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SIMULATION ANALYSIS OF ECDIS' ROUTE EXCHANGE FUNCIONALITY IMPACT ON NAVIGATION SAFETY

ABSTRACT

Modern Integrated Navigation Systems (INS) integrate information obtained from various sensors and functions. Processed data are presented on the computer display generally with the aim to increase navigator's situation awareness and to reduce his/her workload. The investigations described in the paper were carried out to assess the advantages of the new functionality of the test INS (e-Navigation enhanced Integrated Navigation System ee-INS), developed in the EU financed EfficienSea Project, that looks and works like a standard ECDIS. This new functionality implements 'Exchange of Intended Route' service. The experiment was conducted in a full mission ship simulator environment with 20 experienced mariners. The bridge layout without ECDIS 'Exchange of Intended Route' functionality, and bridge layout with this functionality implemented, was applied in research and its results enabled to carry out their comparison. The navigators' workload was measured by NASA-TLX method. Navigators' situation awareness in respect to other ship's state and the final passing distance were utilized to evaluate safety of navigation process.

Keywords:
e-Navigation, navigation safety, route exchange.

INTRODUCTION

Modern technology on the vessel bridge provides a lot of information that is supposed to help the navigator. But part of the information is unorganized, and there is a lack of standards. This can lead to confusion. There is an overflow of information on the bridge that could lead to accidents (Efficientsea webpage, 2012).The one of the aims of EfficienSea EU Project was to improve maritime safety in the Baltic Sea region by working out of best practice within the e-Navigation concept in order to facilitate the further development and full scale implementation of the e-Navigation functionality.

With e-Navigation a new standard for organizing the information is developed, providing for better means of navigation. One system integrates all the necessary information to give the right information at the right time, filtering out everything that is irrelevant for safe navigation (fig. 1). e-Navigation is an evolutionary and dynamic concept that will continue to develop as new user needs arise and emerging technological opportunities become available.

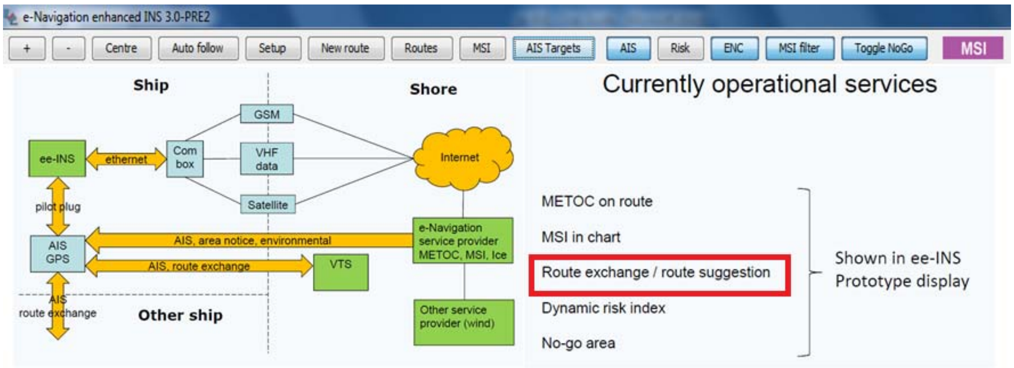


Fig. 1. EfficienSea ee-INS — e-Navigation enhanced Integrated Navigation System [own study]

Within EfficienSea project the test system was developed, called the e-Navigation enhanced Integrated Navigation System (ee-INS), looks and works a lot like a normal ECDIS. However not all ECDIS functionalities have been implemented as the main objective of the system is to test the new services; METOC, MSI, Exchange of Intended Route and Route Suggestion. In the articles authors focused on exchange of intended route functionality. When vessel's exchange intended route is activated on the ee-INS the routes are broadcasted on VHF AIS every 6 minutes. This makes it possible for vessels in the vicinity to see vessels planned track and adjust own navigation accordingly. If route is changed — waypoint's positions or arrival time to waypoints — the new route is broadcasted right away and again every 6 minutes. The transferred routes can be presented on ECDIS chart or other navigation aiding systems as ARPA, pilot systems etc. It makes it possible for vessels engaged in navigation process to plan efficiently and safely their manoeuvers with respect to future positions and courses of other ships.

The main aim of the investigation discussed in this paper was to assess the advantages and disadvantages of intended exchanged route functionality compared to the traditional ECDIS layout with respect to execution of collision avoidance and route monitoring [6].

The main goal of this article was to investigate how and to what extend the application of the function influences the process of navigation especially in aspect of navigator's workload [1]. Apriori theoretical analysis of problem leads to conclusions that exchange route could be useful information for vessels and reduce the workload and probability of collision. Having in mind practical context of research subject and Convention on the International Regulations for Preventing Collisions at Sea (COLREG 72) many questions and doubts arises in relation to essence of system functioning.

What will be the way of monitoring if the ships follow the 'announced' track and what are the consequences in the case when one follows other track than that sent around? What will be the legislative status of information with reference to the COLREG? Do professionals really need next additional information among those already confusing them during the watch? The problem is quite complex and it was not possible to answer all asked questions in scope of this article. The authors' approach was systematized and some assumptions and limitations must have been made during the experiment. The navigation scenario was planned in anti-collision aspect and came down to the situation when only two power driven vessels were involved.

SIMULATION EXPERIMENT

Simulation experiment examines the impact of intended route exchanged application on navigator's workload and was conducted in full mission bridge simulator by Kongsberg in Marin Traffic Engineering Centre. In the experiment twenty navigators with chief mate and captain certificate and five second level students took part. The execution of the trials was segmented in 4 separate periods, each with the duration of 1 workday [3]. The reason was availability of simulator time, availability of participants. All participants were given a brief of the study's purpose and training in the use of the Polaris simulator and the equipment needed in the simulator. Some time had to be spent training on the Polaris radar and ECDIS because not all participants were familiar with the equipment. Following assumptions to the simulation experiment evaluating navigators were made:

- two vessels in sight of each other;
- only anti-collision aspect;
- AIS (port of call)is not monitored;
- two variants: with IREF (Intended Route Exchanged Functionality), without IREF;
- 20×2 simulations.

Expected outcome:

- TLX form filled by officers;
- statistical analysis.

For experiment purposes interaction situation between two power driven vessels were prepared. Weather conditions set as very good with no wind and excellent visibility. Vessel A after leaving port of Calais was heading North-West cutting North-Eastbound traffic in order to join South-Westbound traffic within Dover Strait traffic separation scheme. Vessel B was heading South-Westbound traffic and was supposed to alter course to port (South-East direction) with intention to approach to port Calais (fig. 2). The course of the vessel were set to collision and CPA was around 0.2 NM. The vessel A crossing TSS was manned and steered from bridge A, where on ECDIS screen route of vessel B was presented. Vessel B was steered automatically by means of predefined route. Vessel were in 6.73 NM distance when the simulation started and were vessel B was clearly visible on radar screen of vessel A.

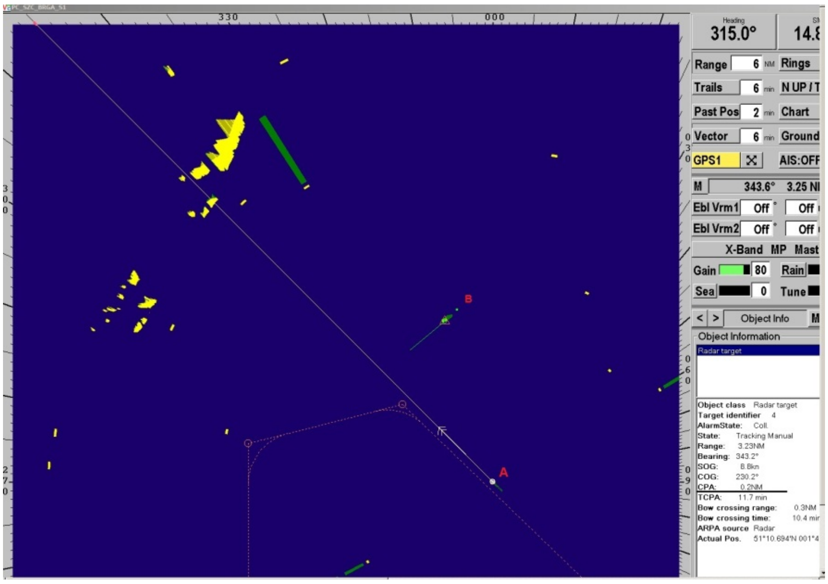


Fig. 2. Screenshot of the simulation trial [own study]

From the moment when the risk of collision first begins to apply , the give-way vessel A is required to take proper action to achieve safe passing distance and safely join the traffic of TSS. Scenario was designed in the way to simulate situation in which vessel A does know the intention of altering course to port by vessel B and assumes vessel B continuing moving her way South-West, according to fairway direction. Altering the course by vessel B (dist. = 3.26) to port is the moment when vessel A realizes of intention of vessel B (fig. 3 and 4). The idea of scenario was to lead to uncertain situation for vessel A in aspect of further action. That caused some manoeuvres unsafe and demanding especially for those who took action earlier and were just during giving way for vessel B. Some navigators decided to come closer than 3.26 NM and alter course slightly to port or reduce speed. For those the action of vessel B was less demanding when they found out of the intention vessel B.

Fig. 3. ECDIS displays of simulation trials with IERF applied, dist. = 6.7 [own study]

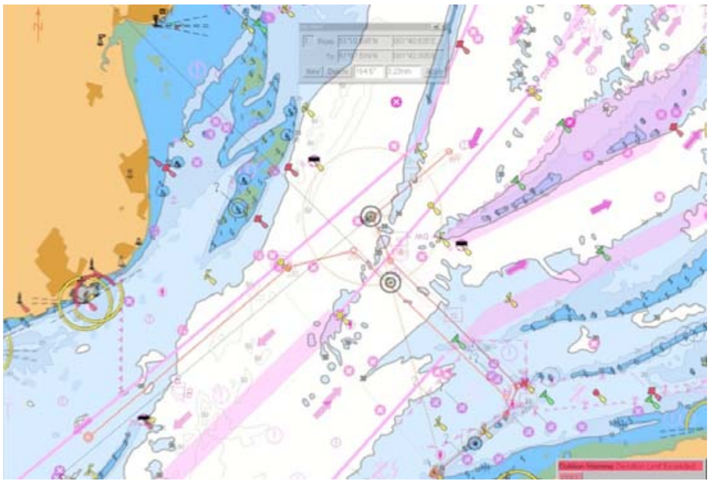


Fig. 4. ECDIS displays of simulation trials with IERF applied, dist. = 3.26 [own study]

Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREG)

The following rules of COLREG had to be applied by navigators in decision making presses during experiment:

Rule 15. Crossing situation

When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.

Rule 16. Action by give-way vessel

Every vessel which is directed to keep out of the way of another vessel shall, so far as possible, take early and substantial action to keep well clear.

Rule 17. Action by stand-on vessel

(a) (i) Where one of two vessels is to keep out of the way the other shall keep her course and speed.

(ii) The latter vessel may however take action to avoid collision by her manoeuvre alone, as soon as it becomes apparent to her that the vessel required to keep out of the way is not taking appropriate action in compliance with these Rules.

(b) When, from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision.

(c) A power-driven vessel which takes action in a crossing situation in accordance with subparagraph (a) (ii) of this Rule to avoid collision with another power-driven vessel shall, if the circumstances of the case admit, not alter course to port for a vessel on her own port side.

(d) This Rule does not relieve the give-way vessel of her obligation to keep out of the way.

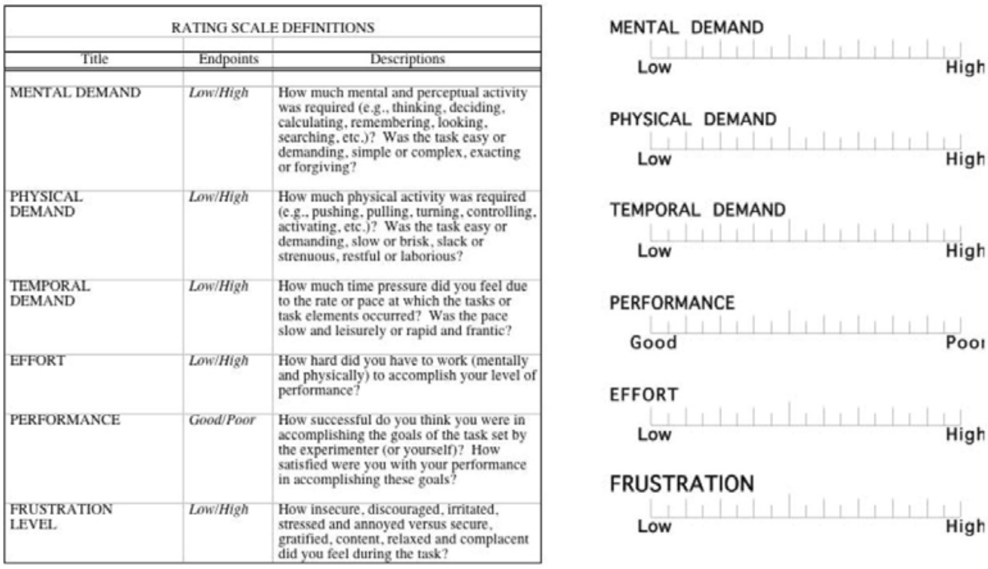
TOTAL WORKLOAD METHODOLOGY

NASA-TLX is a multi-dimensional scale designed to obtain workload estimates from one or more operators while they are performing a task or immediately afterwards. The years of research that preceded subscale selection and the weighted averaging approach resulted in a tool that has proven to be reasonably easy to use and reliably sensitive to experimentally important manipulations over the past 20 years. Its use has spread far beyond its original application (aviation), focus (crew complement), and language (English). This survey of 550 studies in which NASA-TLX was used or reviewed was undertaken to provide a resource for a new generation of users. The goal was to summarize the environments in which it has been applied, the types of activities the raters performed, other variables that were measured that did (or did not) covary, methodological issues, and lessons learned [4].

Workload is a term that represents the cost of accomplishing mission requirements for the human operator. If people could accomplish everything they are expected to do quickly, accurately, and reliably using available resources, the concept would have little practical importance. Since they often cannot, or the human cost (*e.g.*, fatigue, stress, illness, and accidents) of maintaining performance is unacceptably high, designers, manufacturers, managers, and operators, who are ultimately interested in system performance, need answers about operator workload at all stages of system design and operation. The many definitions that exist in the psychological literature are a testament to the complexity of the construct as are the growing number of causes, consequences and symptoms that have been identified. Given the confusion among the 'experts', it seems equally likely that people who are asked to provide ratings will have a similar range of opinions and apply the same label (workload) to very different aspects of their experiences [4].

For this reason, the NASA Task Load Index (NASA-TLX) consists of six subscales that represent somewhat independent clusters of variables: Mental, Physical, and Temporal Demands, Frustration, Effort, and Performance (fig. 5). The assumption is that some combination of these dimensions are likely to represent the 'workload' experienced by most people performing most tasks. These dimensions were selected after an extensive analysis of the primary factors that do (and do not) define the subjective experience of workload for different people performing a variety of activities ranging from simple laboratory tasks to flying an aircraft. Coincidentally, these dimensions also correspond to various theories that equate workload with the magnitude of the demands imposed on the operator, physical, mental, and emotional responses to those demands or the operator's ability to meet those demands.

A weighting scheme was introduced to take such individual differences into account when computing an overall workload score. Essentially, overall workload represents the total areas of the six bars. The weights are derived for each participant at the beginning of a study by requiring simple decisions about which member of each paired combination of the 6 dimensions are more related to their personal definition of workload. Each subscale rating provided by that person during the study is then multiplied by the appropriate weight, developing a composite tailored to individual workload definitions. The benefit of this weighting scheme was an increase in sensitivity (to relevant variables) and a decrease in between-rater variability. The development and theoretical rationale for the scale were described in a chapter published in 1988 by Hart & Staveland.



RATING SCALE DEFINITIONS		
Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Fig. 5. NASA Task Load Index subscales definitions [4]

TXL — simulation experiment results

Self reported workload test was conducted immediately after completion of each trial using NASA — TLX (Task Load Index) and a quality of manoeuvre assessment with emphasis on COLREGs and good seamanship. The results are presented on fig. 6 and 7 where gathered TXL values from trials with intended route exchange functionality and without.

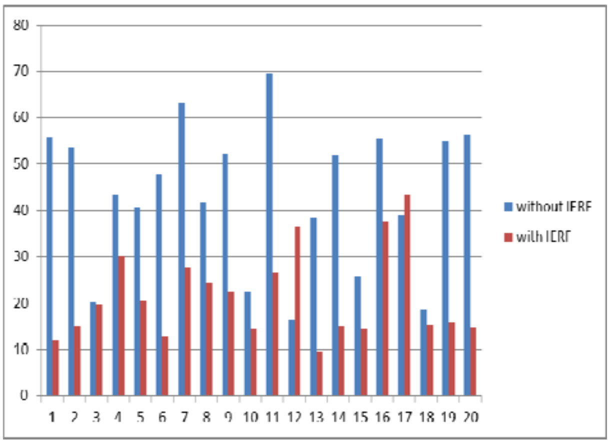


Fig. 6. TXL index for simulation trails with and without IERF [own study]

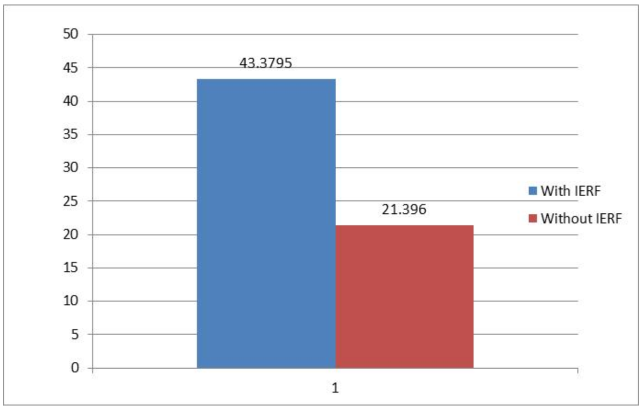


Fig. 7. Mean TXL index for simulation trails with and without IERF [own study]

The significant differences between trials with EIRF and trials without IERF applied were observed. The mean TXL values for 20 trials with IERF was 43.4, and men value for those without was 21.4.

STATISTICAL TEST

Having TXL values determined, the statistical test were performed to verify statistical differences at assumed significance level between variances and mean TXL values for trails with and without TXL functionality applied. The following test were conducted and hypothesis were formulated:

Null hypothesis criteria: critical probability level 'p' to assume statistical significance $\alpha = 0,05$:

— if $\alpha < p$, null hypothesis is rejected at assumed statistical significance α;
— if $\alpha \geq p$, null hypothesis is not rejected.

Particular hypothesis for equal means:

— H0: TLX means for both variants are equal, mb = mo;
— H1: TLX mean without IREF is greater than TLX mean with IREF, mb > mo.

Particular hypothesis for variances homogeneity (Levene, Brown and Forsyth tests applied):

— H0: TLX variances for both variants are equal, $\sigma 2b = \sigma 2o$,;
— H1: TLX variance without IREF is greater than TLX variance with IREF, $\sigma 2b > \sigma 2o$.

Two tests for significant differences of means depending on homogeneity of variances:

— T-student test for homogeneous variances;
— Cochran-Cox for non-homogeneous variances.

T-test for Independent Samples (Nowy dokument tekstowy)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	t separ. var.est.	df	p 2-sided	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances	Levene F(1,df)	df Levene	p Levene	Brn-Fors F(1,df)	df Brn-Fors	p Brn-Fors
no ER vs. ER applied	43,37950	21,39600	5,364346	38	0,000004	5,364346	31,36835	0,000007	20	20	15,65763	9,524870	2,702304	0,035963	4,930159	38	0,032431	4,460530	38	0,041317

Fig. 8. The results of statistical variance and mean value statistical tests [own study]

The significance levels 'p' for homogenious variances tests in all cases were lower than 0.05. There were arguments for null hypothesis rejection (TLX variances for both variants are equal, $\sigma 2b = \sigma 2o$) and acceptance of alternative hypothesis (TLX variance without IREF is greater than TLX variance with IREF, $\sigma 2b > \sigma 2o$). In such case the T-student test value was determined for non-homogeneous variances and corresponding to it significance level 'p'. T students value was 5.36 and 'p' was 0.000004 what explicitly confirms significant difference between mean TXL values. Based on above it could be stated that application of intended exchange route functionality application in simulation trails had an impact on navigator's workload and consequently on safety of navigation.

CONCLUSIONS

The conducted experiment led to following conclusions:

1. The IREF (Intended Route Exchange Functionality) makes it possible for vessels in the vicinity to see other vessels planned track and adjust (or not adjust!) own navigation accordingly.
2. The workload (including stress) of navigator during decision phase of anti-collision manoeuvre with IREF is significantly less than without IREF.
3. The good ECDIS/GNSS/AIS performance (data fidelity) and fluency in their operation have been assumed which in reality can lower differences in the statistics obtained.
4. No verbal or electronic (VHF/AIS without IREF) communication regarding vessels' intended routes (either direct or coming from VTS) has been assumed which in reality can lower differences in the statistics obtained.

Eventually:

Simulated situation with IREF applied is rather ambiguous with respect to Colregs compliance. The questions arise:

Will Intended Route Exchange Functionality lead to Colregs contradictions?
Shall we update Colregs if such functionalities are implemented?

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