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Navigation Safety Assessment in the Restricted Area with the Use of ECDIS

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ABSTRACT: This paper presents an analysis of vessel safety parameters used in the ECDIS system while navigating in restricted areas. Apart from defining their priorities, a group of parameters indispensable for the safe navigation in restricted waters is identified.
The function of ship domain is proposed on the basis of safety parameters defined in the ECDIS system. This function may be utilized in the navigation decision support system that uses ECDIS data and included as a new function in the ECDIS system.

1 INTRODUCTION

The year 2012 will be the first year of mandatory installation of the Electronic Chart Display and Information Systems (ECDIS) onboard ships. The first installation requirements refer to newly built vessels, depending on their type and size. Then in the years 2016-2018 the regulation will come in force for ships in service. The navigator of the vessel under the mandatory requirements of the SOLAS Convention will receive an essential tool changing the rules of navigation, watchkeeping and assessment of ship's safety. This tool has alarm and indicator functions that provide important aid to the navigator. Its proper use requires a valid user-defined parameters of safe navigation and activation of selected alarms. A large number of applicable safety features causes difficulties in its use in navigation along a desired route. Therefore, it is advisable to specify a group of basic safety parameters as a minimum for the planning and safe monitoring of sea passage.

The analysis of alarms and related safety parameters was carried out on with ECDIS NaviSailor 3000i device by Transas Ltd. (Transas, 2004a, Transas, 2004b, Grzeszak et al. 2009)

It should be noted that not all alarms and safety parameters dealt with are mandatory according to the performance standards for ECDIS systems (IMO Resolution A.817/19 1995, IMO Resolution A.232/82 2006, Weintrit 2009). Some of them are introduced by manufacturers of such systems as part of enhancing their functionality.

2 ALARMS IN ECDIS

2.1 *Types of alarms*

There is a large number and variety of alarms, so they can be classified according to various criteria. The authors propose the division of alarms according to these criteria: 1) priority of the alarm, 2) possibility of activation and deactivation, 3) source, 4) the scope of the alarm, and 5) basic / others.

The first criterion divides the alarms into: a) alarms, b) indications . This division results from the provisions of IMO Resolution A.817(19), A.232(82) and IMO "Code on Alarms and Indicators" (IMO-867E). The state of the system requiring attention and action is signaled by an alarm in the form of acoustic or acoustic and optical signal. The state of the system requiring attention mainly of the user, without having to take immediate action, is indicated in the form of an optical indication only.

Among alarms implemented in ECDIS system the following are distinguished (criterion 2): a) the alarms that cannot be deactivated (e.g. Safety Contour, Depth Safety), b) alarms that can be deactivated (e.g, Sounder Depth, Anchor Watch), c) alarms that can be deactivated, but the user responsible for the safety protects them with a password. These alerts are activated in different ways, and some require implementation of the safety parameter in advance.

The division of alarms due to the source (criterion 3) includes alarms by: a) hardware, sensors) b) system. The former signal states of disability or reduced functionality of devices, including sensors of the system and the system as a whole, such as networking. The other group contains alarms associated with the implementation of functions relating to navigational situation. They signal a significant event for the safety of navigation.

The fourth division includes the proposed classification of alarms according to the criterion of scope of activities. This term is understood as the functions of alarms associated with the types of threats. These can be distinguished: a) antigrounding alarms b) alarms associated with the route of the ship – “Route alarms” c) Target / Radar alarms d) Area type alarms or "Area alarms" , e) other alarms; f) AIS alarms g) alarms and indications related to the scale and type of the chart.

Experiments conducted at the Maritime University of Szczecin during model ECDIS courses, resulting in issuing the ECDIS operator's certificate, show that course participants do not use many system capabilities, and also have problems with the interpretation of alarms and indications. This is mainly due to the different specifics of the work on the ENC as compared to working with paper or raster charts. Lack of understanding by the operator of the principles of interpretation of ENC content by the ECDIS system results in significantly reduced utilization of the system, and even the use inconsistent with the idea of the system. This involves the use of ECDIS system on the principles applied to classical paper charts, where interpretation of the contents of the chart lies belongs to the user only. It is connected with the fact in that during the process of navigator training primarily paper charts are still used. A better use of ECDIS systems requires, therefore, wider use of ENC in the training of navigators.

Table 1. Alarms classification criteria

Criterion				
Alarm type	Activation/ deactivation	Source	Scope of activities	Priority
1	2	3	4	5
a) alarm	deactiv. impossible	equipment, sources	anti-groun-ding	basic
b) indication	deactiv. possible	system	route	other
c)	deactiv. possible (password-protected)		target	
d)			area alarms	
e)			others	
f)			AIS alarms	
g)			chart alarms	

Significant help in the correct use of the system may be an additional division and allocation of alarms and indications (criterion 5): a) basic alarms and indications, necessary for safe voyage monitoring b) other, complementary to the previous one.

These criteria and the classifications of alarms are summarized in Table 1.

2.2 *Basic and other alarms*

Taking into account the above, an analysis of alarms and indications was performed according to the criterion of ECDIS scope of activities (criterion 4), with the proposal and explanation for the division into basic and other alarms (criterion 5).

The alarms in question are presented in Table 2., categorized by the groups of alarms identified in the ECDIS NaviSailor 3000i system.

Table 2. Groups of alarms according to the presented criteria (see Table 1).

Group of alarms/ indications	Location (ECDIS NaviSailor 3000i)	Criterion 1	2	3	4	5
antigroun-ding alarms	monitoring/ nav. alarms	a, b*)	a, b, c*)	b	a	a
	system	a, b*)	a, b, c*)	b	a	a
route alarms	monitoring/ route mon.	a	a, b*)	a, b*)	a, b*)	a, b*)
	system	a	a, b*)	a, b*)	a, b*)	a, b*)
target/ alarms	targets/ ARPA	a	a, b*)	a, b*)	a, c*)	a, b*)
	system	a	a, b*)	a, b*)	a, c*)	a, b*)
areas/ basic areas	monitoring nav. alarms	a	a	b	d	a
areas/ add. areas	monitoring nav. alarms	a	a	b	d	b
other alarms	monitoring/ nav. alarms	a	a	b	e	a, b
	system	a	a	b	e	a, b
	config.	a	a	b	e	a, b
AIS alarms	alarms/ AIS alarms	a	a	b	d	a
chart alarms	system	a, b*	b	b	g	a, b*)
	charts	a, b*	b	b	g	a, b*)
	monitoring.	a, b*	b	b	g	a, b*)

*) due to the diversity of alarms in the group, it was necessary to assign some of them to more than one group according to the criterion.

The group of "Antigrounding Alarms" contains: a) Nav. danger, b) Safety contour changed, c) Anchor watch, c) Safety contour, e) Safety depth, f) Ag monitoring off, g) Safety scale changed.

The group of "Route Alarms" contains: a) Off chart, b) End of route, c) Out of XTE, d) Behind schedule, e) Ahead of schedule, f) WP approach, g) Course difference, h) Prim / Sec diverged, i) Chart datum unknown, j) Prim. not WGS 84, k) Sec. not WGS 84, l) Track control stopped, m) Backup navigation, n) Low speed, o) Dangerous drift, p) Course change.

The group of "Target / Radar Alarms" contains: a) CPA / TCPA, c) Lost target, c) Guard zone target, d) Disk full save reset, e) Disk full adjust save, f) Head marker failure, g) Bearing failure, h) Trigger failure, i) AIS message.

The group of alarms "Area Alarms" contains 28 "Basic Areas" alarms and 14 "Additional Areas " alarms.

The group of "Other Alarms" contains: a) Timer went off, b) End of watch, c) Time zone changed, d) No official chart, e) Add info warning, f) Add info chart full.

The group of "AIS Alarms" contains: a) Tx malfunctioning, b) Antenna VSWR exceeds limit, c) Rx channel1malfunctioning, d) Rx channel 2 malfunctioning, e) Rx channel 70 malfunctioning, f) general failure, g) MKD connection lost, h) External EPFS lost, i) No sensor position in use, j) No valid SOG information, k) No valid COG information, l) Heading lost / invalid, m) No valid ROT information.

The group of "Chart Alarms" contains: a) Dangerous scale, b) Not recommended scale, c) Layers lost, d) Look up for better chart, e) Larger scale chart available, f) ENC data available, g) Chart priority / HCRF mode, h) Safety scale / check on larger scale than, i) No official chart (also included in "Other Alarms".

Basic alarms are considered as alarms which are important for the safety of sea passage. Among others, they include: commonly used collision warning, sounder depth alarm, lost target, cross track error - XTE. The newly introduced alarms for ECDIS systems which work on the basis of vector charts were considered as important. These include safety contour, safety depth, area alarm, navigational danger.

Selecting the basic alarms may facilitate their activation, and editing the safety parameters associated with them.

3 NAVIGATION SAFETY PARAMETERS

The effectiveness of alarms depends on the proper definition of safety parameters associated with them. These efforts should include the nature and circumstances of the area of navigation. A necessary condition is also their selective activation (except for system alarms), taking into account the type of area and navigational situation. Another problem, not analyzed in this article, is the selection of alarms to be activated reflecting the experience and knowledge of a specific sea area by the navigator.

The analysis highlights the safety parameters associated with the movement of the vessel on the surface and in the third dimension - depth and underwater hazards.

3.1 *Navigation safety parameters associated with the movement of the vessel on the water surface*

These parameters apply to both fixed and mobile objects that threaten the safety of navigation, also including parameters related to the navigation accuracy and maintaining the vessel's position and route.

CPA, TCPA. The basic parameters of this group are the Closest Point of Approach (CPA) and Time to Closest Point of Approach (TCPA), edited by the navigator and activating collision warning alarm. They cover both AIS targets (if the presentation is switched on) and the radar / ARPA objects. When the ARPA is connected to the ECDIS as its sensor, the limit values of these parameters can be edited independently in the ECDIS and the ARPA. In this case, the ARPA is treated as a system sensor for the ECDIS, which means that the alarm from system ARPA must be repeated in the ECDIS system.

Guard Ring (Rings), Guard Zone (Zones). Important safety parameters are the radius of the area of automatic acquisition or parameters that define the zone or zones of automatic acquisition. In the latter case they may be the values of angle sectors with inserted distance from the unit. These parameters, similarly to the parameters of CPA and TCPA can be edited independently in the ARPA and the ECDIS.

Area Vector. This is a vector representing time from the intersection of area type objects. Time setting, selected by the navigator, is represented as a vector calculated on the basis of a calculated COG and SOG. It may be displayed together with the Safety Vector. The navigator has a choice of area objects. The selection of area objects should be done depending on the crew experience and knowledge of the sea area.

RMS Circle (Root Mean Square Error Circle - at 95% confidence level). The parameter is calculated automatically by the system, but the novelty of increasing its relevance and practical use in ECDIS is introduced in a graphical presentation of the circle and the expected trajectory. This allows to verify the setting of parameter XTE.

Limit of Cross Track Error - XTE. This parameter is independently defined by the navigator to the left and right side of the route and may be different at each leg of the route. Its importance lies in the fact that it determines the width of the ship trajectory checked by the system (by using the "Check" function, checking whether the planned route exceeds or not the safety parameters set by user. Importantly, the automatic system " Track Control " (mandatory in ECDIS) will try to keep the ship within this limit.

Divergence in the primary and secondary positioning system. This parameter allows the navigator to monitor the difference in position of the vessel obtained from two positioning systems (generates optional alarm “Primary / Secondary Diverged”). In addition to activation, the user sets a limit of the distance at which positions from the main and secondary positioning systems can diverge.

Parameters related to the monitoring of the ship's planned route. These are course difference, WP approach, out of schedule, off chart, last WP passed. Incorrect setting of these parameters may cause a navigational accident.

Parameters describing the activation of functions related to charts to be used: priority of loaded charts (Chart Priority), and automatic chart loading "Chart Autoload". Improper use of these features can result in a lack of alarms specific to the ECDIS system (working with the charts other than ENC S-57 standard charts).

3.2 *Navigation safety parameters associated with underwater hazards*

Safety Contour. This parameter, defined by the navigator, is one of the most important safety parameters of modern navigation. The parameter possible for use in ECDIS only when the system uses vector charts. It generates an alarm of intersecting the safety contour. If the chart does not have a selected safety contour in its database, the system automatically sets the next higher (safer) contour.

Safety Depth. Parameter defined by the navigator. It extends the ability to detect underwater hazards found at depths greater than specified by safety contour.

Time from the intersection of safety contour - Safety Vector. The parameter is defined by the navigator. It allows designation and presentation of the "Safety Vector" on the basis of calculated COG and SOG.

Sounder Depth. Parameter defined in the echo sounder as a sensor of ECDIS system. This means that the alarm will be repeated in the ECDIS system. This allows the verification of depth, read from the ENC.

Navigational danger ring radius. It defines a circle of safety "Navigational Danger Ring". This enables the detection of underwater hazards on the basis of ENC. It also allows detection of: a) Navtex objects that have the attribute "Danger" added, b) objects inserted by the user as "User chart object" or "Manual correction object" which was given the attribute "Danger" and / or inserted depth less than the "Safety Depth ".

3.3 *Other safety parameters*

Safety scale. Parameter defined by the user. It determines the chart scale for checking safety contour and safety depth. It means that the system will monitor underwater hazards on charts with a scale larger than that determined (Fig. 1).

Differential mode lost. The time for which signal is lost from the DGPS reference station. The excess value of this parameter generates an alarm. This is important because of the decline in accuracy of fixing the position from DGPS to GPS.

Display category imaging. This parameter defines the scope of the presented on-screen navigation information: Base, Standard, Custom, All.

Shallow Contour and Deep Contour (Fig. 1). The parameters are defined after the function “Four Shades” is activated to present additional areas of shallow water (Shallow Contour) and deep water (Deep Contour). The function modifies the displayed chart by creating four depth areas with different colors.

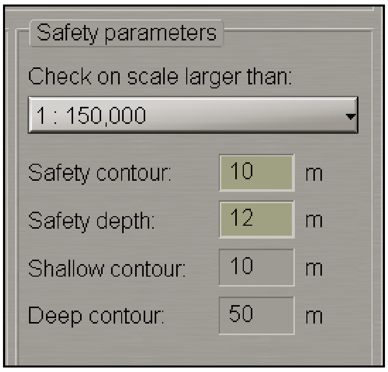

Fig. 1 Safety parameters window (safety contour, safety depth and safety scale)

3.4 *The basic safety parameters*

The analysis of alarms and safety parameters, their location in the ECDIS system and the consequent difficulty of access to them makes it advisable to introduce the function “Basic Safety Parameters Settings”. This function would allow the operator, in one tab or window, to define and monitor the basic safety parameters, and activate alarms necessary to ensure safe voyage realization by the ship equipped with ECDIS. It should include viewing and editing, and the activation state of alarm associated with them. These are:

1 safety contour,

2 safety depth,
3 safety scale,
4 chart display category,
5 „chart priority”,
6 CPA/TCPA,
7 cross track error – XTE,
8 course difference,
9 WP approach,
10 safety vector (advance in the intersection safety contour),
11 area vector (advance in the intersection of area objects),
12 Navigational Danger Ring, its radius,
13 chart display and ship's motion (North Up, Head Up, Course Up, Relative Motion, True Motion)
14 difference in the position of the vessel from primary and secondary positioning system (Primary / Secondary diverged),
15 presentation of AIS targets (on / off),
16 presentation of ARPA objects (on / off),
17 special areas detecting defined (yes / no),
18 presentation of the COG (course over ground) and COW (course over water) vectors (on / off),
19 off chart (on / off).

Before the start of a voyage or when the system is restarted, ECDIS should automatically require the operator to define or confirm the values of these safety parameters with the possibility of automatic switch to the window where the operator activates and edits that alarm.

4 SHIP DOMAIN

4.1 *Ship domain as a safety criterion*

Safe operation of the ship requires constant analysis and evaluation of the situation. On this basis navigator undertakes decisions concerning navigation. The analysis and assessment of the situation are carried out in accordance with the criteria adopted by the navigator. A commonly used criterion in collision avoidance systems is the closest point of approach. However, in the case of navigation in restricted waters, particularly in narrow fairways and channels, it is difficult to apply in most cases. This is due to the lack of free choice of route and the need for compliance with safety rules, taking into account local conditions (restriction of one of the three dimensions defining the distance of the ship from other objects).

An alternative to the mentioned criterion of the navigational safety is the criterion of the ship domain. Application of the criterion of ship domain enables quick identification and assessment of the navigational situation and thus developing the decision support in ship's maneuver. It should be noted that this criterion is also possible to use in the open sea areas. For example, this criterion was implemented in the prototype of navigational decision support system for seagoing vessels developed at the Maritime University of Szczecin (Pietrzykowski et al.2009).

The concept of ship domain was introduced in the 1970s (Fuji & Tanaka 1971, Goodwin 1975). It is assumed that the domain is an area (domain two-dimensional) or space (three-dimensional domain) around the vessel which should be kept clear of other objects.

Assuming a certain level of discretization of relative bearings (eg $\Delta\angle K = 1°$), the domain boundary of the vessel B_{DS} is described by a curve passing through the n points p_{Di} ($i = 1,2,..., n$), located on the relative bearings $\angle K_i$ at the distances d_{DSKi} from centre of the vessel (eg, centre of waterline):

$$B_{DS} = \{p_{D1}, p_{D2}, ..., p_{Dn}\} \qquad (1)$$

Ship domain boundary D_S at different bearings is then described as follows:

$$D_S(\angle K_i) \le d_{DSKi} \qquad i = 1, 2, ..., n \qquad (2)$$

The basic problem is to define the domain boundary, dividing the area around the ship into sub-areas: dangerous and safe. It is a difficult task because the shape and size of the domain are affected by many factors. These include: size and maneuverability of the vessel, parameters of the area where the ship maneuvers, hydro-meteorological conditions, vessel speed and the speed of other vessels, the intensity of vessel traffic in the area, the accuracy of position fixing, training level, knowledge and experience of navigators. Also significant is the adopted method of determining the ship domain boundary.

The issue of determining the domain was presented in many publications, including (Fuji & Tanaka 1971, Goodwin 1975, Coldwell 1983, Zhao et al. 1993, Smierzchalski & Weintrit 1999, Pietrzykowski 2008, Pietrzykowski & Uriasz 2009, Wang et al. 2009). There are two-and three-dimensional domains proposed in the literature. The former describe the area around the ship. Domains of two-dimensional shapes include circle, rectangle, ellipse, polygon, complex plane figures. In the case of three-dimensional domains - they describe also vertical space included between ship and sea bottom and the air draft of the ship. Their shape often corresponds to sphere, ellipsoid, cylinder, truncated cone.

Among the methods of determining the ship domain one can distinguish three groups: statistical methods, analytical methods and artificial intelligence methods. It is characteristic for all these methods that they make use of navigators' knowledge, both procedural and declarative.

Application of statistical methods requires the registration of relevant data. In addition to difficulties in collecting them, the problem that arises is to separate various factors that influence the shape and size of the domain.

Analytical methods are based on the analytical description of the domain space. These methods ensure precise description of the ship domain. The main difficulty is to take into account and balance all relevant factors affecting the shape and size of the domain.

Methods of artificial intelligence (AI) were developed to acquire and use the knowledge of expert navigators using the tools of artificial intelligence. They include and use, *inter alia*, fuzzy logic, artificial neural networks and evolutionary algorithms.

4.2 *Possibility to define a domain based on the safety parameters in the ECDIS*

Safety parameters available in the ECDIS system do not define directly a ship's domain. These authors analyzed the possibility of identifying the two-and three-dimensional domain using the parameters analyzed in the article. The problem was brought down to the determination of the length, width and shape for two-dimensional domain, and in the case of three-dimensional domain additionally the depth and shape of the geometric solid.

If we use the CPA parameter value to determine the length of the domain D_L then the length of the domain takes the value

$$D_L = 2CPA \tag{3}$$

This results from the fact that this parameter defines a safe distance at which other vessels pass, is widely used, and its interpretation is unambiguous.

Due to the difficulty in determining the safety parameter indicating the width of the domain designation was proposed based on the analytical relationship between the length and width of the domain. This relationship can be derived on the basis of ship domain analytical descriptions proposed, *inter alia*, in (Coldwell 1983, Zhao et al. 1993, Smierzchalski & Weintrit 1999, Pietrzykowski 2008, Pietrzykowski & Uriasz 2009, Wang et al. 2009):

$$D_W = f(D_L) \tag{4}$$

The simplest figure describing the domain of the ship on the basis of the parameters (D_L, D_W) is a rectangle. Taking into account the results of statistical research on the shape of the domain, the domain was proposed in the shape of an ellipse inscribed in a rectangle with sides (D_L, D_W).

The parameter BCR- bow crossing range can be an alternative to the CPA safety parameter, used for describing the length and, consequently, the width of the domain.

ECDIS system gives definitely a lot more opportunities for determining the domain of the third dimension - depth D_D (three-dimensional domain). The parameter defining the third dimension of the domain can be safety contour or properly set safety depth. It seems to be necessary to use safety depth, which results from a broader range of hazards analyzed by the system for that parameter.

Then a three-dimensional domain is described as a solid with two bases in parallel planes. The upper base is an ellipse (two-dimensional domain). The bottom base is a circle defined by the radius D_R of navigational danger ring. The circle origin is an orthographic projection of the ellipse origin. The side surface of a geometrical solid is a section of the plane connecting the two bases with the smallest surface area (Fig. 2).

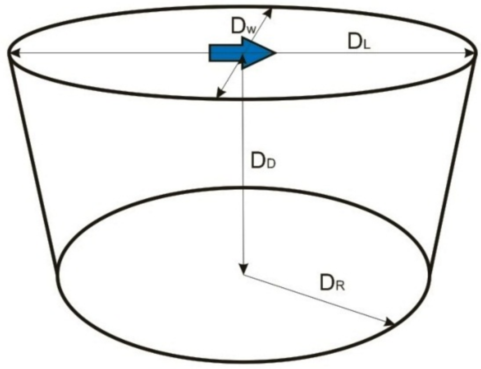

Fig. 2 Three-dimensional domain

When the domain function is implemented in the ECDIS, the domain parameters (D_L, D_W, D_D, D_R) will be generated automatically as a default with the possibility of correction by the navigator (like other safety parameters).

5 CONCLUSIONS

Based on analysis of alarms and indications of ECDIS system and safety parameters defined by the navigator, the group of basic parameters necessary for the safe sea passage was proposed particularly for use in restricted areas. These parameters will be available after activating the "Basic Safety Parameters Settings" in an additional window. This allows the navigator to set alarms, activate them and define the safety parameters necessary to ensure safe sea passage of the ship equipped with ECDIS. When the solutions herein proposed are implemented by manufacturers and positively verified by navigators in practice, it will be recommendable to consider options for revising the performance standards for ECDIS systems.

Due to the limited capacity of the CPA parameter to be used in the safety assessment when navigating in restricted areas, these authors considered the possibility of defining the ship domain as a safety criterion in the ECDIS system. The definition of two- and three-dimensional ship domain based on the safety parameters defined in the ECDIS system is proposed.

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