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Risk based model of information optimization in maritime electronic chart application

Keywords

navigational risk, information optimization, navigation chart

Abstract

The paper is concerned on a statistical approach to the solution of practically very important problem, of risk based criteria's, in field of testing and development of a sea electronic chart. Criteria estimation in human - computer systems is difficult, and not in every case might be satisfactory. In many cases wrong criteria estimation might occur in inapplicability of whole system. In paper author copes with universal model of information optimization for navigation chart system using example of pilot navigation system.

1. Introduction

Safe passage of vessel at confined area depends on several phenomena's that occurs during dynamic movement. These phenomena's are described by marine traffic engineering (MTE) and particularly these are: safe maneuvering of vessel by means of its destination with acceptable movement risk level.

Practically MTE leads to choose of most efficient maneuver for given vessel type at given area and in given conditions. Researches over navigator-vessel-environment system are indispensable for decision making support systems construction. These systems contribute to increase of safety level at area. Information provided by such system must have following attributes [2]:

- be sufficient for safe performance of given maneuver;
- displayed in optimal way that may be used directly by operator.

These assumptions could be fulfilled by:

- minimization of information required for safe performance of planned maneuver;
- such visualization of these information which allows operator to transform it to rudder and propeller settings without diversion of operator.

Although optimal visualization is very complex some elements are crucial for its safe improvement usability. These are chart and user interface.

Navigation in restricted waters is often referred to as pilotage or pilot navigation. In the process of navigating in restricted waters, because of the fast changes in the vessel's position in relation to objects ashore, the observed and the reckoned positions are not marked on the chart, as in navigation in unrestricted and coastal areas. The vessel's position is determined in the mind of the pilot or the master conducting the ship. In the process of conducting pilot navigation the pilot can be supported by the PNS (Pilot Navigation System).

2. Assumption of investigated system

Currently, there are a few solutions of pilot navigational systems produced in the world. These systems are constructed on ECS basis (systems of electronic charts) or ECDIS (systems of imaging electronic charts and navigational information), the latter being a detailed development of the former. Their common characteristic is the vessel imaged on the electronic chart in the shape of an outline called "conventional waterline". The accuracy of the PNS depends on the positioning system applied and ranges from 1m to 20m.

The basic faults of the PNSs currently produced are [2]:

- the information presented is not the optimal information which causes it not to be taken advantage of in the utmost degree and there are

difficulties with its being absorbed by the pilot;
- lack of special images useful in pilotage navigation, like: in relation to the shore, in relation to the fairway axis;
- lack of optimal user interface;
- lack of a maneuver prediction system.

These faults result from the systems being only modernizations of the systems functioning in unrestricted water areas (ECS or ECDIS) for the needs of pilotage, and were not worked out by scientific methods.

A team of scientists from the Navigational Department of the Maritime University of Szczecin, within the framework of a project co-financed by the Ministry of Education and Science, undertook to work out the optimal solution for a pilotage navigational system, making use of scientific methods of constructing navigational systems. As a result of research carried out, two PNS prototypes emerged:
- a stationary one, designed for sea ferries,
- a portable one, designed for pilotage.

Following elements make up these systems:
- subsystem of electronic charts,
- positioning subsystem,
- information processing and imaging subsystem.

Construction of model for described system is constrained be the following:
- size of system,
- accuracy of solution,
- reliability of solution.

Size of system is defined by amount of subsystems and applied functions for complete solution. Available information os determined by the size of system. Accuracy of system is defined by positioning receiver. It determines the quality of information available in given system, and it is possible to implement following subsystems (categorized from least accurate to most):
- GPS,
- DGPS,
- WAAS GPS,
- RTK GPS.

3. Target function for information optimization

Optimization process for universality requires formal mathematical notation. It is assumed that:
- different types of sea areas are taken into account where $a \in \mathbf{A}$, and a is sub type of area like entrance to port, passage etc.
- at area different types of vessel i might maneuver, $i \in \mathbf{I}$; division on ins in size and type of vessel,
- vessel at area might perform one of maneuver types j that are in set $j \in \mathbf{J}$; and maneuvers are: entrance to port, rotation, passage,
- presented information l is from available set of information $l \in \mathbf{L}$,
- there are k types of information, $k \in \mathbf{K}$,
- vessels might maneuver in navigation conditions n from set, $n \in \mathbf{N}$;

Definition of optimization task requires definition of decision variables and target function. Decision variables are:
- type of vessel i,
- type of maneuver j,
- presented information l
- form of information k,
- navigational conditions n.

Thus navigational information for area a is represented by set of matrixes χ_a with dimensions I×J×L×K×N. Matrixes are used for safe passage of vessel on area a. Optimization task might be represented by question: obtain the matrix $\mathbf{X_a} \in \chi_a$ with elements: $x^a_{i,j,l,k,n}$ of values 0 and 1. Where 0 is for omitting and 1 for taking into account decision variable such that the sum of its elements is minimum, i.e.

$$F(\mathbf{X_a}) = \sum_i \sum_j \sum_l \sum_k \sum_n x^a_{i,j,l,k,n} \to \min, \qquad (1)$$

with restriction,

1. $R_a(\mathbf{X_a}) \leq R_a^{dop}$
2. $Q_a(\mathbf{X_a}) \leq Q_a^{dop}$
3. $Z_a(\mathbf{X_a}) \leq Z_a^{dop}$

where:

$a \in A,\ i \in I,\ j \in J,\ l \in L,\ k \in K,\ n \in N,$

$\mathbf{X_a}$ – Matrix of information used ina given system for safe performance maneuvers AT Niven area a;

R_a – Navigation risk of performance given j-th maneuver by i-th ship in k-th navigation conditions at area a;

R_a^{dop} – Admissible navigation risk at area a;

Q_a – Information related with position of i-th vessel at area a, Turing performance of manuver j-th in k-th conditions;

Q_a^{dop} – Maximum amount of information that captian or pilot can use for maneuvering at area a;

Z_a – Cost of support system implantation at area

a;
Z_a^{akc} – Acceptable cost of support system implantation at area *a*.

Solution of this task is matrix X*a, that minimizes value of target function (1).

3.1 Information optimization task in pilot navigation system

Presented in 3 optimization task demands large amount of decision variables: types and ranges of navigation information that are available on vessel and possible presentation forms. This element is related to the Reed of determination of all permissible solutions and criteria within identified decision variables. Opposition of these criteria puts optimization task to area of multicriteria optimization tasks; thus problem of target function arises, and whole problem must be reduced to single criteria optimization, where each function has own wages. It especially is desired for navigation risk criteria, defined as partially single criteria; and these are: width of traffic lane, distance of anchor drop, vessel speed etc. Alternatively problem could be defined in two tasks:

1. assessment of minimal navigation information required for safe performance of maneuver ;
2. optimization of information form to determined, finite set of admissible solutions.

Such definition lets reduce area of admissible solutions, helps statement and verification of target function, and reduces time consumption in optimization ie. whole solution of problem.
Realization of 1. is typical minimization process in field of navigation information. This task can be achieved with use of expert knowledge. Expert elicitation allows to restrict whole area of solutions to those ones that are used by experts in navigation process. And relating to previously used symbols, this task is determination of matrix $\chi_a^{'}$ subset so that: $\chi_a^{'} \subset \chi_a$.
Realization of 2 is determination of matrix $X_a \in \chi_a^{'}$ with elements $x_{i,j,l,k,n}^{a}$, minimizing target function determined by collision risk at given area *a*, with restrictions previously stated. Assuming that $m \in \mathbf{M}$ partial criterias were used, optimization task can be written as:

$$F(\mathbf{X_a}) = R_\mathbf{a}(\mathbf{X_a})=\{f_1(\mathbf{X_a}),\ f_2(\mathbf{X_a}),\ f_m(\mathbf{X_a}),\ \ldots,\ f_M(\mathbf{X_a})\} \rightarrow \min$$

with restrictions:

1. $f_m(X_a) \le R_{am}^{dop}$
2. $Z_a\,(X_a) \le Z_a^{dop}$

for

$a \in A,\ i \in I,\ j \in J,\ l \in L,\ k \in K,\ n \in N,\ m \in M$

where:
X_a – Matrix of information used ina given system for safe performance maneuvers at given area *a*;
R_a – Navigation risk of performance given *j*-th maneuver by *i*-th ship in *k*-th navigation conditions at area *a*;
f_m – m-th partial criteria of global target function;
R_a^{dop} – Admissible navigation risk at area *a*;
Z_a – Acceptable cost of system impelentation at area *a*; koszt budowy systemu na akwenie *a*;
Z_a^{akc} – Acceptable cost of system impementation at area *a*.

Partial criteria $\mathbf{f_m}$ are maneuvering safety criteria commonly used in Marine Traffic Engineering. Presented solution in formulation of optimization task, used in technical system development, lets to reduce time and costs of prototype implantation; and here is used for Pilot Navigation System.

3.2. Optimization method for pilot navigation system.

Optimization method for pilot navigation system development consist of:

- preliminary definition of assumptions – expert researches:
  - analysis of user requirements,
  - determination of user tasks performed in system,
  - definition of main system algorithms,
- identification of usability factors;
- construction of parallel system models;
- construction of computer based model system and simulation researches;
- analysis of simulation researches;
- improvements in system based on researches;
- consistency assessment;
- implementation of system on sea ferry – real researches – validation.

3.3. Formulation of optimization task

General optimization task presented in 3.1 is very demanding in practical use, although all input parameters are well described. The reason is large differentiation in performed maneuvers, and criteria used to asses it. Basing on experiences from marine traffic engineering it could be stated that each maneuver shall be assessed individually. And following discretation of maneuvers types ($j \in$ J) is used:

1. anchoring maneuvers;
2. fairway entrance maneuvers;
3. fairway passage maneuvers and port entrance maneuvers;
4. mooring maneuvers.

For each maneuver type following assessment criteria were used:

Type of maneuver	Criteria used and unit
Anchoring manuver	1. Distance of dropped anchor to given point [m] 2. Speed of vessel in anchoring point[kts] 3. Time of anchoring[s]
Fairway entrance	1. Distance of entering fairway from given point [m] 2. Time of entering the fairway [s]
Fairway passage maneuvers and port entrance maneuvers	1. Traffic lane width
Mooring maneuvers	1. Energy induced in first contact point [J] 2. Distribution of first contact point on quay [m]

Such formulated optimization task is multicriteria task with different partial criteria functions. Solution from each type of criteria is treated individually so:

$$f_{jm}^{*} = f_{jm}(\mathbf{X_j}^{*}) = f_{jm}(\mathbf{X_j}) \rightarrow \min \qquad (2)$$

where:

j – type of maneuver; $j \in$ J,
m– number of partial criteria; $m \in$ M.

Algorithm of proposed optimization task is presented at *Figure 1*.

4. Application of proposed method

Proposed method was applied for all presented in 3.3 maneuvers, although for purpose of this article only maneuvers of fairway passage were presented.

In this type of maneuver (indexed in researches as j=3) criteria were based on traffic lane width, and especially partial criteria of: mean traffic lane width (m=1) and maximum traffic lane width (m=2)

$$f_m^{*} = f_m(\mathbf{X_j}^{*}) = f_m(\mathbf{X_j}) \rightarrow \min$$

Assessment method is based on estimation of particular navigation chart orientations during this type of maneuvers, that lets determine optimal solution by means of m-th criteria. Assuming $\chi_j^{'}$ as finite set of orinations variants i.e.:

$$\chi_j^{'} = \{ \mathbf{X_{j1}, ..., X_{jn}, ..., X_{jN}} \}$$

where: N is number of analyzed variants of orientations, set of measurable partial criteria for presented type of maneuver can be defined as:

$$\mathbf{F}=\{f_1(\chi_j^{'}),\ f_2(\chi_j^{'}),\ ...,\ f_m(\chi_j^{'}),\ \ldots,\ f_M(\chi_j^{'})\}$$

Thus, **N** variants are compared to **M** (M=2) criteria [1]. Variants (N) are determined by expert researches means.

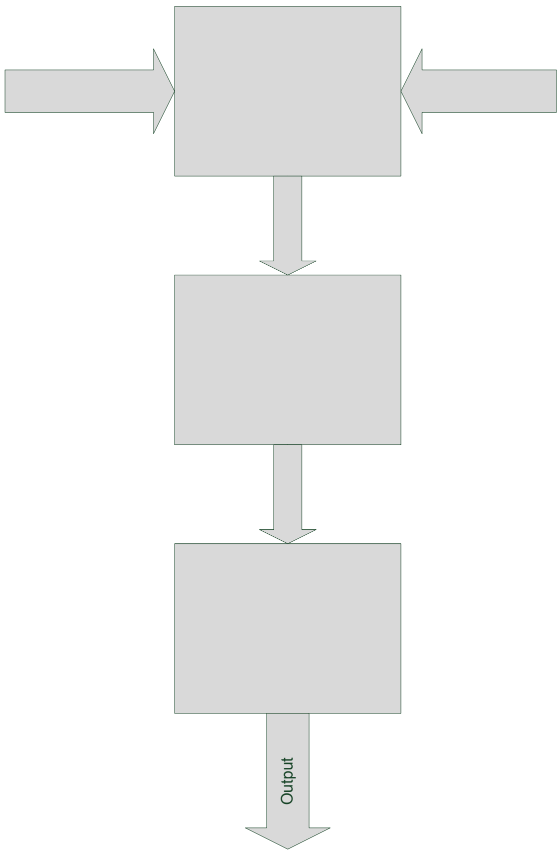

Figure 1. Algorithm of optimization task in pilot navigation system

5. Conclusion

Maritime chart system and especial case of it as pilot navigation system is demanding application, where risk based criteria shall be used. Author presents novel method of information optimization for PNS purposes. Such method might be used to asses particularly any technical system for maneuvering support like: berthing systems, laser mooring system etc.
Proposed system is now being produced for sea ferries cruising on Baltic Sea.

References

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