	Technical failure (not related to main engine)	Technical Failures	(19) Other machinery deficiency (20) Fatigue of Hull (21) Electronic facility deficiency (22) Steering gear related deficiency (23) Auxiliary machinery deficiency (24) Deficiency in closing (25) Deficiency of Nav. equipments

		Inadequate Handling machinery or cargo	(26) Lack of checking fuel oil/lubrication (27) Lack of Maintenance of (28) Steering/navigational gears (29) Inadequate Fire machinery
External Factors	Strong currents Severe heavy weather	External Factors	(30) Other ship's errors (31) Deficiency of AtoN facility
The detailed direct causes among the lists of the KMST, which are not considered to be reducible by RCOs		Technical Failures	(32)Loading/Unloading facility deficiency (33)Main Engine trouble
		External Factors	(34) Deficiency of shore facilities
		Inadequate Handling machineries or cargos	(35) Inadequate handing IMDG (36) Inadequate Handling cargo (37) Inadequate Loading Cargo (38) Lack of Eng. Maintenance (39) Self-ignition, Explosion of cargo (40) Cargo shifted
		Others	(41) Other, Unknown (42) Irresistible natural disasters (43) Irresistible natural disasters (typhoon)

Source: Based on the NMA statistics and the KSMT statistics

5.3.2 Discussion of RCOs applicable to non-SOLAS ships

With regard to applying the rate of risk, the author selected the relevant RCOs based on the scope of the SMART-navigation services related to the non-SOLAS ships as examined in paragraph 5.2.2.1 and 5.2.2.2.

As a result, except for RCO 2 (Bridge alert management), the author identified another 6 kinds of RCOs that have the same rate of risk reduction as shown in Table 29. The rate for non-SOLAS ship is 55% in total, which is 84.6% of the rate of risk reduction for SOLAS ships, "65% in total".

Table 29 *RCOs for non-SOLAS ships*

SOLAS Ships				Non-SOLAS Ships
RCOs		**Rate of risk reduction**		**Remark**
RCO 1	Integration of navigation information and equipment including improved software quality assurance	**11%**	**11%**	applied
RCO 2	Bridge alert management	**10%**	**-**	excluded
RCO 3	Standardized mode	**7%**	**7%**	applied
RCO 4	Automated and standardized ship-shore reporting	**8%**	**8%**	applied
RCO 5	Improved reliability and resilience of onboard PNT systems	**8%**	**8%**	applied
RCO 6	Improved shore-based services	**7%**	**7%**	applied
RCO 7	Bridge and workstation layout standardization	**14%**	**14%**	applied
Total		**65%**	**55% (84.6% of 65%)**	

Source: Annex 1 of NAV 59/6 (pages 37-38) for SOLAS ships only.

5.3.3 Expert survey by questionnaire

The author carried out an expert survey by questionnaire[30] through e-mail in order to increase the validity of the decisions made in paragraphs 5.3.1 and 5.3.2. The survey was focused on assessing the validity of selecting the RCOs as shown in Table 28, which are applicable to non-SOLAS ships, and identifying the detailed direct causes as shown in Table 29, which are reducible by the RCOs.

Seventeen persons responded in total, whose average experience working for the safety of navigation was 14.3 years. The responders are currently working in maritime safety-related research and development institutes (41.2%, 7 persons), the safety management departments of shipping industries (29.4%, 5 persons) and vessel accident investigation agencies (29.4%, 5 persons). They were all involved in establishing the SMART-navigation strategy directly as researchers, and indirectly as participants in the related brainstorming sessions and workshops discussing the strategy.

[30] The questionnaire was drafted according to the guideline on WMU research ethics committee.

With regard to the validity of Table 28, 13 persons (76.5%) supported the validity of identifying the detailed direct causes as proposed. Among them, 4 persons (23.5%) were of the opinion that items 33 to 38 and 43 were also partially reducible by e-navigation, and suggested that the service of "remote monitoring ship's systems[31]", including main engine, should be introduced to enhance the management of such items by shore side.

On the other hand, 4 persons (23.5%) pointed out that items 2, 4, 7, 17, 22 to 27, and 30 are somewhat limited in their ability to be reduced by RCOs. One person (5.9%) insisted that the causes reducible by RCOs should be identified based on the conditions: (1) exchanging information between ship and shore should be harmonized, and (2) collecting, analyzing and presenting information should be harmonized between ship and shore.

In the case of the validity of Table 29, 14 persons (94.1%) supported the validity of selecting the RCOs that are applicable to non-SOLAS ships. Among them, 2 persons (11.8%) even insisted that RCO 2 (Bridge alert management) should be also selected as the RCO that is applicable to non-SOLAS ships, and, in particularly, small non-SOLAS ships like fishing vessels need to be provided with it. On the other hand, only one person (5.9%) was of the opinion that RCO 7 is not effective to non-SOLAS ships.

In brief, even though 23.5% of opinions differed with regard to the author's proposals for Table 28 and 5.9% with regard to Table 29, the majority of the respondents supported the validity of the Tables. Further, the Tables were proposed based on reliable facts such as the case that the FSA team selected the detailed direct causes for carrying out risk and cost-benefit analysis of e-navigation, and the service scopes of SMART-navigation. Therefore, the author decided to apply the Tables 28 and 29 as they are for evaluation of the effect of SMART-navigation on reducing accidents.

[31] This was one of the MSPs, but deleted. See para. 2.2.5 for the detail reason.

5.3.4 Effects of reducing navigational accidents by SMART-navigation

5.3.4.1 Rate of risk reduction

Table 30 *Rate of reduction of direct causes by RCOs*

<table>
<tr><th colspan="2">RCOs</th><th>PLL reduction of total</th><th>Scope of detailed direct causes expected to be reduced by RCOs</th></tr>
<tr><td>RCO 7</td><td>Bridge and workstation layout standardization</td><td>14%</td><td rowspan="7"><Human Errors>
Inadequate observation/ inattention
Poor judgment of ship movement
Fatigue/work overload
Poor judgment of other factors
Inadequate planning of voyage
Intoxicated
Failure to use navigational aids
Failure to give way /high speed
Lack of knowledge/skill/ training
Communication problems
Injury/sickness
Use of defective equipment

<Technical Failures>
Technical failure (not related to main engine)

<External Factors>
Strong currents
Severe heavy weather</td></tr>
<tr><td>RCO 1</td><td>Integration of navigation information and equipment including improved software quality assurance</td><td>11%</td></tr>
<tr><td>RCO 2</td><td>Bridge alert management</td><td>10%</td></tr>
<tr><td>RCO 4</td><td>Automated and standardized ship-shore reporting</td><td>8%</td></tr>
<tr><td>RCO 5</td><td>Improved reliability and resilience of onboard PNT systems</td><td>8%</td></tr>
<tr><td>RCO 3</td><td>Standardized mode</td><td>7%</td></tr>
<tr><td>RCO 6</td><td>Improved shore-based services</td><td>7%</td></tr>
<tr><td colspan="2">Total</td><td>65%</td><td></td></tr>
</table>

Source: Annex 1 of NAV 59/6 (pages 37-38)

Table 30 shows the rate of potential possibility to reduce the loss of lives (PLL) for navigational accidents of SOLAS ships, including collisions and groundings, as examined in Chapter 3. However, the rate of risk reduction, "65%", does not mean the rate to reduce volume of accidents, but the rate to reduce percentage of selected direct causes of navigational accidents by RCOs in terms of PLL as described in paragraph 5.1.

Therefore, the author calculated the actual rate of the detailed direct causes to be reduced by RCOs by using the formula described in paragraph 5.1. The result of the calculation is 52.7% for SOLAS ships as shown in Table 31. The figure in blank, "( )", is the rate for non-SOLAS vessels. Based on Table 31, the author calculates the actual rate of the volume of accidents to be reduced by RCOs for all ships in Korean water areas and all Korean-flagged ships worldwide as shown in Tables 32, 33 and 34, in terms of human error, technical failures, and external factors, respectively.

Table 31 *Actual rate to reduce the direct cause of the navigational accidents*

Percentage of direct causes among navigational accident(%)	Selected detail direct causes	Percentage of distribution among direct cause (%)[32]	Rate of reduction of risks by RCOs	Actual rate to reduce each detailed direct causes by RCOs
Human Errors (65%)	Inadequate observation/ inattention	28	65% (55%)	18.2 (15.4)
	Poor judgment of ship movement	17		11.2 (9.4)
	Fatigue/work overload	13		8.5 (7.2)
	Poor judgment of other factors	12		7.8 (6.6)
	Inadequate planning of voyage	9		5.9 (5.0)
	Intoxicated	3		2 (1.7)
	Failure to use navigational aids	3		2 (1.7)
	Failure to give way /high speed	3		2 (1.7)
	Lack of knowledge/skill/ training	3		2 (1.7)
	Communication problems	2		1 (1.1)
	Injury/sickness	1		0.6 (0.5)
	Use of defective equipment	0		0
	Total rate to reduce each detailed human errors			61.1% (52%)
	Total rate to reduce direct cause of Human Errors (65%*61.1% =)			**39.7% (33.8)**
Technical Failures (18%)	Technical failure (not related to main engine)	82	65%	**53.3% (45.1)**
	Total rate to reduce each detailed technical failures			53.3% (45.1)
	Total rate to reduce direct cause of Technical Failures (18% * 53.3% =)			**9.6% (8.1)**
External Factors (17%)	Strong currents	16	65%	10.4% (8.8)
	Severe heavy weather	14		9.1% (7.7)
	Total rate to reduce each detailed external factors			19.5% (15.8)
	Total rate to reduce direct cause of External Factors (17% * 19.5% =)			**3.3% (2.8)**
Total rate to reduce navigational accidents				**52.7% (44.7)**

Source : Calculated based on Annex 1 of NAV 59/6 (Figures 9, 10 and 11 and Tables 11 and 12)

[32] based on the Figure 4, 5 and 6 (pages 29 to 30 of this dissertation)

Table 32 *Human error cause distribution*

Human error	Non-Fishing Vessel						Fishing Vessel						Total	
	Navigational Accident		Non-Navi		Sub-Total		Navigational Accident		Non-Navi		Sub-Total			
	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual
Inadequate observation	553 (70.4%)	45.8%	42 (16.5%)	10.7%	595 (57.2%)	37.2%	864 (76.1%)	49.5%	357 (50.3%)	32.7	1221 (66.2%)	43.0%	1816 (62.9%)	40.9%
Over loading			1 (0.4%)	0.3%	1 (0.1%)				3 (0.4%)	0.3%	3 (0.2%)	0.1%	4 (0.1%)	
Failure to equipments									3 (0.4%)	0.3%	3 (0.2%)	0.1%	3 (0.1%)	
Other Navigational failure	24 (3.1%)	2.0%	38 (14.9%)	9.7%	62 (6.0%)	3.9%	21 (1.9%)	1.2%	165 (23.2%)	15.1%	186 (10.1%)	6.6%	248 (8.6%)	5.6%
Negligence of duty	9 (1.1%)	0.7%	2 (0.8%)	0.5%	11 (1.1%)	0.7%	11 (1.0%)	0.7%	1 (0.1%)		12 (0.7%)	0.5%	23 (0.8%)	0.5%
Pilot error/violations	5 (0.6%)	0.4%	7 (2.7%)	1.8%	12 (1.2%)	0.8%							12 (0.4%)	0.3%
Inadequate Anchoring	3 (0.4%)	0.3%	1 (0.4%)	0.3%	4 (0.4%)	0.3%			3 (0.4%)	0.3%	3 (0.2%)	0.1%	7 (0.2%)	0.1%
Inadequate safety management	2 (0.3%)	0.2%	1 (0.4%)	0.3%	3 (0.3%)	0.2%			4 (0.6%)	0.4%	4 (0.2%)	0.1%	7 (0.2%)	0.1%
Not observing safety manual on board	1 (0.2%)	0.1%	70 (27.5%)	17.9%	71 (6.8%)	4.4%	1 (0.1%)		93 (13.1%)	8.5%	94 (5.1%)	3.3%	165 (5.7%)	3.7%
Inadequate positioning	41 (5.2%)	3.4%	16 (6.3%)	4.1%	57 (5.5%)	3.6%	91 (8.0%)	5.2%	15 (2.1%)	1.4%	106 (5.7%)	3.7%	163 (5.6%)	3.6%
Inadequate Manuvouring	63 (8.0%)	5.2%	45 (17.6%)	11.4%	108 (10.4%)	6.8%	21 (1.9%)	1.2%	34 (4.8%)	3.1%	55 (3.0%)	2.0%	163 (5.6%)	3.6%
Inadequate departure preparing			2 (0.8%)	0.5%	2 (0.2%)	0.1%			1 (0.1%)		1 (0.1%)		3 (0.1%)	
Inadequate actions to avoid collision	63 (8.0%)	5.2%			63 (6.1%)	4.0%	96 (8.5%)	5.5%			96 (5.2%)	3.4%	159 (5.5%)	3.6%
Inadequate Course plan and keeping	3 (0.4%)	0.3%	3 (1.2%)	0.8%	6 (0.6%)	0.4%	2 (0.2%)	0.1%	1 (0.1%)		3 (0.2%)	0.1%	9 (0.3%)	0.2%
Violation of COREG							8 (0.7%)	0.5%			8 (0.4%)	0.3%	8 (0.3%)	0.2%
Lack of sailing plan	2 (0.3%)	0.2%	1 (0.4%)	0.3%	3 (0.3%)	0.2%	1 (0.1%)		1 (0.1%)		2 (0.1%)		5 (0.2%)	0.1%
Lack of preparing heavy weather	15 (1.9%)	1.2%	19 (7.6%)	4.9%	34 (3.3%)	2.1%	13 (1.1%)	0.7%	29 (4.1%)	2.7%	42 (2.3%)	1.5%	76 (2.6%)	1.7%
Inadequate Management	1 (0.2%)	0.1%	7 (2.7%)	1.8%	8 (0.8%)	0.5%	6 (0.5%)	0.3%			6 (0.3%)	0.2%	14 (0.5%)	0.3%
Total	803 (100%)	65.1%	282 (100%)	65.3%	1,085 (100%)	65.2%	1,155 (100%)	64.9%	740 (100%)	64.8%	1,895 (100%)	65%	2,980 (100%)	64.5%

Source: KMST investigation statistics and data base (2014)

Table 33 *Technical failure cause distribution*

Technical Failures	Non-Fishing Vessels						Fishing Vessel						Total	
	Navigational Accident		Non-Navi.		Sub-Total		Navigational Accident		Non-Navi.		Sub-Total			
	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual
Other machinery deficiency			8 (12.5%)	8.1%	8 (12.5%)	8.1%			18 (6.9%)	4.5%	18 (6.8%)	4.4%	26 (8.0%)	5.2%
Fatigue of Hull			12 (18.8%)	12.1%	12 (18.8%)	12.2%			10 (3.8%)	2.5%	10 (3.8%)	2.5%	22 (6.7%)	4.4%
Electronic facility deficiency			8 (12.5%)	8.1%	8 (12.5%)	8.1%			61 (23.4%)	15.2%	61 (23.2%)	15.1%	69 (21.1%)	13.7%
Steering gear related deficiency									4 (1.5%)	0.8%	4 (1.5%)	1.0%	4 (1.2%)	0.8%
Auxiliary machinery deficiency			1 (1.6%)	1.0%	1 (1.6%)	1.0%			7 (2.7%)	1.8%	7 (2.7%)	1.8%	8 (2.4%)	1.6%
Deficiency in closing			10 (15.6%)	10.1%	10 (15.6%)	10.1%			10 (3.8%)	2.5%	10 (3.8%)	2.5%	20 (6.1%)	4.0%
Deficiency of Nav. equipments							1 (50%)	32.5%	1 (0.4%)	0.3%	2 (0.8%)	0.5%	2 (0.6%)	0.4%
Lack of checking fuel oil, lubrication oil			7 (10.9%)	7.1%	7 (10.9%)	7.1%	1 (50%)	32.5%	17 (6.5%)	4.2%	18 (6.8%)	4.4%	25 (7.6%)	4.9%
Lack of Maintenance of steering/navigational gears			9 (14.1%)	9.2%	9 (14.1%)	9.2%			96 (36.8%)	23.9%	96 (36.5%)	23.7%	105 (32.1%)	20.9%
Inadequate Fire machinery			9 (14.1%)	9.2%	9 (14.1%)	9.2%			37 (14.1%)	9.2%	37 (14.1%)	9.2%	46 (14.1)	9.2%
Total			64 (100%)	64.9%	64 (100%)	65%	2 (100%)	65%	261 (100%)	64.9%	263 (100%)	65.1%	327 (100%)	65.1%

Source: KMST investigation statistics and data base.

Table 34 *External factors distribution*

External Factors	Non-Fishing Vessels						Fishing Vessels						Total	
	Navigational Accident		Non-Nav		Sub-Total		Navigational Accident		Non-Nav		Sub-Total			
	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual	Original	Actual
Other ship's errors	25 (100%)	65			25 (100%)	65%	16 (100%)	65%	10 (90.9%)	59.1%	26 (96.3%)	62.6%	51 (98.1%)	63.8%
Deficiency of Aisd to Navigation facility									1 (9.1%)	5.9%	1 (3.7%)	2.4%	1 (1.9%)	1.2%
Total	25 (100%)	65%	7 (100%)	65%	25 (100%)	65%	16 (100%)	65%	11 (100%)	65%	27 (100%)	65%	52 (100%)	65%

Source: KMST investigation statistics and data base

5.3.4.2 The effects of reducing accidents

Table 35, which combines Tables 32, 33 and 34, shows the apparent rate of reducing the relevant accidents involving SMART-navigation, without classifying the ship types of the SOLAS and Non-SOLAS ships. For example, 64.9% among total accidents, including 22.9% for non-fishing vessels and 42.0% for fishing vessels, are expected to be reduced by introducing e-navigation.

Table 35 *Apparent effects on reducing accidents by the SMART-navigation*

Accident Type			Human Errors	Technical Failure	External Factor	Total	
						Actual	Effect
Non-Fishing Vessels	Navigational Accident	Actual %	803 (23.9%)		25 (0.7%)	828 (24.6%)	16.1%
		Risk Reduction Rate	65.1%		65%		
		Effect	15.6%		0.5		
	Non-Navigational	Actual %	282 (8.4%)	64 (1.9%)	7 (0.2%)	353 (10.5%)	6.8%
		Risk Reduction Rate	65.3%	64.9%	65%		
		Effect	5.5%	1.2%	0.1%		
	Sum	Actual %	1,085 (32.2%)	64 (1.9%)	32 (0.95%)	1,181 (35.1%)	22.9%
		Effect	21.1%	1.2%	0.6%		
Fishing Vessels	Navigational Accident	Actual %	1,155 (34.3%)	2 (0.1%)	16 (0.5%)	1,173 (34.8%)	22.5%
		Risk Reduction Rate	64.9%	65%	64.9%		
		Effect	22.2%	-	0.3%		
	Non-Navigational	Actual %	740 (22.0%)	261 (7.8%)	11 (0.3%)	1,012 (30.1%)	19.5%
		Risk Reduction Rate	64.8%	64.9%	65%		
		Effect	14.2%	5.1%	0.2%		
	Sum	Actual %	1,895 (56.3%)	263 (7.8%)	27 (0.8%)	2,185 (64.9%)	42.0%
		Effect	36.4%	5.1%	0.5%		
Total		Actual %	2,980 (88.5%)	327 (9.7%)	59 (1.8%)	3,366 (100%)	64.9%
		Effect	57.5%	6.3%	1.1%		

Source: KMST investigation statistics and data base (2014)

However, in this table, both SOLAS and non-SOLAS ships accidents are combined, and their rates of risk reduction are different as explained in paragraph 5.3.4.1 and as shown in Table 31. Therefore, it is necessary to convert Table 35 again, by applying the appropriate rates to the SOLAS and non-SOLAS ships, in order to discuss the exact effects on reducing accidents. The converting conditions are as follow:

- The risk reduction rate for SOLAS ships by seven RCOs is 65%, while the risk reduction rate for non-SOLAS ships by seven RCOs is 55%, which is 84.6% of 65%, as explained in paragraph 5.3.2.
- The accident distribution of SOLAS ship and non-SOLAS ship among total accidents are 57.9% and 42.1% respectively, calculated based on Table 36.

Table 36 *SOLAS and non-SOLAS ship distribution among accidents ships*

Category		2009	2010	2011	2012	2013	Total	
							Q'ty of ships	Distribution
Non Fishing	SOLAS	119	177	171	156	163	786(57.9%)	16.27%
	Non- SOLAS	71	112	138	132	119	572(42.1%)	11.83%
	Total	190	289	309	288	282	1,358(100%)	
Fishing	Non- SOLAS	725	672	888	653	536	3,474	71.90%

Source: Preliminary feasibility study on e-navigation (p. 5-44), which was carried out by the Ministry of Oceans and Fisheries (MOF) in 2014

Based on the above condition, the author finally calculates the effects of reducing accidents involving SMART-navigation as shown in Table 37[33].

According to Table 37, SMART-navigation is expected to reduce more than the 56.6% of total accidents of 3,366 vessels, including 13% of SOLAS ships and 43.6% of non-SOLAS ships, including fishing vessels.

[33] To see each effect based on the total number of accidents, "4,871", it is necessary to multiply 69.9 % with rate calculated in these Tables: 69.9% is calculated by 3,366, divided by 4,871. This is because that the Table 35 was calculated based on the accident vessels of 3,366 as described in the paragraph 5.3.1 and in the Table 29.

In the case of navigational accidents, including collisions and groundings, more than 33.9 %, composing 14.8% for non-fishing vessels and 19.1% for fishing vessels, are expected to be reduced. Even the non-navigational accidents are expected to be reduced up to 22.7%, including 6.2% for non-fishing vessels and 16.5% for fishing vessels. In terms of the direct causes, 50.2% of the accidents caused by human error are expected to be reduced, and 5.4% of the accidents caused by technical failures and 1% of the accidents caused by external factors.

Table 37 *Effects on reducing accidents by the SMART-navigation*

Accident Type				Human Errors	Technical Failure	External Factor	Total	
							Actual	Effect
Non-Fishing Vessels	Navig-ational accident	SOLAS	Actual %	465 (13.8%)		14 (0.4%)	828 (24.6%)	14.8%
			Risk Reduction Rate	65.1%		65%		
			Effect	8.9%		0.3%		
		Non-SOLAS	Actual %	338 (10.0%)		11 (0.3%)		
			Risk Reduction Rate	55.1%		55.0%		
			Effect	5.5%		0.1%		
	Non-Navig-ational	SOLAS	Actual %	163 (4.8%)	37 (1.1%)	4 (0.1%)	353 (10.5%)	6.2%
			Risk Reduction Rate	65.3%	64.9%	65%		
			Effect	3.1%	0.7%	-		
		Non-SOLAS	Actual %	119 (3.5%)	27 (0.8%)	3 (0.1%)		
			Risk Reduction Rate	55.2%	54.9%	55%		
			Effect	1.9%	0.4%	0.1%		
	Sum		Actual %	1,085 (32.2%)	64 (1.9%)	32 (0.95%)	1,181 (35.1%)	21.0%
			Effect	19.4%	1.1%	0.5%		
Fishing Vessels	Navigational		Actual %	1,155 (34.3%)	2 (0.1%)	16 (0.5%)	1,173 (34.8%)	19.1%
			Risk Reduction Rate	54.9%	55%	54.9%		
			Effect	18.8%	-	0.3%		
	Non-Navigational		Actual %	740 (22.0%)	261 (7.8%)	11 (0.3%)	1,012 (30.1%)	16.5%
			Risk Reduction Rate	54.8%	54.9%	55%		
			Effect	12.0%	4.3%	0.2%		
	Sum		Actual %	1,895 (56.3%)	263 (7.8%)	27 (0.8%)	2,185 (64.9%)	35.6%
			Effect	30.8%	4.3%	0.5%		
Total			Actual %	2,980 (88.5%)	327 (9.7%)	59 (1.8%)	3,366 (100%)	56.6%
			Effect	50.2%	5.4%	1.0%		

Source: KMST investigation statistics and data base (2014)

6. CONCLUSION

This dissertation aimed to evaluate how and to what extent vessel accidents could be reduced by introducing e-navigation application into the maritime sector. The questions were examined by a comprehensive case study, especially investigating the Korean shipping. Focus was laid on accidents in Korean waters and all Korean-flagged ships worldwide as well.

For that purpose, the IMO's methodological approach to establishing the e-navigation SIP, and especially the methodology used for the risk and cost-benefit analysis of the SIP has been studied and adapted to the Korean SMART-navigation project. The SMART-navigation is reviewed, its scope of services and tool kits to be introduced, in order to quantitatively evaluate its potential effects on non-SOLAS ships and SOLAS ships as well.

Finally, this dissertation aims to provide a sample to IMO Member States for effectively and efficiently introducing respectively prioritized e-navigation tool kits of e-navigation. Member States may apply the methodology developed and applied in this dissertation to their specific situation and especially taking into account potential effects on non-SOLAS vessels. This is suggested because the situation of maritime safety is different from country to country while IMO's e-navigation concept shows effects on reducing accidents for SOLAS ships only.

For the mentioned purpose, the author proposed a set of formulas, to evaluate and quantify the effects of e-navigation on reducing vessel accidents considering SOLAS but also non-SOLAS ships. The proposed set of formulas is applicable to other Member States of the IMO, and not only valid for the Republic of Korea.

In addition, the author provided results of evaluating the effects of SMART-navigation, by applying the formula, as a kind of model case for other Member States references. It is hoped that this study will be referred to the maritime safety policy bodies of the Member States of IMO, as well as to the practices of the maritime sectors such as shipping companies, crews on board ships and manufacturers developing e-navigation related systems.

At the outset, in Chapter 2, the author examined IMO e-navigation tool kits, and especially how they had been developed and how they are assessed to be able to reduce the risks causing navigational accidents, including collisions and groundings, by up to 65%.

As a result, the author identified 3 kinds of tool kits, including 5 kinds of solutions, 7 kinds of RCOs and 16 kinds of MSPs. They are all included in the SIP of IMO e-navigation concept.

E-navigation, among others, aims to increase the capability of shore based stations to manage and assist in improving safety of navigation by supporting decision making and provision of safety information to crews on board ships, so as to prevent or detect human errors that might lead to accidents.

Human error that causes accidents is one of the most significant concerns of maritime sectors. In fact, according to numerous sources most accidents happen mainly due to human error, and such accidents even have a rising trend. Human error is considered to be mainly rooted in fatigue, the lack of situational awareness and the safety culture of crews on board ships.

There have been limitations to preventing human error in terms of quantity and quality of information, complexity, lack of providing sufficient support to decision making and to effectively help avoid dangerous navigational situations, and lack of response to emergency situations in a timely and adequate manner. Further, this is clearly supported by user needs, which reflect the concerns experienced most often during their work, as surveyed for e-navigation as shown, e.g., in the IMO document NAV 55/INF. 9.

However, these problems are expected to be solved by e-navigation, through implementation of its tool kits, by supporting a ship's decision making to avoid accidents. Moreover, e-navigation will allow for provision ships with safety information and warning of dangerous situations, from shore based stations in a timely and adequate manner. In addition, due to the digitalized and standardized e-navigation systems with harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore, e-navigation could greatly improve the efficiency of maritime-related businesses. Thus, IMO is able to simultaneously address safety and efficiency of navigation, which was generally not possible in the past.

This dissertation has analyzed the 3-step-methodology of the FSA team in order to evaluate the effects of e-navigation on reducing accidents, and especially estimate the rate of risk reduction. The FSA team determined the rate of risk reduction through mainly 3 steps: (1) determining RCOs; (2) analyzing risks; and (3) determining the rate based on the first and second results. This basic steps have been identified and prepared for a more comprehensive assessment.

A case study of the extended evaluation of potential risk reduction of e-navigation has been conducted in Chapter 4. For that purpose, vessel accident data for all ships in Korean water areas and all Korean-flagged ships worldwide during the period 2009 to 2013, based on KMST investigation statistics were analyzed. This analysis was carried out from several points of view: the categories of SOLAS ships and non-SOLAS ships, fishing vessels and non-fishing vessels; the categories of navigational accidents, including collisions and groundings, and others; as well as the direct cause categories of human error, technical failure and external factors.

Finally, in Chapter 5, the author discussed the effect of SMART-navigation in terms of to what extent it could reduce vessel accidents. The effects were calculated based on the same methodology used by the FSA team for the risk and cost-benefit analyses of the IMO e-navigation SIP, and the rate of risk reduction, 65%, as the coefficient of the formula that the author proposed in the paragraph 5.1.

Additionally, the author identified the detailed direct causes of accidents based on the KMST investigation statistics in order to make their scope similar to the IHS Fairplay database and the Norwegian investigation statistics that the FSA team used. Further, the author selected six RCOs, including RCO 1, RCO 3, RCO 4, RCO 5, RCO 6 and RCO 7, which are applicable to non-SOLAS ships, among seven RCOs that the FSA team identified for SOLAS ships. The selection of RCOs was based on the service scope of the SMART-navigation plans for non-SOLAS ships.

With regard to the identified detailed direct causes and RCOs above, the author carried out a spotlight questionnaire survey to experts in order to verify the validity of the methodology. The questionnaire was responded by 17 in total, whose average experience in working for the safety of navigation-related field was 14.3 years. Among them, 76.5% supported the validity of identifying detailed direct causes and 94.1%

supported the validity of identifying RCOs.

The most important point from the findings in Chapter 5 is that the evaluation results show that the situation of maritime safety is different among different countries as the author assumed in the background.

For example, in the case of the Republic of Korea, 64.1% of non-fishing vessel accidents, including 37.2% of SOLAS ship accidents and 26.9% of non-SOLAS ship accidents, involved in navigational accidents. These figures are different from the statistic, 43.2%, that the FSA team obtained based on IHS Fairplay and the NMA statistics. However, in the case of calculating all kinds of accidents involving both SOLAS and non-SOLAS ships, more than 43.5 % involved navigational accidents, including 18.3% for non-fishing vessels and 25.1% for fishing vessels, which is more similar to the statistic, 43.2%, that the FSA team obtained.

In brief, as outcome of this research is shown, the effect of implementing e-navigation, SMART-navigation is expected to reduce accidents by more than 56.6% the total accidents, including 13% of SOLAS ships and 43.6% of non-SOLAS ships (including fishing vessels). In the case of navigational accidents, including collisions and groundings, more than 33.9 %, including 14.8% for non-fishing vessels and 19.1% for fishing vessels, are expected to be reduced, while the NMA statistics show 22.8% for these accidents of SOLAS ships only.

Even the non-navigational accidents are expected to be reduced by up to 22.7%, including 6.2% for non-fishing vessels and 16.5% for fishing vessels. In terms of the direct causes, 50.2% of the accidents caused by human error are expected to be reduced, and 5.4% of the accidents caused by the technical failures and 1% of the accidents caused by the external factors.

With regard to the results above, however, it should be noted that the coefficient acts as the most important factor in calculating the effect of e-navigation on reducing accidents according to each detailed direct cause of vessel accidents. The author calculated the effects in the case study by applying the coefficient, which was quantified by experts through a somewhat qualitative methodology at a workshop during the FSA for the IMO e-navigation strategy.

However, as former research pointed out the traditional method to quantify the rate of risk reduction through estimation by experts, there might be problems related to using the subjective probability as a calculation of uncertainty in risk analysis (Li et al, 2011). Therefore, the author concluded that there is an urgent need for further investigation into the determination of the coefficient and the set of formulas, which is proposed in paragraph 5.1, as follows:

- To improve the result of this dissertation and make it more meaningful, it is desirable to quantify the coefficient using a more quantitative methodology and draft it into the result of this dissertation.
- For this, the quantitative relationship and dependencies between the accident types and the detailed direct causes should be researched in more detail and comprehensively.
- Further, the quantitative relationship between the RCOs and their rate of risk reduction should be researched based on the research results above.
- The research recommended above might be done based on statistical calculations using actual databases, for example, Bayesian Network (BN) as mentioned in Chapter 3.

The other point that the author wishes to highlight as a rather general conclusion is the importance of human error and especially non-SOLAS ships as follows:

First, one of the most important aims of e-navigation among others is to prevent human error. The KSMT statistics show that more than 88.1% among navigational accidents involving non-fishing vessels and 92.0% of navigational accidents involving fishing vessels were caused by human error as analyzed in Chapter 4. Both of them are higher than the 43.2% that the FSA team found based on NMA statistics as shown in Chapter 3. This might mean that there are possibilities for the Republic of Korea to gain more benefits by introducing SMART-navigation, by targeting its services to non-SOLAS ships as well as SOLAS ships.

Second, it should be noted that the accidents caused by combined multiple human errors might be preventable if one of them had been prevented or corrected in advance and their chain had been blocked. This is clearly supported by the research conducted by Wagenaar and Groeneweg (1987). They found that most accidents, 93%, were caused by a combination of multiple reasons and each of the human errors in an accident acted as one of the conditions to cause the accident.

This can be interpreted in a way that e-navigation has potential to reduce many more accidents than the results shown in Chapter 5 because e-navigation aims to increase the safety of navigation by reducing human error and its strategy was driven based on user needs. The user needs reflect problems experienced most often that might potentially cause human error and lead to an accident, during their work on board ships.

Third, the KMST investigation statistics show that more than 83.7% of all accidents involved non-SOLAS ships including fishing vessels as shown in the Table 35 in paragraph 5.3.4.2. The statistics show that non-SOLAS vessels are much more vulnerable to accidents, and it is mainly due to lack of the navigational equipment on board ships and workforce as explained in Chapter 5. This is clearly supported by research of An (2011). He emphasized that non-SOLAS ships, including fishing vessels and small non-fishing vessels, are more vulnerable to marine accidents compared to SOLAS Convention ships, based on the fact that 72.2% of marine accidents involved small-sized ships of less than 100 G/T and 67% of marine accidents occurred in coastal waters among total Korea-related accidents during 2005 to 2010.

The fact above might mean that there is potential for SOLAS ships to face accidents due to such vulnerable non-SOLAS ships because they interface with each other during their operations nearby coastal waters and in port areas. Therefore, it is more urgent and significant for non-SOLAS ships apply e-navigation in terms of reducing the vulnerability to cause accidents as shown in the case of SMART-navigation.

Lastly, human error is related to the human element. Crews consist of individual human beings living in a modernized society. They have families just like the people who live and work ashore. In addition, many human errors, even though this dissertation did not examine that, are caused by fatigue rooted in the work burden.

Therefore, the author would like to emphasize that it is time to change the environment of maritime sectors. That is, with modern technologies and demands of the stake-holders of maritime sectors, e-navigation will significantly contribute to reduce human error, which is the main reason for vessel accidents as experienced by the maritime sectors. In addition, the author hopes that e-navigation is able to provide crews with welfare such as the opportunity to enjoy the internet and chatting, and even to quarrel with their husband or wife ashore while reducing their work burden on board ship.

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APPENDIX

- Vessel accident investigation and e-navigation experts survey questionnaire

Vessel Accident Investigation & e-Navigation Experts Survey Questionnaire

(Object) The e-navigation is defined as "the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment"

I, Sunbae Hong who is a student of World Maritime University, am now writing a dissertation on the effects of e-Navigation on reducing vessel accidents. For the purpose of increasing the reliability of its analysis, I am surveying opinions of the relevant experts as follows;

- For e-Navigation Experts : Which risk control options (RCOs) among 7 Kinds of them are applicable to non-SOLAS ships based on the strategic implementation plan of the Korean version of e-Navigation?

- For Vessel Accident Investigation experts : Is the method, which is proposed in this questionnaire, of shuffling the detailed direct accident causes of KMST adequate?

Please, fill in this document and send it via e-mail to: s15001@wmu.se

Part I. Experience background for both experts

0.1 Which sector are you working now? Please select and type the relevant number in the blank here (____)

1. e-Navigation related Research Institute
2. e-Navigation related Industries/e-Navigation
3. Vessel Accident Investigation related
4. Others (In this case, please specify below)
   Other______________________________

0.2 How many years have you been engaging in the above sectors? Please type in the number of years in the blank (_____years)

Part II. Shuffling the detailed direct cause of accidents

(Background) The list of the detailed direct causes categorized in the NMA investigation statistics is different from the one of KMST. I shuffled the detailed direct causes of KMST, which are considered to be reducible by RCOs, as shown in Table 1 below in order to group them into a similar category of the NMA statistics.

0.3 If there are any detailed direct causes that you do not agree? Please type the number and the reason of your opinion in the blank below.

<Answer>

Table 1 Shuffled Direct Causes of KMST

List of Direct Causes by NMA		Shuffled Direct Cause of KMST to match with NMA	
Human Errors	Inadequate observation/ inattention Poor judgment of ship movement Fatigue/work overload Poor judgment of other factors Inadequate planning of voyage Intoxicated Failure to use navigational aids Failure to give way /high speed Lack of knowledge/skill/ training Communication problems Injury/sickness Use of defective equipment	Human Errors	(1) Inadequate observation (2) Over loading (3) Failure to equipments (4) Other Navigational failure (5) Negligence of duty (6) Pilot error/violations (7) Inadequate Anchoring (8) Inadequate safety management (9) Not observing safety manual on board (10) Inadequate positioning (11) Inadequate Maneuvering (12) Inadequate departure preparing (13) Inadequate actions to avoid collision (14) Inadequate Course plan and keeping (15) Violation of COREG (16) Lack of sailing plan (17) Lack of preparing heavy weather (18) Inadequate Management

Technical Failures	Technical failure (not related to main engine)	Technical Failures	(19) Other machinery deficiency (20) Fatigue of Hull (21) Electronic facility deficiency (22) Steering gear related deficiency (23) Auxiliary machinery deficiency (24) Deficiency in closing (25) Deficiency of Nav. equipments
		Inadequate Handling machineries or cargos	(26) Lack of checking fuel oil, lubrication (27) Lack of Maintenance of (28) steering/navigational gears (29) Inadequate Fire machinery
External Factors	Strong currents Severe heavy weather	External Factors	(30) Other ship's errors (31) Deficiency of Aids to Navigation facility
The detailed direct causes among the lists of the KMST, which are not considered to be reducible by RCOs		Human Errors	(32) Nothing, all included in lists to apply
		Technical Failures	(33) Loading/Unloading facility deficiency (34) Main Engine trouble
		External Factors	(35) Deficiency of shore facilities
		Inadequate Handling machineries or cargos	(36) Inadequate handing IMDG (37) Inadequate Handling cargo (38) Inadequate Loading Cargo (39) Lack of Eng. Maintenance (40) Self-ignition, Explosion of cargo (41) Cargo shifted
		Others	(42) Other, Unknown (43) irresistible natural disasters (44) irresistible natural disasters (typhoon)

Part III. RCOs applicable to reduce accidents of non-SOLAS ships

(Background) The IMO's e-Navigation strategic implementation plan (SIP) demonstrates that 65% of the detailed direct causes of SOLAS ship's navigational accidents could be reduced by introducing 7 RCOs. I identified 6 RCOs among them as the RCOs as shown in Table 2 below, which are considered to be applicable to non-SOLAS ships, based on the service scope of the Korean version of e-Navigation as shown in Table 3.

For your reference, I attached the relevant information as shown in Tables 4, 5 and 6 below, including the main services of the Korean version of e-Navigation, the Maritime Service Portfolios (MSPs) of IMO e-Navigation, and the description of IMO e-Navigation's solutions, respectively.

0.4 If there are RCOs that you do not agree? Please type the number and the reason of your opinion in the blank below.

<Answer>

Table 2 Rate of reducing the detailed direct cause of vessel accidents.

SOLAS Ships			Non-SOLAS Ships	
RCOs		Rate of risk reduction		Remark
RCO 1	Integration of navigation information and equipment including improved software quality assurance	11%	11%	applied
RCO 2	Bridge alert management	10%	-	excluded
RCO 3	Standardized mode	7%	7%	applied
RCO 4	Automated and standardized ship-shore reporting	8%	8%	applied
RCO 5	Improved reliability/resilience of onboard PNT systems	8%	8%	applied
RCO 6	Improved shore-based services	7%	7%	applied
RCO 7	Bridge and workstation layout standardization	14%	14%	applied
Total		**65%**	**55% (84.6% of 65%)**	

Table 3 Scope of main services of the Korean version of e-Navigation

Service Groups and its concept	Main Functions	Relevant MSPs
<Vessel Traffic Management> The Services to increase the safety and efficiency of vessel traffics by using safety information, which is based on CMDS, to the vessel traffic management and coordination	● Providing VTS information to ship : other ships' position, destination, and intention of movement; any changes in safety information of the VTS areas ● Monitoring the ship's routing plan ● Supporting ship's navigation decision-making ● Organizing vessel traffic ● Providing port information : local port; pilot-age, berthing and un-berthing	- MSP 1 - MSP 2 - MSP 3
<Automation of maritime information> Serve to increase the efficiency of maritime related businesses as well	● Maritime safety information (MSI) service ● Safety fishing related information service ● Pilot-age information service	- MSP 4 - MSP 5 - MSP 6

as the safety of navigation by improving their efficiencies through automation of creating, delivering, utilizing and inter-connecting the maritime information.	● Single window service for automatic reporting to shore for decreasing crews' unnecessary work burden and making them focus on safety of navigation ● Transferring nautical charts and nautical publications for supporting automatic up-dating them electronically ● Meteorological information service for safety navigation and fishing activities ● Real-time hydrographic and environmental information service	- MSP 7 - MSP 8 - MSP11 - MSP12 - MSP14 - MSP15
<Pro-active managing and supporting the maritime safety> Service to prevent the potential accident causes in advance by proactively managing the ships and areas, which are identified as being vulnerable to accidents based on utilizing the real time of relevant statistics and local situation data	● Managing ships and areas, which are identified as being vulnerable to accident, in timely manner, based on real-time statistics and information ● Supporting ships' safety navigation decision-making, based on the real-time vulnerability above, for their proactive responding to avoid accidents ● Analyzing maritime safety factors based on Big-data ● Providing safety information to ships, which are vulnerable to accidents, and supporting their safety decision-making ● Providing service of streaming electronic navigational charts (ENCs) to ships of medium and small size ● Remote supporting and managing safety training crews	Korean version of special services for non-SOLAS ships
<Remote real-time emergency and medical supporting service> Service to minimize loss of lives and properties from accidents and variable emergencies happened in remote water areas by prompt and comprehensive responding to them	● Remote telemedical assistance in order to prevent delaying in remedial treatment ● Assisting ships' emergency responding ● Supporting the search and rescue (SAR) operation ● Supporting maritime affairs, regarding MAS services ● Assisting remote crews' training to increase their competences	- MSP9 - MSP10 - MSP16
<Maritime Domain Awareness> Service to increase maritime security by real-time monitoring and managing all maritime domains in Korean water areas	● Comprehensive recognizing and responding to all maritime domains over all Korean water areas ● Providing information regarding the illegal unreported unregulated fishing activities ● Providing information regarding oil spill ● Supporting activities preventing illegal discharge of wastes and pollutants from ships ● Supporting the other activities related to maritime security	Korean version of service

Table 4 Maritime Service Portfolios (MSPs) of IMO e-Navigation

MSPs No	Services	Responsible Service Provider
MSP1	VTS Information Service (IS)	VTS Authority
MSP2	Navigational Assistance Service (NAS)	National Competent VTS Authority/Coastal or Port Authority
MSP3	Traffic Organization Service (TOS)	National Competent VTS Authority/Coastal or Port Authority
MSP4	Local Port Service (LPS)	Local Port/Harbour Operator
MSP5	Maritime Safety Information Service (MSI	National Competent Authority
MSP6	Pilotage service	Pilot Authority/Pilot Organization
MSP7	Tugs Service	Tug Authority
MSP8	Vessel Shore Reporting	National Competent Authority, Shipowner/Operator/Master
MSP9	Telemedical Assistance Service (TMAS)	National Health Organization/dedicated Health Organization
MSP10	Maritime Assistance Service (MAS)	Coastal/Port Authority/Organization
MSP11	Nautical Chart Service	National Hydrographic Authority/ Organization
MSP12	Nautical Publications Service	National Hydrographic Authority/ Organization
MSP13	Ice Navigation Service	National Competent Authority Organization
MSP14	Meteorological Information Service	National Meteorological Authority/WMO/ Public Institutions
MSP15	Rea-time Hydrographic and Environmental Information Service	National Hydrographic and Meteorological Authorities
MSP16	Search and Rescue Service	SAR Authorities

*Source : Table 6 (List of proposed MSPs) in the Annex 7 of NCSR 1/28

Table 5 RCOs' function of IMO e-Navigation

RCOs	**Functions to be provided by RCOs** (summary based on the paragraph 7, page 20 to 31 of NAV 59/6 Annex 1)	Relevant Solutions
(RCO 1) Integration of navigation information and equipment including improved software quality assurance	to provide **integrated and augmented functions to the navigator, i.e. an improved basis for navigational decision-making,** taken from the INS standard, as follows; ● **Route planning and monitoring :** the route check against hazards based on the planned minimum under keel clearance as specified by the mariner; overlaying radar video data on the chart to indicate navigational objects, restraints and hazards to own ship in order to allow position monitoring evaluation and object identification; determination of deviations between set	S1.6 S1.7 S3.1 S3.2 S3.3 S4.1.2 S4.1.6

	values and actual values ● **Supporting decision making of collision avoidance** ● **Providing navigation control data :** under keel clearance (UKC), STW, SOG, COG, position, heading, ROT (measured or derived from change of heading), rudder angle, propulsion data; set and drift, wind direction and speed (true and/or relative selectable by the operator); the active mode of steering or speed control; time and distance to wheel-over or to the next waypoint; safety related messages e.g. AIS safety-related and binary messages, NAVTEX, SafetyNet or other GMDSS information. ● **Status and data display** : ship's static, dynamic and voyage-related AIS data ; safety related messages, such as AIS safety-related and binary messages, Navtex, SafetyNet or other GMDSS information; ● **Function editing AIS** own ship's data and information to be transmitted by AIS messages. ● **Redundancy of important equipment and Software testing**	
(**RCO 2**) Bridge alert management	To **provide alert management** in order to enable the bridge team to devote full attention to the safe navigation of the ship and to immediately identify any abnormal situation requiring action to maintain the safe ● Danger of collision, Danger of grounding	S1.5
(**RCO 3**) Standardized mode(s) for navigation equipment	Safe navigation relies on the ability **of key personnel to easily operate navigational equipment as well as comprehend the information** that is presented to them. Lack of familiarity with bridge equipment and/or slow response due to not finding correct information/control/alarm is thus considered to adversely affect safe navigation. Standard modes are to provide a standardized and common display familiar to all stakeholders, reducing the need for personnel to familiarize themselves with variations of HMIs in order to safely navigate. ● Offer default display configurations for the ECDIS and the radar to provide the bridge team and pilot with a standardized display and a simple operator action. ● Provide operational modes for a set of predefined operational areas such as open sea, coastal, confined waters (pilotage, harbour berthing, and anchorage).	S1.4
(**RCO 4**) Automated and standardized ship-	Forms are usually manually filled out and sent individually to each authority requesting the information. Compliance with IMO FAL forms normally takes about two hours to fill. For example, around	S2.1, S2.2, S2.3 and S2.4

shore reporting	25 documents had to be sent from the ship, or the ship's agent, in conjunction with a port call. The data requested in many of these documents are fully or almost identical. Documents are also often in paper or other non-computer-compatible formats, which is a time-consuming and costly affair The S-mode provides followings in order to **reduce workload due to filling out and delivering reportable information** is identified. ● The system would integrate relevant onboard systems enabling collection and edition of information and data needed for reporting. ● The system should allow for automated digital distribution of required reportable information **(single window solution)**, including both static, dynamic, voyage related and SAR information to authorized authorities, with the least possible intervention required by the ship during and/or before navigation.	
(**RCO 5**) Improved reliability and resilience of onboard PNT systems	Ensuring reliable and resilient PNT data, providing ship's position, velocity, and time data (PVT) for navigators and navigational functions, is important for safe navigation. However, for the time being, due to insufficient redundancy within single sensors and unsupported exploitation of multi-sensor based redundancy the classic approach is considered unable to meet e-navigation user needs such as improvement of availability, reliability and indication of integrity based on monitored and assessed data and system integrity. In order to improve reliability and resilience of position, navigation, and timing data (PNT) an integrated and harmonized utilization of PNT related systems and services is envisioned.	S3.4
(**RCO 6**) Improved shore-based services	VTSs and other shore-based stakeholders gather and hold a lot of information regarding navigational warnings, incidents, operations, tide, AIS, traffic regulations, chart corrections, meteorological conditions, ice conditions, etc., which often is referred to as the Maritime Service Portfolio. As per today this information is mostly communicated via voice VHF and paper documents. Information transfer via voice communication can be time-consuming and distractive as navigators may need to make notes of information received and possibly consult various written documentation on the bridge. The voice communication procedure also holds a potential for incorrect transfer and misinterpretation of information. ● Implementation of system for automatic and digital distribution of shore support services would make information more available, updated and applicable for navigators. ● Maritime Safety Information (MSI) received by the ship	S4.1.3 and solution S9

	should be applicable to the ship's specific voyage, i.e. it should not contain information related to other areas which is not relevant to that ship, and be presented on one location, the ENC/ECDIS or AIS/RADAR display. ● Notices to mariners, ENC updates and corrections to all nautical publications should be received electronically without any delays in the delivery. ● All MSI to be sent out digitally and using a standard such as the IHO S-100 data framework standard enabling better visualization on board, for example, Virtual Aids to Navigation (AtoN) for warning of new navigational hazards, such as wrecks, obstructions or floating debris, displaying on AIS/ECDIS ● In addition automatic updating and correction of nautical charts via satellite is envisioned	
(**RCO 7**) Bridge and workstation layout standardization	Cumbersome equipment layout on the bridge adversely influences the mariner's ability to optimally perform navigational duties. Therefore, regulation, based on existing guidelines and standards, regarding the physical layout of all bridge equipment regarded as essential for safe and efficient navigation, is envisaged to Workstation for navigating and maneuvering including; ● radar/radar plotting ● ECDIS ● information of AIS ● Indications of: rudder angle, rate-of-turn, speed, gyro compass heading, compass heading and other relevant information ● VHF point with channel selector	S1.1

Table 6 Description of IMO e-Navigation's Solution

Solutions and Sub-Solution		Description
S1 **improved, harmonized and user-friendly bridge design**	**S1.1**	Ergonomically improved and harmonized bridge and workstation layout.
	S1.2	Extended use of standardized and unified symbology for relevant bridge equipment.
	S1.3	Standardized manuals for operations and familiarization to be provided in electronic format for relevant equipment
	S1.4	Standard default settings, save/recall settings, and S-mode functionalities on relevant equipment.
	S1.5	All bridge equipment to follow IMO Bridge Alert Management
	S1.6	Information accuracy/reliability indication functionality for relevant equipment.
	S1.6.1	Graphical or numerical presentation of levels of reliability together with the provided information.
	S1.7	Integrated bridge display system (INS) for improved access to shipboard information.

	S1.8	GMDSS equipment integration – one common interface.
S2 **means for standardized and automated reporting;**	**S2.1**	Single-entry of reportable information in single-window solution.
	S2.2	Automated collection of internal ship data for reporting.
	S2.3	Automated or semi-automated digital distribution/communication of required reportable information, including both "static" documentation and "dynamic" information.
	S2.4	All national reporting requirements to apply standardized digital reporting formats based on recognized internationally harmonized standards, such as IMO FAL Forms or SN.1/Circ.289.
S3 **improved reliability, resilience and integrity of bridge equipment and navigation information;**	**S3.1**	Standardized self-check/built-in integrity test (BIIT) with interface for relevant equipment (e.g. bridge equipment).
	S3.2	Standard endurance, quality and integrity verification testing for relevant bridge equipment, including software.
	S3.3	Perform information integrity tests based on integration of navigational equipment – application of INS integrity monitoring concept.
	S3.4	Improved reliability and resilience of onboard PNT information and other critical navigation data by integration with and backup of by integration with external and internal systems.
S4 **integration and presentation of available information in graphical displays received via communication equipment**	**S4.1**	Integration and presentation of available information in graphical displays (including MSI, AIS, charts, radar, etc.) received via communication equipment.
	S4.1.1	Implement a Common Maritime Data Structure and include parameters for priority, source, and ownership of information.
	S4.1.2	Standardized interfaces for data exchange should be developed to support transfer of information from communication equipment to navigational systems (INS).
	S4.1.3	Provide mapping of specific services (information available) to specific regions (e.g. maritime service portfolios) with status and access requirements.
	S4.1.4	Provision of system for automatic source and channel management on board for the selection of most appropriate communication means (equipment) according to criteria as, band width, content, integrity, costs.
	S4.1.5	Routing and filtering of information on board (weather, intended route, etc.).
	S4.1.6	Provide quality assurance process to ensure that all data is reliable and is based on a consistent common reference system (CCRS) or converted to such before integration and display.
	S4.1.7	Implement harmonized presentation concept of information exchanged via communication equipment including standard symbology and text support taking into account human element and ergonomics design principles to ensure useful presentation and prevent overload.
	S4.1.8	Develop a holistic presentation library as required to support accurate presentation across displays.
	S4.1.9	Provide Alert functionality of INS concepts to information received by communication equipment and integrated into INS.
	S4.1.10	Harmonization of conventions and regulations for navigation and communication equipment.
S9 **improved Communication of VTS Service Portfolio**	**S9**	Improved communication of VTS service portfolio (not limited to VTS stations)

*Source : Solutions (paragraph 15, p5, NAV 59/6), Sub-Solution (Table 1 to 5, Annex 7 of NCSR 1/28