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e-Navigation: Five Years Later

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Abstract—The paper presents brief information on the results of research and development activities undertaken in 2015–2019 and aimed at the practical implementation of e-Navigation concept. Current state of practical application of S-mode, the only global product created within the concept, is studied. Most of the new technologies developed under the main regional projects are discussed. Special focus is made on the situation with e-Navigation in Russia.

Keywords: e-Navigation, navigational safety, sea traffic management systems, S-mode, maritime connectivity platform, VDES

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INTRODUCTION

In 2016, the *Gyroscopy and Navigation* journal, no. 1, published an article "The Tenth Anniversary of e-Navigation" [1] dedicated to the history of e-Navigation (e-N hereinafter) concept, its main statements and implementation results as of the time of publication. As a reminder, e-N is defined as "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 the marine environment" [47].

Five years have passed since that publication [1], and now it is time to discuss the results again. First of all, it should be noted that during all these years, the International Maritime Organization (IMO) and its committees paid exceptional attention to the e-N and supported global and regional projects on this subject. Yet, it appears that the S-mode introduction can only be considered as a global project.

The following is a brief review of the work performed in the e-N area, as well as the resolutions taken by the IMO committees.

S-MODE

The purpose of this mode is to standardize the operation of similar products by various manufacturers [2], and its implementation in accordance with the Resolution of the 95th Session of the IMO Maritime Safety Committee (MSC 95) was expected in 2019 [3]. However, there is no apparent consensus on this issue between the IMO regulatory authorities and the marine equipment manufacturers. This is evidenced by the article by Richard Doherty, the Deputy Secretary General of the Comité International Radio-Maritime (CIRM), an association of the representatives of 50 companies from 16 countries, manufacturing navigation equipment [4]. In his article, the author mentions that CIRM is actively discussing the initial set of guidelines on S-Mode with a number of organizations, including the Nautical Institute (a non-commercial organization located in London and involving the experts from 110 countries) which has proposed the S-Mode concept. Then the author notes, however, that the views of CIRM on this specific matter differ from most of those organizations. While acknowledging that the proposal to introduce this mode is definitely justified, CIRM do not believe that it is of top priority.

At the same time, it is stated that the only requirements for the navigation equipment development, adopted by IMO, are the requirements of SOLAS, the International Convention for the Safety of Life at Sea. Besides meeting these basic requirements, the manufacturers introduce some innovative components in their products, mainly in order to serve the needs of their customers. In the author's opinion, it is important that the navigation officers prefer the navigation equipment of particular brands not only because they know how to operate it, but also because it suits their philosophy of using it at sea.

Therefore, instead of rigid standardization of human-machine interface, which will inevitably "cut off" the innovative ideas of the manufacturers and

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make them ignore the users' preferences, a different approach to the navigation equipment unification is proposed, where a "magic button" is not expected to appear.

This approach, according to the author, should be elaborated by joint efforts of equipment manufacturers and users, and aimed at the navigation equipment standardization in a more general sense. First of all, it is necessary to unify the following:

—operating modes of failure detection systems;

—terminology used in designing the human-machine interfaces;

—lists of data displayed to the navigator during the equipment operation;

—equipment repair procedures in case of failure.

These ideas are also supported by Transas, the largest manufacturer of navigation equipment, primarily the electronic chart display and information systems (ECDIS). Its specialists believe that ECDIS should be standardized, with the minimum information essential for safe navigation being displayed. At the same time, it is advisable to remove all potentially ambiguous indication elements from the display, as well as the most of control buttons, thus providing a standard content of the display, which does not require any special S-Mode.

Finally, the Nautical Institute insists that the S-Mode should take in the experience of more than 400000 navigation officers of the world's merchant marine. Based on this experience, a limited number of key procedures implemented in particular equipment should be generated and studied comprehensively before making a decision on implementing them specifically in the S-Mode. For this purpose the Nautical Institute and some other organizations are interviewing the above 400000 navigation officers in order to find out their preferences when following certain procedures in course of navigation.

Based on the above, the S-Mode implementation will require further discussions, if nothing else; and to the point is the prediction made as recently as 2015 by D. Patraiko, the Director of Projects at the Nautical Institute, that this would happen no earlier than in 2020 [5].

EFFICIENSEA 2

In 2017, the EfficienSea2 project was completed, for which 11 million Euros were allocated. It was implemented by 32 companies from 12 countries including Sweden, Norway, Finland, Denmark, Estonia, Poland, Germany, France, Austria, Malta, the UK, and Latvia, which made it a pan-European project in contrast to its regional predecessor EfficienSea.

First of all, it is necessary to note further development of Maritime Cloud concept which was proposed within the EfficienSea project. Maritime Cloud is the main element of both onshore and onboard component of e-N; its purpose is to provide physical communication between the users by means of corresponding human-machine interface. This upgrade was carried out by the EfficienSea 2 developers in cooperation with the specialists conducting research within the projects STM Validation (European Union) and SMART-Navigation (South Korea). As a result, the Maritime Connectivity Platform (MCP) was created. The MCP creators changed its name in order to emphasize the transition of the Maritime Cloud from the concept to real implementation phase [6].

The MCP consists of three components:

—Maritime Identity Registry which provides all users with a special digital certificate recorded in so-called almanac functioning as digital "yellow pages" for the maritime entities and information services registered in the MCP. At the same time, the certificate facilitates the encrypted data transfer and digital signature entry;

—Maritime Service Registry where each user may register their information service. For instance, the port authorities can provide their web page address, the Vessel Traffic Management Center (VTMC) can publish the data on the service for automatic forwarding of the information on weather, vessels traffic, etc.;

—Maritime Messaging Service which communicates, among other information, the above-mentioned almanac.

As part of the work under discussion, not only the MCP components were developed, but also relevant tests were carried out [7], most of which took place in the area of Busan seaport in South Korea. During these tests, it was checked whether a foreign vessel (in the experiment, it was a Danish one) which had never been to Busan before, would be able to moor at the port using the MCP data only. To do so, the vessel had to pass identification in the MCP, find the mooring service in the registry of services provided by the seaport, and then, using the messaging service, choose the cheapest channel for data transmission and receive the required recommendations via this channel. The test was completed without any problems.

According to some experts [12], the MCP can actually become not only the cornerstone in developing the Internet of Things at sea, but it is a prerequisite for the e-N concept transition from the testing phase to real implementation. Moreover, it has been announced [13] that further development of the MCP will be performed within the SMART Navigation project.

The MCP cannot work effectively without appropriate efficient communication tools; in the EfficienSea 2 this role is played by VDES (VHF Data Exchange System). It should be noted that before it was developed, most of useful information was transmitted between the vessels and the onshore facilities by means of the automatic identification system (AIS) installed on the vessels since 2002. Originally it was intended for preventing the collisions of vessels, and now it is one of the most important elements of their motion control systems. At the same time, today the AIS exchange channel is so overloaded that it is impossible to supplement it with any additional functions demanded by the e-N development.

That is why the VDES was designed [14] to perform the following functions:

—functions of existing AIS, including identification of vessels, transmission of messages on the vessel's location and route, support of search and rescue (SAR) operations, etc.;

—high-speed (up to 302 Kbs) data transmission using both onshore (VDE terrestrial) and satellite (VDE satellite) communication channels. This means that in contrast to the AIS, VDES provides global coverage due to the available satellite channels, and it will facilitate, in particular, broadcasting of information on the vessels' safety, including the messages on navigational hazards, maps of ice fields, etc.

It is also important that the system has additional channels for high-speed and special data transmission, which considerably unloads the AIS and thus improves its performance, especially in constrained waters.

In order to implement the system, the International Telecommunication Union (ITU) provided a special UHF band which was previously used for voice messages. The system prototype tests in Brisbane (Australia), Harwich (the UK) and in the Baltic Sea region confirmed the declared characteristics of the system, and now a number of manufacturers are busy with making the prototypes of VDES equipment.

The marine messaging template developed within the project [36] and intended for standardization and automation of the procedure of mandatory reporting to the coastal and port authorities will also be quite helpful for the ship captains, because currently these procedures take up to two hours. When introduced, it will reduce by 80% the load on the captain to perform these procedures. Even today, a report prepared by means of this template can be transmitted via the MCP Messaging Service.

It is essential to mention another new technology created within EfficienSea 2 and facilitating more efficient implementation of both navigation and SAR tasks in remote areas, especially in the Arctic [8]. To do this, one just needs to connect via the Internet to the ArcticWeb platform based on digital mapping, which provides, in particular, the following information:

—position of all vessels in the navigation area using the AIS data, which is extremely important when organizing group procedures during SAR;

—ice and satellite maps of the navigation area;

—data on ice conditions, such as the presence of passages in the ice, ice field thickness, presence of icebergs, etc.;

—provision of nautical charts of the International Hydrographic Organization (IHO) standard S-100;

—meteorological data, including those for the planned route;

—warnings about navigation hazards;

—data on coordinated navigation with planned routes sharing;

—access to various information resources, e.g. the web site of Danish Meteorological Institute.

EFFICIENTFLOW

Since the works on the EfficienSea 2 were completed in 2017, further promotion of e-N concept in terms of sea traffic management (STM) is carried out under the EfficientFlow project, for which the European Union has allocated 4.5 million Euros [9]. This project is to be implemented in 2018–2020; it is coordinated by Swedish Maritime Administration and participated by Satakunta University of Applied Sciences, Administration of Rauma (Finland) and Gävle (Sweden) Seaports, and by the Finnish Transport Agency.

The aim of the project is to optimize the STM procedures in Rauma and Gävle areas, the ferry traffic routes between the islands of Sweden and Finland, as well as in the adjacent segment of Scandinavian-Mediterranean Corridor (ScanMed) between Stockholm and Turku.

At the same time, introduction of the EfficientFlow results should ensure:

—flexible route planning;

—improvement of data exchange between the ports and the part of the country distant from water ways;

—optimization of seaport operations;

—fuel saving;

—reduced time of mooring;

—improvement of mooring operations;

—development of procedures in case of unforeseen events.

e-NAVIGATION UNDERWAY 2017

In general, the information on the e-N concept implementation progress as of the beginning of 2017 can be found in the materials presented at the e-Navigation Underway 2017 International Conference [17] which took place in February 2017. The most important issues discussed at the Conference were as follows.

The following tasks attracted the most focused attention (their numbers according to the strategic plan of e-N implementation [1] are given in brackets):

—development of integrated navigation systems (S1);

—automation of procedures for mandatory reporting to coastal authorities (S2);

—integration and graphic display of the information received by means of communication systems (S4).

A significant part of the first task is carried out by China which proposed two new modules for S1 implementation: unification of bridge designs and the systems receiving the information transmitted by communication equipment.

In the second discipline, the leadership in developments is held by Norway whose specialists have demonstrated the first attempt to automate the transmission of a standard message to the seaport authorities using the SSN (SafeSeaNet, ship traffic management system). On the other hand, Norway and the International Hydrographic Organization (IHO) have presented a draft regulatory document governing the procedures for displaying the information transmitted by communication equipment, on multifunctional displays.

An important event noted by the Conference participants was the release of IEC 61174 standard which regulated the procedure of ship route sharing between the ships and the coast, as proposed within MonaLisa2 project [10]. This standard provides for the coastal line to be included in the route representation, which removed a number of uncertainties that previously existed in its displaying.

ENSI

To develop the ideas of e-Navigation, the Finnish Transport Agency in cooperation with the stakeholders of the Finnish maritime industry are testing the service which provides digital route sharing both between the vessels and with the maritime administrations, including seaport authorities [11]. During these tests, which involves the Finnish coastal centers of vessel traffic services (VTS) and the vessels frequently visiting the Finnish seaports, the performance of available VTS services transmission system is checked simultaneously.

The most important of these services is ENSI (Enhanced Navigation Support Information) intended for navigation safety improvement. The study of a number of maritime incidents has shown that, when the navigational safety of a planned route is checked using the software of existing ECDIS, the navigation officer may sometimes misunderstand the real situation. The ENSI suggests additional control of navigation routes by external maritime authorities, including hazards identification and provision of relevant information to the navigation officer.

At the same time, other services were also checked for efficiency, such as transmission of weather information along the voyage route, information on navigational hazards and ice conditions, and preparation of mandatory reports to the coastal authorities and pilotage orders. In particular, it was found that the existing procedure for route points transmission from the VTS centers to the vessels moving in ice, using a VHF channel often leads to errors. On the other hand, when using the ENSI service, the required route can be shown on the ECDIS display together with the information on the coordinates of turning points on the route.

Another development funded by the EU in line with e-N is carried out by the Norwegian company Vissim in cooperation with the Finnish Transport Agency. Its aim is to create a ship route sharing system, the first one in the Baltic Sea [32].

At present, a vessel voyaging from Helsinki to Oslo passes through several zones covered by the VTS centers, and every time they have to tell them their route. Different centers request different information, so in most cases the navigator has to contact them by radio, which distracts them from their main operations. As soon as the above-mentioned development is completed, it will provide route sharing between the VTS centers, thus removing the inconvenience, because it will be enough to enter these data only once.

To solve the task at issue, the developers from Vissim set out to integrate the ENSI system with the VTS. In this case, the VTS will receive these data in an automatic mode and at the same time transmit the information on navigational safety, weather, etc. to the navigator. It is obvious that the principles laid down in the ENSI and VTS integration are applicable in any part of the world. This suggests that the ongoing work is not exclusively regional.

HULL-TO-HULL

Of all the works funded by the EU since 2018 to support the e-N concept, special attention should be paid, first of all, to the Hull-to-Hull (H2H) project developed by companies from Norway (Konsberg Seatex, Sintef Ocean and Sintef Digital), the Netherlands (Mampaey Offshore Industries), and Belgium (KU Lueven) [16].

The goal of this project, which will be completed in 2020, is to ensure safe navigation in close proximity of moving and stationary objects; this creates some prerequisites for promoting the products created within this projects for unmanned vehicles as well. Implementation of this task is based on using the readings from different navigation sensors, primarily of the global navigation satellite system (GNSS) Galileo and EGNOS, as well as 3D models of the objects themselves. It is expected that the information will be displayed to the navigator in both 3D and 2D formats.

Such an approach will allow the navigator to precisely estimate the distance to surrounding objects, including moving vessels, as well as the approach speed. According to the existing estimations, in case of unmanned vehicles, the error of this distance should not exceed several decimeters, which is supposed to be achieved by integrating the data received from GNSS receiver operating in dual-frequency multisystem mode, inertial measurement unit, AIS, lidar, radar, and video cameras. Moreover, the readings of sensors and the 3D models themselves will be transmitted to the surrounding vessels.

Generally, the project is headed by the specialists from Konsberg Seatex. Sintef Ocean and Sintef Digital will conduct the expertise of the decisions made, involving the KU Lueven university, with regard to navigation on inland waterways, while Mampaey Offshore Industries will do the same with regard to towing, docking and mooring operations. The project coordinator Per Erik Kwam believes that upon the H2H completion it will be possible to carry out the maneuvers and procedures that had never been known to mariners before.

The project developers pay special attention to the problems of unmanned vehicles navigation. If these vehicles are recommended for commercial applications, there will be extremely stringent requirements for safety and reliability of their equipment and implemented technologies. This will require continuous data sharing between the interacting vessels, which will be provided by means of a fail-safe high-speed channel to support the tasks of relative positioning and 3D models transmission. Such a channel will be also developed within the H2H project.

Finally, demo tests of interaction procedures between an unmanned vehicle and a traditional vessel will be performed in Norway, an UAV mooring test—in the Netherlands, and the tests of its positioning on inland waterways, based on the Galileo and EGNOS GNSS data in various environments—in Belgium.

e-NAVIGATION UNDERWAY 2018

The 8th International Conference E-Navigation Underway 2018 was dedicated to the discussions of practical realization of the solutions provided in the Maritime Service Portfolios (MSP). Its participants made the following conclusions:

(1) ship owners started to realize the importance of solutions proposed within the e-N projects in terms of navigation safety, improved maritime efficiency, and reduction of operational expenses;

(2) standardization of the procedures proposed within various services plays a crucial role in the development of relevant products;

(3) the unmanned vehicles, whose development is driven by the business community, are already at hand, and the maritime authorities and organizations should be prepared for that.

Another event important for the navigation practice is the 19th IALA Conference (South Korea) conducted under the sponsorship of the International Association of Lighthouse Authorities (IALA) [18], the participants of which stated the following:

(1) it is highly important to change the existing AIS technologies for VDES solutions;

(2) there is an increasing need to struggle with cybercrimes the aim of which is to distort the data shared by the participants of navigation process;

(3) there is an urgent need to revise the IMO Resolution A.857 on the main VTS technologies, in order to harmonize corresponding services globally;

(4) there are some serious problems in solving the navigation tasks for unmanned vehicles, due to the instability of GNSS signals. Unfortunately, the proposed solutions, including radar-based positioning, the use if e-Loran system signals, etc., are generally perceived ambiguously by the world community.

Finally, the IALA seminar on the problems of e-N promotion in the Arctic, the development of which is attracting more and more attention, is worth special mentioning [19]. Having reviewed the presentations made there, the following conclusions can be made:

(1) the existing volume of hydrographic data is obviously insufficient for creating a relevant complete set of electronic navigation charts (ENC) of a given region;

(2) ideally, it is necessary to create a unified information system to service the navigation in the Arctic; however, this will hardly be possible in the current political situation;

(3) to ensure reliable communication in the Arctic basin, it is essential to use the solutions provided by VDES and MCP in a coordinated manner;

(4) with appropriate cooperation of the countries within the IALA pool, the IALA-NET platform could become an efficient aid for AIS data collection and transmission via satellites in the Arctic;

(5) the most important thing for the VDES system is to be acknowledged by ship owners and equipment manufacturers. In the Arctic this problem is complicated by the need to convince the coastal authorities of its efficiency in order to get access to appropriate funding.

SEDNA

Talking about the Arctic, it is necessary to mention that global warming has significantly changed the ice conditions in this region and made it possible to lay new routes in the areas that used to be blocked before. Being aware of this, the EU developed the e-N concept by launching the SEDNA project (Sedna is the Eskimo goddess of sea animals) which is implemented by a consortium of 14 partners, mainly universities, representing the UK, Sweden, Norway, Ireland, Finland and China. The project coordinator is BMT Group LTD (the UK); the cost of works carried out from June 2017 till July 2020 is 6.73 million Euros.

The objectives of the project are [20]:

(1) to develop a human-oriented approach that allows the ship's crew to safety navigate in the Arctic, especially if they do not have any experience of navigation in the ice conditions. In this case, only the most state-of-the-art technologies will be used, for example, the augmented reality;

(2) to develop a special algorithm for route planning, taking into account the forecasts of ice fields evolution and weather changes, based on the big data technologies;

(3) to propose special anti-icing measures to be taken into account in the vessels' design, including the development and testing of special coatings;

(4) to research the possibilities for using fuels with low flash point on ice class vessels, and to estimate the hazards of bunkering the vessels with methanol fuel from trucks, onshore facilities or from other vessels during the voyage.

A-SUITE

The project of Transas company, which is an attempt to systematically prevent the errors of operators who work with the equipment developed under the auspices of the IMO, is of particular interest. For this purpose, the company has presented the first package of algorithms for A-Suite system designed on the basis of the latest advances in the machine learning concept and intended for managing the errors of bridge watch officers, the personnel of VTS centers and other coastal services, as well as for posterior assessment of their performance quality [21]. The purpose of these algorithms is to detect anomalies in the operators' behavior and to generate an alarm signal before the sequence of their actions or a critical error has lead to irreversible consequences.

The presented version of the system consists of three basic modules:

—Advanced Intelligent Maneuvering;

—Advanced Intelligent Diagnostics; and

—Advanced Intelligent Routing.

The purpose of the first module is to predict the trajectory of the vessel and to support the solutions for preventing the collisions with meeting vessels. The data on the procedures used by the navigator and the crew's behavior during navigation in the same region are stored in the memory of the system, and together with the well-developed hydrodynamic model of the vessel these data are used for improving the reliability of the current navigational situation estimation by the system, and for reducing the probability that the watch officer will make an inadequate opinion on this situation, which may lead to undesirable incidents.

The second module is intended for detecting anomalies in the vessel's maneuvering pattern by analyzing the parameters such as speed, turning speed or fuel consumption from the data received from conventional equipment. At the same time, the vessel's motion control operations are recorded, which helps to identify the bridge errors upon the voyage completion.

The third module is a software platform for route planning and optimization based on the analysis of the oceanic metadata, the vessel's hydrodynamics, the traffic intensity and jams on the given route.

The basic modules of the A-Suite system are supplemented by two service applications: Advanced Data Delivery and Advanced Remote Maintenance. The former makes the watch officer free from the routine operations such as ENC updating, and reception of weather data and other messages for mariners. Moreover, it helps to audit the coastal services to make sure that their representatives have full information on the navigational situation on the vessels they support.

The other application performs remote diagnostics of the technical condition of the bridge and satellite communication equipment. In addition, it provides the redundancy of the system's key applications with their current settings in the Transas Cloud, which makes it possible to quickly restore the system in case of failure.

At the same time, A-Suite provides the Advanced Remote Training for Seafarer, a service based on the e-N ideas, with online access to training courses on the ECDIS manufactured by Transas, which fully comply with the requirements of relevant IMO structures.

As a result, A-Suite helps to establish stable communication between the vessels and the coastal services, VTS and training centers, which fully corresponds to the THESIS concept proposed by Transas who believe that it fully meets the most urgent demands of all stakeholders. The THESIS is Transas Harmonised Eco System of Integrated Solutions, which is based on cloud technologies and helps the maritime community to effectively solve the navigation problems and ensure safety at sea [22]. A-Suite continues the development of this concept.

As a cloud application, A-Suite can be accessed both onboard the vessel and on shore. At the same time, taking into account possible outage of communication at sea, A-Suite suggests a special server to be located onboard a vessel and ensure the system operation when the Transas Cloud cannot be connected with. It should be mentioned that the THESIS network was designed with the account for security considerations. For this purpose, all critical data, such as the vessel's route, the ENC updates etc. are shared via encrypted channels, without using e-mail messages which are vulnerable to external invasions. This approach radically distinguishes A-Suite from most of the software products available in the market.

SWANS

As has been mentioned above, the era of autonomous (unmanned) surface vessels (ASV) is already on the doorstep. That is why the UK started funding the SWANS (Shared Waterspace Autonoumous Navigation by Satellite) project at a cost of 1.6 million USD, the aim of which is to study the problem of coexistence of ASV and traditional vessels at sea [23]. The contractors are the international companies BMT and ASV Global, and the British company Deimos Space.

The developers focused their efforts primarily on solving the problem of collision avoidance, which, as follows from the project title, should be based on satellite technologies; and on the problems of communication between such vessels. It is obvious that the greatest difficulties occur in the areas of congested maritime traffic, where some of the existing vessels are using AIS for clear passage. However, it is indistinct how such a vessel can pass clear of a vessel not equipped with a similar receiver, or with other objects.

The first stage of the project will include the following tasks:

—to study the efficiency of satellite technologies as a solution to clear passage problem;

—to create a high-quality model of an operator controlling the vessel's motion;

—to simulate numerous possible scenarios of ASV control.

To do this, it is proposed to combine the ASV control system simulator that is available at ASV Global, and the Rembrandt simulator owned by BMT and intended for a vessel maneuvering simulation. This will provide 3D visualization of the processes during clear passage and help to estimate real conflicts in the situations when several vessels are passing clear of each other.

STM VALIDATION

The most significant achievement of the recent years is completion of the STM Validation project in 2019. The goal of the project was practical validation of the efficiency of the VTS procedures the first versions of which were proposed as early as in 2010 within the MONALISA project [24]. The scale of the project research is evidenced by the fact that the EU allocated a total of 75 million Euros for the development of VTS technologies created by 39 companies, and 49 more companies and organizations participated in the works within the STM Validation project which involved 215 vessels, 13 ports and 6 coastal centers [25].

It is remarkable that only the preparation for the necessary testing procedures took more than one year. A number of e-N technologies from third-party projects were used for that. For instance, the scenarios of works to be performed were successfully developed using the European network of maritime simulators combining 11 simulation centers with 45 bridges; it was created within the MONALISA2 project [10]. The EfficienSea2 project also made its contribution; its MCP was used to register all digital services available in the project, otherwise it would be impossible to effectively use them on the vessels and onshore.

It is believed that by 2030, the procedures developed within the STM project and ensuring the comprehensive exchange of information on the vessel routes, including their optimization using the cloud technologies and big data processing techniques, will [26]:

—reduce the number of sea incidents by 50%;

—reduce the cost of shipping services by 10%, and the waiting time for mooring by 30%;

—reduce fuel consumption by 7%, and harmful emissions in the atmosphere by 7%.

It is important that the STM services allow the onboard and onshore personnel to make decisions based on reliable current information. These services ensure better compliance with the vessels traffic schedule, reduce the managerial load and the risks associated with the human factor.

The most important STM service is optimization of a vessel's route, the information on which is transmitted in accordance with the RTZ protocol developed within the STM Validation project and supporting the route data sharing between the ECDIS, where it is generated by preliminary plotting, and various users of the information, such as radar, neighboring vessels, or VTMC.

From the moment the vessel starts moving, the "controlled" data on its route are transmitted to the external users via AIS or VDES. Based on these data and the data on the routes of surrounding vessels, the route is optimized both at the VTMC (with further data transmission to the vessel) and on the vessel itself. At that, the estimated time of the vessel arrival to the destination point is minimized, taking into account fuel consumption, speed and direction of wind and currents, and other parameters. While AIS can transmit the data on seven closest legs of the route, VDES is able to transmit 13 ones.

Within the framework of the STM Validation project, an extremely useful service of automated hazard alert has also been developed [27]. Using this application, the newly created Baltic Navigational Warning Service displays relevant information directly on the ECDIS screen. The service forms this information only for the route of a given vessel and, as soon as the hazardous section has been passed, it is automatically removed. Thus, the watch officer does not need to regularly monitor the Navtex equipment receiving the messages from mariners, and to manually put the received data onto the map.

Generally, the STM provides the following basic services:

—route optimization;

—route data sharing between the vessels;

—warning of navigational hazards;

—route passage monitoring;

—coordination and synchronization of port service operations;

—winter navigation support;

—SAR operations after accidents.

The IMO Secretary General Kitack Lim highly appreciated the work done [33]. First of all, he noted that the STM procedures provide efficient data sharing between the vessels, port operations, service providers and ship owners, which considerably improves the quality of navigation and reduces the risk of collisions and stranding of the vessels. At the same time, he proposed the VTS developers to present the main results of tests at respective committees of the IMO and discuss the possibility of global application of the developed technology. It is expected that this will be implemented by 2030.

SMART-NAVIGATION

One of the most serious e-N projects currently being developed is SMART-Navigation [37, 38]. This project is worth USD 115 million (!) and is implemented under the auspices of the Ministry of Oceans and Fisheries of South Korea. The project was launched in 2016 and is to be completed by December 2020. It is implemented in view of the fact that 72% of all the incidents at the country's coast involve small boats, and 82% of them are human-induced.

The goal of the project is to integrate the e-N concept into the maritime traffic management technology for both SOLAS and, importantly, non-SOLAS vessels (e.g. fishing boats) by implementing the following:

(1) coordination of shipping, which will ultimately optimize the maritime traffic as a whole;

(2) allowance for the specific features of sea navigation, in order to identify the risks a vessel may face;

(3) vigorous proactive management of navigation safety to anticipate potential hazardous situations at sea;

(4) remote monitoring of onboard systems;

(5) development of a maritime off-board system which provides reliable data on navigation safety;

(6) establishment of services to support the following:

—route planning optimization;

—supply and correction of ENC in real time;

—pilotage and mooring procedures.

The results of these technologies implementation will be:

—integrated onboard e-N systems;

—digital communication systems, primarily based on VDES solutions;

—high-speed wireless maritime communication network using the LTE standard, for ENC and multimedia data sharing.

Finally, all the solutions will be harmonized with the international e-N standards, including the MCP development and the S-mode introduction.

One of the problems the project developers are facing is the specific use of chart tools on fishing vessels. Since they are not governed by SOLAS requirements, they usually use GPS plotters with unstandardized charts of so-called electronic chart systems (ECS charts). For this reason, a standard is being developed for the ECS charts with respect to SMART Navigation, as well as a prototype of such a chart according to S-101 standard, and a procedure for upgraded ECS charts uploading and updating. All these activities are carried out as part of the REDSS package.

The work on the MESIS package realization is also well under way. This package provides:

—navigation safety data;

—weather forecast;

—nautical publications;

—hydrographic information for navigators.

It is supposed that, before installation onboard the vessels, the REDSS and MESIS software will be debugged at a special testing center of the Korea Research Institute of Ships & Ocean Engineering, where 4 special-purpose simulators are available.

SESAME

One of the effective players implementing the IMO's ideas is SENA HLAB, the joint advisory board for e-N technologies promotion, founded by the governments of Singapore, Norway, Indonesia and Malaysia, as well as the IMO, IHO, IALA, the International Chamber of Shipping, and CIRM. Its goal is to develop and introduce innovative e-N procedures through suitable national projects over the next 10–15 years [39].

The first of such projects is SESAME Straits, the primary objective of which is to improve the navigation efficiency in the Straits of Malacca and Singapore and to develop the e-N technologies that had been previously created for the same region within the Marine Electronic Highway project. This project was implemented in 2014–2017 under the funding support of Norway in the amount of NOK 23 million; the project contractor was the Norwegian company Norcontrol in close cooperation with the Norwegian Coastal Administration, the University of South East Norway, and some Norwegian and Singaporean companies.

The first task of the project was to develop a procedure for ensuring safe navigation in congested water areas in coordination with VTS services. The second step was to solve the problem of just-in-time arrival, taking into account the regional MSP. As a result, the SESAME Straits project yielded the following services which use a VDES channel for communication:

—just-in-time arrival;

—forming a recommended route, taking into account the weather forecast;

—route passage monitoring and its real-time optimization;

—detection of congested traffic on the route and traffic optimization in this region;

—navigational hazard alerts;

—automated reporting to coastal and seaport authorities;

—ENC updating.

The SESAME Straits was continued by the SESAME 2 project aimed at the improvement and testing of the previously developed procedures, harmonization of the created services with the international standards, and their cooperation with the results obtained in other projects, especially SMART Navigation [40]. This project is funded by Norway and Singapore and supported by the British Maritime and Coastguard Agency and the Seaport of Southampton.

At the same time, it is planned to assess the load of SESAME 2 services on the operators both onboard and onshore. The developed procedures will be tested not only in Norway, but also in Singapore and in Dover (UK), in order to promote them in other regions and bring to the commercial market in 2021.

e-NAVIGATION UNDERWAY 2019

Based on the proceedings of two conferences with the same name, which took place in Seoul (South Korea) in September and in Tampa (USA) in November [41], the following conclusions can be generally made:

—the e-N services introduced for non-SOLAS vessels will significantly improve the navigation safety;

—for harmonization and compatibility of various e-N services, their design and documentation should be developed in accordance with unified requirements, such as S-100 standard or IALA Directive G1128;

—it is necessary to create a global cluster of marine innovations which can serve as a mechanism facilitating the international cooperation in practical realization of the e-N concept;

—the use of the global satellite communications system Iridium and the BeiDou GNSS in implementing the Global Maritime Distress and Safety System (GMDSS) mode will bring the quality of communications used in the e-N services to a new level;

—the use of augmented and mixed reality will significantly increase the efficiency of the marine services provided for in the strategic plans of e-N implementation, including MSP9 for remote medical aid;

—it is necessary to make provisions for using the developed standard S-421, IEC 63173 in the procedures of planned route sharing;

—due attention should be paid to the development and testing of new satellite systems, such as OneWeb.

IN THE IMO COMMITTEES

Now let us consider the proposals that have been discussed recently at the Maritime Safety Committee (MSC) and the Committee for Navigation, Communications, Search and Rescue (NCSR) [28–30], and aimed at promoting the e-N concept.

Most of all, they are concerned with the unification of design of integrated bridge systems (IBS) and navigation sensors. In particular, in January 2019 the NCSR held a meeting where draft regulatory documents on the harmonization of IBS, ECDIS, radars and other navigation equipment with electronic interface were presented. It is important that they contain some proposals on unified representation of all the navigation parameters displayed on the screens and recorded in such equipment. Final revision of relevant standards is expected by January 1, 2024.

At the same time, the NCSR approved the MSC's proposals on the harmonization of formats and structure of the e-N services, considering the fact that only its regional services are currently available, while the global ones do not exist. It is essential that all of them should be in line with the S-100 standard.

With regard to the e-N, the IMO declared its readiness for cooperation with other organizations in developing the services, in particular:

—ship traffic management;

—maritime communications quality improvement;

—notification of coastal services;

—navigation in ice conditions;

—search and rescue operations;

—vessels towing;

—telemedicine health care;

—weather and hydrographic data sharing.

Another issue is modernization of the GMDSS. For this purpose, the Iridium company has presented a low-orbit space system of new generation, which provides a global solution to the GMDSS problems. The vessels governed by SOLAS will be able to use the new technology no earlier than in 2020, when the Convention will be brought in line with the realities of today. Other vessels can use the new terminals as soon as they appear in the market.

A remarkable event was the 100th meeting of the MSC held in December 2018 and dedicated mainly to the problems of unmanned vessels [31]. At the first stage, every navigation tool was checked for the possibility of its application on maritime autonomous surface ships (MASS) according to the following chain of criteria:

—applicable on MASS or cannot be used on them;

—applicable on MASS and can be used on them after modernization;

—applicable on MASS and can be used without upgrades.

At the second stage, the unmanned ships were classified as follows:

—type 1: a vessel is automated, including the decision-making procedure, but there is a crew onboard, which can interfere with some procedures;

—type 2: a vessel is controlled remotely, but there is a crew onboard, which can take control in a critical situation;

—type 3: a remotely controlled vessel with no crew onboard;

—type 4: an absolutely autonomous vessel.

It is expected that during 2020, the IMO will determine the ways to implement each of the MASS application modes, taking into account the technical limitations, human factor and situation at sea.

The problems of MASS were also addressed at the 101st session of the MSC (June 4–5, 2019) [34]. First of all, their testing was discussed, and it was decided that the tests should be organized in such a way that the level of requirements for the MASS navigation was at least no lower than for conventional vessels.

At the same time, the Committee discussed a draft circular on Guidelines for the Standardization of User Interface Design for Navigation Equipment, the aim of which is to unify the user interface and the information used on bridge when solving the navigation tasks, in accordance with the e-N concept. A decision was made that the standardized images of navigation information should appear on the displays of the integrated navigation system, ECDIS and radar by January 1, 2024, and on other bridge displays — by July 1, 2025.

Finally, the document on the Initial Descriptions of Maritime Services in the Context of e-Navigation was adopted. The document regulates the content of primary descriptions of maritime services and is the first attempt of their format and structure standardization [35]. It is supposed to be updated regularly in accordance with the works on harmonization, carried out in cooperation with the IHO, IALA and some other organizations.

e-NAVIGATION IN RUSSIA

It has already been mentioned in [1] that Russia does not participate in any international projects on e-N, although it is a member country of both IMO and IALA. Generally, the situation has not changed to date. At the time of this article publication, the only company promoting this concept in Russia was Transas Group; however, in 2015 it split into Transas company and Kronstadt Group. The former already had some minimum contacts in Russia, but in 2018 it was taken in by Wärtsilä holding (Finland); and the latter became the legal successor of work in the focus area. There are no other active participants in the e-N approach development in Russia. Considering the above, it should be noted that the results of the works on e-N carried out before 2018 were to a major extent obtained by the developers from the former Transas Group.

In the period 2015–2019 studied in this article, the work on e-N was carried out mainly within the federal target program (FTP) of the Ministry of Transport of the Russian Federation "GLONASS Maintenance, Development and Use in 2012–2020." At the same time, preparations were under way for implementing the MariNet action plan (road map) within the National Technological Initiative approved by the RF President's Council on the Economy Modernization and Innovative Development of Russia in 2017 [42].

Most of the FTP work was carried out in accordance with the Terms of Reference (ToR) for the e-Sea development and engineering project which was approved by the RF Ministry of Transport in 2016. In 2019, the second governmental contract was completed for this project, and in 2020 the ToR for the development and engineering project "e-Sea—non-SOLAS" (for the future FTP GLONASS 2021–2024) is expected to be approved; it will be focused on the development of e-N procedures for the vessels not governed by SOLAS [43].

At the initial stage, the following e-N services were developed (or planned to be developed):

—transmitting and receiving the planned routes between the vessel and the VTS operator, or between two vessels via AIS channel;

—vessel's position monitoring by the VTS operator, including warnings on deviation from the planned route and approaching the hazardous areas;

—transmitting the information on the target monitored by the VTS to the vessel and pilot;

—transmitting the VTS data on navigation safety and weather to the vessels;

—transmitting the parameters of the targets monitored by the automatic radar plotting aids to the fleet management system of Rosmorport branch, and Volgo-Balt Administration, for remote monitoring and analysis of navigators' actions;

—remote monitoring of operation and maintenance of ship navigation systems.

Naturally, it was necessary to create a special test bed for debugging the services listed above. For this purpose, within the e-Sea project, a so-called e-N test water area "Hermitage" was realized [44]. It included (see figure 1 below):

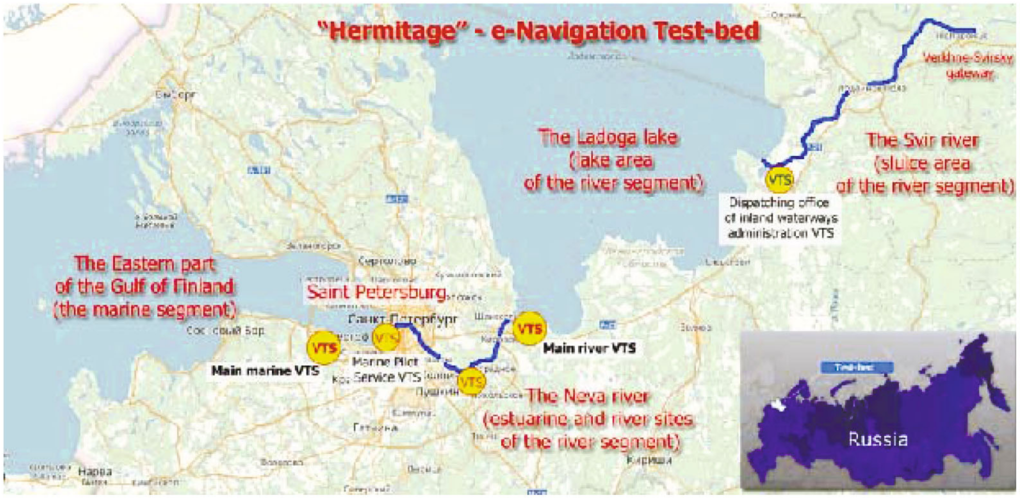

Fig. 1. e-Navigation test water area.

—a sea part: the eastern part of the Gulf of Finland from the Hogland Island to the Big Port of St. Petersburg, covered by the regional VTS in Petrodvorets and St. Petersburg;

—a river part: the Neva and the Svir Rivers, as well as the southern part of the Ladoga Lake.

All the VTS were equipped with automated e-N workstations. Moreover, seven vessels of Rosmorport, operating in the test area in the eastern part of the Gulf of Finland, and five vessels of Volgo-Balt Administration were equipped with ECDIS prototypes customized for the e-N tasks.

The most important feature of the test water area equipment is that there is a possibility to use traditional VHF radio channels in combination with the latest telecom technologies, such as 3G and 4G wireless networks, WiFi and WiMax, and satellite communication channels Iridium SBD and Sat-Ais. Finally, Kronstadt Group started developing a VDES-based automated data interchange system; for this purpose the company is developing a special transceiver.

The abovementioned MariNet action plan in the e-N segment stipulates the development of the focused technologies in two stages [45]:

(1) forming the standards and technological solutions, their trials within the pilot and R&D projects, and approval at the IMO in 2025;

(2) systems installation on the vessels, at ports and other maritime infrastructure facilities in accordance with the regulatory requirements by 2035.

Corresponding products will be supposedly created within the e-NAV development and engineering project. The deliverables of this project will be the following developments [46]:

—architecture of e-N pilot zones in the RF;

—the Russian cloud-based segment of MCP, which interconnects the navigators, offices of shipping companies, port services, VTMC, and other service providers;

—onshore station of the automated data interchange system (ADIS) in VHF band as a communication channel interconnecting the vessels, pilots, VTMC, and onshore users;

—a standard system for remote monitoring and control of ship navigation systems in the operator's office;

—a ship-based integrated system customized for e-N tasks.

At the same time, there is an objective to integrate the newly developed Russian segment of the MCP with the overseas segments in the Baltic Sea and in the European Arctic, developed within the EfficienSea2 Project, and to spread the availability of provided services to other sea regions, including the Russian Northern Sea Route. Finally, the ADIS, being a telecommunication tool for the MCP, will provide broadband communication via the coast—satellite channel, thus making it possible to refuse from AIS coastal stations.

CONCLUSIONS

To summarize the above, the following conclusions can be drawn:

(1) the ideas of e-N, formulated at the 81st session of the MSC in 2005 and the 94th session in 2014, and presented in the form of the problems to be solved within the Strategic Plan of e-N Implementation (SIP), are mesmerizing more and more maritime stakeholders;

(2) practical implementation of the e-N concept is driven by the EU and the South Asia countries;

(3) in 2014, it was supposed that implementation of the products created within the SIP would start

already in 2020; however, the actual time shifts till the 2025–2030;

(4) after a long period of fragmented developments in the field of e-N, Russia has finally got a road map, and corresponding development and engineering projects have been initiated to create the national e-N technologies and to integrate them with the results of works performed abroad.

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