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Original article

Improving and Assessing the Impact of e-Navigation applications*

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Abstract

The scope of this paper is implementation issues of the e-Navigation concept of the International Maritime Organization (IMO). IMO has adopted the e-Navigation strategic implementation plan (SIP) in 2014. This plan, i.a., bases on estimating the effect of e-Navigation applications on reducing navigational accidents, including collisions and groundings of ships falling under the International Convention for the Safety of Life at Sea (SOLAS) by approximately 65 per cent. However, IMO Member States are responsible for safety of navigation and efficient vessel traffic at international but also on national levels. Regarding the introduction of new concepts and innovative systems into vessel traffic there is a need to comprehensively assess potential effects not only for SOLAS ships but also for non-SOLAS ships. This paper aims at a more comprehensive and theoretically sounded estimation of e-Navigation potentials by investigating and applying IMO's methodology for quantification of those effects also to the implementation of e-Navigation solutions to ships not falling under the SOLAS convention (non-SOLAS ships). The authors carried out a case study using the SMART-Navigation concept of Korea as model case for impact assessment. For the mentioned purpose, this paper identifies main tool kits of IMO e-Navigation, proposes and applies a set of formulas to comprehensively assess and quantify effects of new functions or services based on IMO's methodological approaches. From gained results authors suggest investigations not only taking into account expert opinions but also simulation trials to identify factors and coefficients for thorough calculations. From the results the authors conclude and recommend to extend the impact assessment of e-Navigation also to vessel traffic involving non-SOLAS ships as a general and global recommendation to coastal states. Further, results are provided as a potential model case for IMO Member States' reference for their state-specific individual situation and conditions.

Keywords: "e-Navigation, Non-SOLAS ships, Impact Assessment"

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I. Introduction

IMO, at the 85th meeting of its Maritime Safety Committee (MSC, 2008), adopted the e-Navigation development and implementation strategy and defined the e-Navigation concept, among others, "to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment." With the e-Navigation Strategy Implementation Plan (SIP) IMO has provided its vision of the concept in relation to on board, onshore and communication elements. The SIP is mainly to implement five prioritized e-Navigation solutions by taking into account IMO's formal safety assessment methodology.

The SIP evaluates effects of e-Navigation as to reduce navigational accidents, including collisions and groundings, for SOLAS ships by 65%. However, the situation of maritime safety is different from country to country, and SOLAS ships are always interfaced with non-SOLAS ships in the real maritime practices. This might mean that the practices to introduce e-Navigation would be different from countries in terms of their priorities, levels and effects to apply it in their water areas. Therefore, it is important for a country to analyze its own specific data of vessel accidents and assess the effects of e-navigation in terms of accident types, including the other accidents as well as navigational accidents, and ship types, including non-SOLAS ships as well as SOLAS ships. This supports member states to maximize benefits of implementing e-Navigation for its water areas by establishing an effective and efficient National SIP.

National authorities investigate and monitor their individual situations in respect to their national waters and shipping fleets. In this paper, the authors introduce the development of an enhanced method for the comprehensive assessment of implementing e-Navigation applications. The method specifically focuses on the quantification of the impact of e-Navigation solutions in terms of a reduction of the number of accidents that potentially can be avoided by e-Navigation applications. The method will be introduced and discussed by means of the Korean SMART-Navigation project, which includes e-navigation services for both non-SOLAS and SOLAS ships, in order to provide a model case for comprehensively assessing the implementation of e-Navigation taking especially into account the specific individual situation and conditions of the coastal states. In the frame of this project specific solutions are presented as so called e-Navigation tool kit applications. Finally, outcome of research performed and coordinated by World Maritime University in cooperation with other partners into the identification of training needs and user requirements to support the quick and smooth introduction of innovative e-Navigation solutions into real practice will be presented.

II. IMO's initiative on e-Navigation

2.1. Concept of e-Navigation, brief history and state of progress

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). 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 especially by IALA and IHO. Strategy and time frame were approved by MSC as set out in MSC 85/26 Add 1 (Annex 20) and MSC 85/26. Add.1 (Annex 21), respectively. Through these documents, IMO had agreed to the definition and core objectives of e-Navigation that are still valid today.

Since then, IMO took several actions and amended plans and timelines as needed and appropriate. MSC also 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. Finally, based on the report submitted by the CG (NAV 59/6), MSC at its ninety-forth session, approved the e-navigation SIP, as set out in document NCSR 1/28, Annex 7. According to this latest version of the SIP, e-Navigation is expected to be fully operational from 2020 if five prioritized e-Navigation solutions and 18 kinds of relevant tasks to achieve them are implemented over the period 2014 to 2019.

2.2. Main tool kits of e-Navigation to reduce accidents

The authors, based on their survey and review of main IMO documents and outcome of ongoing research and technological developments, identified three kinds of e-Navigation tool kits representing applications expected to reduce maritime risks by up to 65%, especially related to human errors, causing navigational accidents. The term “tool kits” is used and includes new functional, technical and legal “system” and “services in line with IMO’s e-Navigation aims. The chosen approach includes five different solutions, and seven Risk Control Options (RCOs) as well as 16 so called Maritime Service Portfolios (MSPs) prioritized by IMO (see Table 1).

The original e-navigation strategy has been developed based on user-driven rather than technology driven methodology. Therefore the basic idea of e-navigation solutions might be to avoid system failures that, e.g., causing delays because the ship is deemed unseaworthy, avoid loss of basic good seamanship by crews, avoidance of inappropriate substitution of the human element by technology and degradation of bridge resource management. In contrary e-Navigation encourages best practices by crews (MSC 85/26 Add.1. Annex 20). Based on extensive user needs and gap analyses, e-Navigation solutions[1] were identified in order to meet user needs, which mainly reflect concerns experienced most often during daily routine work as the problems that may cause accidents. Moreover these solutions reflect concerns to improve the safety of navigation, as following examples show:

- S1. improved, harmonized and user-friendly bridge design
- S2. means for standardized and automated reporting;
- S3. improved reliability, resilience and integrity of bridge equipment and navigation information;
- S4. integration and presentation of available information in graphical displays received via communication equipment

[1] see Tables 1 to 5, Annex 7 of NCSR 1/28 for detailed description for solution and its sub-solutions.

- S9. improved Communication of VTS Service Portfolio

In a second step the results of the different activities have been merged according to the process sketched in Figure 1 below.

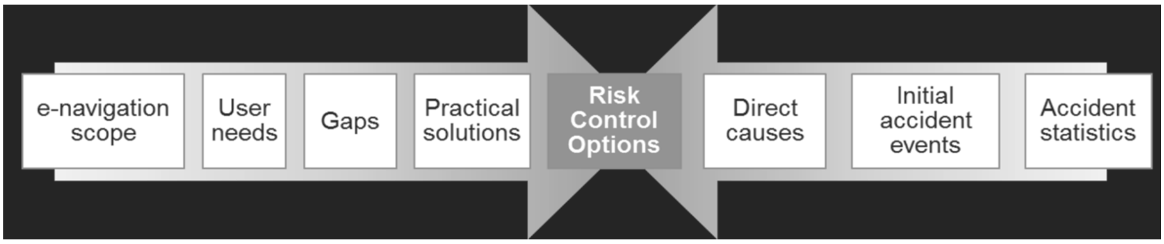

Figure 1: RCOs identification process
(Source: Annex 1 of NAV 59/6 (p. 20))

Table 1: List of the Maritime Service Portfolios (MSPs) – taken from Annex 7 of NCSR 1/28)

MSPs	Services	Responsible Service Provider
1	VTS Information Service (IS)	VTS Authority
2	Navigational Assistance Service (NAS)	National competent VTS Authority, Coastal or Port Authority
3	Traffic Organization Service (TOS)	
4	Local Port Service (LPS)	Local Port/Harbour Operator
5	Maritime Safety Information Service (MSI)	National Competent Authority (NCA)
6	Pilotage service	Pilot Authority/Pilot Organization
7	Tugs Service	Tug Authority
8	Vessel Shore Reporting	NCA, Shipowner, Operator, Master
9	Tele-medical Assistance Service (TMAS)	National Health Organization
10	Maritime Assistance Service (MAS)	Coastal or Port Authority/Organization
11	Nautical Chart Service	National Hydrographic Authority/ Organization
12	Nautical Publications Service	National Hydrographic Authority/ Organization
13	Ice Navigation Service	National Competent Authority Organization
14	Meteorological Information Service	National Meteorological Authority/WMO/ Public Institutions
15	Hydrographic and Environmental Information Service	National Hydrographic and Meteorological Authorities
16	Search and Rescue Service	SAR Authorities

The purpose of this process was to identify tangible and manageable Risk Control Options (RCOs) for which results of user need and gap analysis and prioritized solutions were merged and correlated with the accident data analysis[2] (RCOs are given in Table 2).

However, thirdly, the concept of MSPs was taken into account. The concept, originally introduced at NAV 57, is defined as set of operational and technical services and their level of service, with the need for information and communication services, provided by a shore-based stakeholder such as Vessel Traffic Service (para. 23, NAV 57/6). The MSPs were finalized as given in Table 1 above.

2.3. IMO's Methodology to quantify the effects of e-Navigation on reducing accidents

According to the SIP (NCSR 1/28. Annex 7), the rate of reducing accidents, 65%, were estimated through the following steps based on the IMO Formal Safety Assessment (FSA) process.

1. Identifying problems in terms of safety of navigation: identifying user needs, gap analysis
2. Identifying tool kits of e-navigation to reduce risk: 5 solutions, 7 RCOs and 16 MSPs
3. Estimating risk of navigational accidents based on the result of analyzing accidents data
3.1. Calculating frequencies and the potential loss of lives (PLL)
3.2. Estimating total potential loss of lives (PLL) as risk
3.3. Distributing estimated risks among the probable accident causes
3.4 Estimating the rate of risk reduction potential for each direct cause by each RCO
4. Estimate the rate of reduction of PLL by implementing each RCO (as shown in Table 2)

Table 2: RCOs ranked by PLL (taken from: Annex 1 of NAV 59/6 (p. 37))

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 3	Automated and standardized ship-shore reporting	1.3E-04	8%
5	RCO 4	Improved reliability and resilience of on board PNT systems	1.2E-04	8%
6	RCO 5	Standardized mode	1.1E-04	7%
7	RCO 6	Improved shore-based services	1.1E-04	7%
Total				65%

[2] The IHS Fairplay casualty database and accident data from the Norwegian Maritime Authority (NMA) for the period from 2001 to 2010 were used (Annex 1 of NAV 56/6)

The above steps 1 and 2 were carried out in a qualitative way, while all steps under 3 and 4 were carried out in a quantitative way by using a risk model "the frequency/consequence modelling". However, especially step 3.4, which is to evaluate to what extent the RCOs could reduce risk potential for each direct cause causing navigational accidents, was estimated by experts through workshop sessions.

III. SMART-Navigation - Korean approach to implement e-Navigation

3.1. The SMART-Navigation concept

SMART-navigation is the Korean approach to implementing the IMO e-navigation concept in both Korean waters and on board 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. This is assumed, among others, because non-SOLAS ship are more vulnerable[3] to accidents than SOLAS ships due to the lack of capacity of navigational equipment, higher workload on board and less safety information provided by shore based stations.

3.2. Main tool kits of SMART-Navigation to reduce accidents for non-SOLAS ships

SMART-Navigation is to provide non-SOLAS ships with additional specific services in addition to services of the IMO e-navigation. The services aim to prevent the potential accident causes in advance by proactively supporting them and managing areas, which are identified as being vulnerable to accidents based on utilizing the real time relevant statistics and local situation data, from the shore-based stations. These services include:

- Supporting decision-making to avoid accidents
- Analyzing maritime safety factors based on Big-data
- Providing safety information to ships, which are vulnerable to accidents
- Providing a service of streaming electronic navigational charts (ENCs)
- Remote supporting and managing safety training crews
- 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

For these purposes, SMART-navigation is to provide the LTE-Maritime communication network as a platform for non-SOLAS ships in order to implement the necessary e-navigation

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

services. In addition, the relevant communication networks for e-navigation services are to be provided with a data structure based on the Common Maritime Data Structure (CMDS), including the VHF Date Exchange (VDE), digital HF/MF and satellite-based communication (MOF, 2015).

IV. Comprehensive estimation of e-Navigation effects

4.1. Formulation

The rate of risk reduction of "65%", which was calculated by IMO e-navigation CG, does not mean the rate to reduce the number of accidents, but the rate to reduce the percentage of each detailed direct cause to be reduced by RCOs in terms of the potential loss of lives (PLL). 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 actual volume of accidents to be reduced among all accidents. Thus, the authors suggest the following formulas in order to calculate the effects of SMART-navigation more precisely in respect to actual conditions relevant accidents and RCOs:

$$S_{av} = \sum (r_{sad} * a_{rr})$$
$$= \sum (r_{sad} * c * a_{rr})$$
$$= \sum c (r_{sad} * a_{he} * a_{tf} * a_{ef})$$

where is :

c = Coefficient (65% for SOLAS ships, 55% for non-SOLAS ships)
S_{av} = Actual Volume of selected accident to be reduced among total accidents
r_{sad} = Rate of selected accident distribution
a_{rr} = Actual Rate of risk reduction of each direct cause to be reduced

with $a_{rr} = a_{he} + a_{tf} + a_{ef}$
a_{he} = Rate of risk reduction of each detailed direct cause of Human Error
a_{tf} = Rate of risk reduction of each detailed direct cause of Technical Failure
a_{ef} = Rate of risk reduction of each detailed direct cause of External Factor

For example, in the case of the investigation of statistics of Norwegian Maritime Authority (NMA) that were used in the FSA, the actual volume of navigational accidents, including collisions and groundings, to be reduced by RCOs among total accidents is calculated as to 22.7% by applying the above formula.

4.2. Consideration of potential impact of e-Navigation for non-SOLAS ships

As a very first step the authors applied the same coefficient of 65%, used by IMO e-navigation CG in their study investigating the effect of SMART-navigation on reducing accidents for non-SOLAS ships. However, the authors identified RCOs 1, and 3 - 7, except RCO 2 (Bridge alert system), as RCOs that have the same rate of risk reduction for further details refer to (Hong, 2015). The identification was based on the scope of the SMART-navigation services related to the non-SOLAS ships and the result of expert survey by questionnaire. The rate of reducing accidents by these six RCOs for non-SOLAS ship is 55% in total, which is 84.6% of the rate of risk reduction for SOLAS ships, 65%. From their research he authors suggests dedicated simulation studies reflecting particularities of non-SOLAS vessel traffic in coastal states to quantify related factors.

V. Evaluating the potential effects of SMART-Navigation on reducing accidents

To evaluate the effect of SMART-navigation on reducing accidents, the authors further analyzed the Korean accidents data for all ships in Korean water areas and all Korean-flagged ships worldwide over the period of 2009 to 2013. This data have been collected from the KMST. Based on this analysis, the authors extracted 3,366 accident vessels, which cover the detailed direct causes preventable by the RCOs of e-navigation, from the total 4,871 accident vessels.

Table 3: RCOs ranked by PLL (taken from: Annex 1 of NAV 59/6 (p. 37))

<table>
<tr><th colspan="4" rowspan="2">Accident Type</th><th rowspan="2">Human Errors</th><th rowspan="2">Technical Failure</th><th rowspan="2">External Factor</th><th colspan="2">Total</th></tr>
<tr><th>Actual</th><th>Effect</th></tr>
<tr><td rowspan="14">Non-Fishing Vessels</td><td rowspan="6">Navigational Accident</td><td rowspan="3">SOLAS</td><td>Actual %</td><td>465 (13.8%)</td><td></td><td>14 (0.4%)</td><td rowspan="6">828 (24.6%)</td><td rowspan="6">14.8%</td></tr>
<tr><td>Risk Reduction Rate</td><td>65.1%</td><td></td><td>65%</td></tr>
<tr><td>Effect</td><td>8.9%</td><td></td><td>0.3%</td></tr>
<tr><td rowspan="3">Non-SOLAS</td><td>Actual %</td><td>338 (10.0%)</td><td></td><td>11 (0.3%)</td></tr>
<tr><td>Risk Reduction Rate</td><td>55.1%</td><td></td><td>55.0%</td></tr>
<tr><td>Effect</td><td>5.5%</td><td></td><td>0.1%</td></tr>
<tr><td rowspan="6">Non-Navigational</td><td rowspan="3">SOLAS</td><td>Actual %</td><td>163 (4.8%)</td><td>37 (1.1%)</td><td>4 (0.1%)</td><td rowspan="6">353 (10.5%)</td><td rowspan="6">6.2%</td></tr>
<tr><td>Risk Reduction Rate</td><td>65.3%</td><td>64.9%</td><td>65%</td></tr>
<tr><td>Effect</td><td>3.1%</td><td>0.7%</td><td>-</td></tr>
<tr><td rowspan="3">Non-SOLAS</td><td>Actual %</td><td>119 (3.5%)</td><td>27 (0.8%)</td><td>3 (0.1%)</td></tr>
<tr><td>Risk Reduction Rate</td><td>55.2%</td><td>54.9%</td><td>55%</td></tr>
<tr><td>Effect</td><td>1.9%</td><td>0.4%</td><td>0.1%</td></tr>
<tr><td colspan="2" rowspan="2">Sum</td><td>Actual %</td><td>1,085 (32.2%)</td><td>64 (1.9%)</td><td>32 (0.95%)</td><td rowspan="2">1,181 (35.1%)</td><td rowspan="2">21.0%</td></tr>
<tr><td>Effect</td><td>19.4%</td><td>1.1%</td><td>0.5%</td></tr>
<tr><td rowspan="3">Fishing Vessels</td><td colspan="2" rowspan="3">Navigational Accident</td><td>Actual %</td><td>1,155 (34.3%)</td><td>2 (0.1%)</td><td>16 (0.5%)</td><td rowspan="3">1,173 (34.8%)</td><td rowspan="3">19.1%</td></tr>
<tr><td>Risk Reduction Rate</td><td>54.9%</td><td>55%</td><td>54.9%</td></tr>
<tr><td>Effect</td><td>18.8%</td><td>-</td><td>0.3%</td></tr>
</table>

	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).

The result of analyzing the accidents show that 64.1% of non-fishing vessel accidents, including 37.2% of SOLAS ship accidents and 26.9% of non-SOLAS ship accidents, were involved in navigational accidents. These figures are different from the statistic, 43.2%, of the NMA. 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%, of the NMA.

Most of the navigational accidents were caused by human error: 90.7 % of all navigational accidents were caused by human error, and also 35.1 % of other accidents were caused by human error. The percentage for navigational accidents caused by human error 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. In addition, 88.1% among the navigational accidents of non-fishing vessels and 92.0% of fishing vessel accidents were caused by human error. These figures are higher than the one from NMA statistics, 65%. 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%, of the NMA.

Table 3 shows the effects of SMART-navigation on reducing accidents, which was evaluated by applying the proposed formula based on the results of analyzing accidents. It 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. In the case of navigational accidents, more than 33.9 %, including 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.

VI. Impact Assessment and Challenges of Implementation

From the aforementioned chapter it is obvious that implementation of e-Navigation based applications are expected to significantly reduce number of accidents. The present situation in national waters and including traffic of non-SOLAS ships regarding occurring accidents seem to have a huge potential for future avoidance by introducing new systems and functions that assist in avoidance of collisions, groundings and other accidents and incidents. This is to be expected, when the same assumptions are valid that has been applied in IMO studies for SOLAS ships.

However, from a number of accidents it has become common sense that introduction of new technologies, rules and operational procedures shall be accompanied by adequate training and familiarization measures (among others Schroeder-Hinrichs, Hollnagel & Baldauf, 2012). This means to ensure the success of the ambitious SMART-Navigation program, the introduction of new applications needs to be carefully prepared by training and educating the addressed end users in the correct handling and use of the new tool-kit solutions and making users aware of potential shortcomings and correct interpretation of system displays.

At the present state of technological development and operational integration of suggested new e-Navigation applications, like e.g. tactical route exchange between ships and route suggestions from a shore station to a ship, dynamic path predictions on board to support on-board real-time decision making (Benedict et. al. 2014) or even augmented reality using head-up displays for improved situation assessment (Procee & Baldauf, 2014) one may assume the training needs might be very little if providers are able to provide easy to understand and simple to use tools. However, from history some famous cases of dramatic accidents are known accounted to being caused by new technologies (Radar/ARPA-assisted collision or ECDIS-assisted groundings etc.).

The authors argue, that simulation-based studies including even simulation networks are extremely supportive to also investigate and more reliable quantify the reduction rates of suggested tools, systems and services. Simulation studies using the potential of connected complementing simulation facilities will allow to address the complexity of influencing factors and even potential dependencies that e-Navigation tool kits contain.

The promising results from the desktop research study shall not contribute to overestimation and self-confidence. To realize the results from synthetic impact assessment, further research and study activities are needed. Specific focus shall be on operational integration of newly developed or enhanced and advanced functions and services into existing regimes of a VTS or any future regime providing enhanced e-Navigation services to support bridge teams, pilots and other end users.

VII. Conclusions

In depth research has been carried out into the assessment and the estimation of potential impact of introducing e-Navigation based applications into the maritime transportation system. Limitations are identified in 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. This is clearly supported by identified user needs, which reflect the main concerns experienced most often during daily work. As one of the most important aims of e-Navigation is to prevent human error, those problems are expected to be solved by implementation of new tool kits and systems supporting ship's decision making of shore-based and onboard operators.

The authors further provided first results for more comprehensively evaluating the effects of e-navigation with the SMART-navigation case study. The methodology applied takes especially into account the specific situation regarding maritime safety of an individual member state. It is hoped that this study will be referred to the maritime safety policy bodies of other IMO Member States, as well as to the practices in the maritime sectors such as shipping companies, crews on board ships and manufacturers developing e-navigation related systems. This is suggested because the situation of maritime safety is different from country to country while IMO's assessment of the e-navigation concept shows effects on reducing accidents for SOLAS ships only. For more comprehensive and thorough estimation and quantification of the risk reduction potentials simulation-based studies have been identified as essential element.

With regard to results presented this paper, it should be noted that the coefficients in the proposed formulas acts as the most important factor when calculating the effect of e-navigation on reducing accidents according to each detailed direct cause of vessel accidents. In the case study the coefficient was quantified by experts through a qualitative methodology. However, as former research pointed out this traditional method carries problems related to using the subjective probability as a calculation of uncertainty in risk analysis (Li et al., 2011). Therefore, the authors concluded that there is an urgent need for further investigation into the determination of the coefficient and the further development of the formulas by more detailed estimation of reduction factors related to concrete e-navigation tool kits. From the authors' point of view, simulation trials seem to be the most promising approach for improvement. Those simulations can be combined for training and for estimation of reduction factors as well.

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