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INFORMATION AS AN ELEMENT OF THE NAVIGATION DECISION-MAKING PROCESS

Summary. The operation of vehicles (watercraft, aircraft, land-based, spacecraft, unmanned) requires the use of navigation systems for their control. These systems can be characterized by varying degrees of complexity and technological advancement. However, each system has sources of information about the state (position) of the navigating object, state of the environment in which the object is moving and the task to be accomplished. These components are integrated by the decision-maker (human or automated), who/which makes and implements decisions adjusted to current conditions.
Keywords: safety of navigation.

1. INTRODUCTION

Navigation is an area of human activity at sea. It is considered an art, an element of ship management or a series of operational activities undertaken by engineers, as well as one of the scientific disciplines. It is generally agreed, however, that it is a utilitarian science, which has existed since the dawn of maritime civilizations.

Today, navigation is regarded as a complex process of controlling (conducting) a vessel along a determined trajectory, following a voyage plan and executing tasks. It is a dynamic

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phenomenon because of the variability of external conditions and possible changes of tasks being performed; thus, it also contains in itself a decision-making process.

The navigation process is composed of subprocesses. Generally, they can be categorized as follows [1, 2]:

- acquisition of necessary and additional information ensuring the safety of navigation or supporting the execution of the voyage: it includes measurement and data sources (nautical publications, electronic databases)
- preparation of a voyage plan: processing of navigational information and guidelines on the voyage
- monitoring the trajectory, which includes a number of tasks: determining the status of the implementation of the planned trajectory (position coordinates, velocity vector of the ship, deviations from the planned trajectory etc.), vessel position in relation to navigational dangers
- proceeding along the trajectory, which is steering the ship, making decisions on changes to the voyage plan

By its nature, navigation as the decision-making process is largely based on information, the quality of which has a significant impact on the safety and efficiency of human activities at sea.

Navigational accidents lower voyage economic indicators, reduce the safety of navigation or may even prevent the execution of a ship's tasks. Basic causes of navigational accidents related to the quality or quantity of navigational information are as follows:

- lack of information
- outdated or incorrect information
- insufficient accuracy of the information

To properly execute the navigation process on the ship, one must carefully consider each of the subprocesses, take into account the different categories of navigational accidents (through their elimination or considerable reduction) and incorporate it into the relevant criteria of the ship. This issue is very complex and so far has not found a full and satisfactory solution. Problems related to the quality of navigational information and human factors are commonly encountered in most ships and shipping areas.

2. DECISION-MAKING

We make choices in many different situations, which is why we make decisions. These situations are called decision-making situations and the person (or system) making decisions is the decision-maker. In general, the decision-making situation is a description of the conditions, limitations and purpose of making a decision. However, we can rarely make just any decision. The actual situation often imposes limitations on the choice, as we have to take into account the so-called limiting conditions. The decision that meets the limiting conditions is called the admissible decision. Not every admissible decision generates the same effects. From the point of view of the objectives pursued by a decision-maker, decisions can be better or worse. Therefore, we need to choose the best decision for a given criterion: the optimal decision. This criterion is called the choice (assessment) criterion.

The decision-making process can be divided into the following stages [8]:

- formulation of the decision problem

- construction of a mathematical model or its simulated analogue version (stage of formalization of the problem)
- acquisition and processing of output information necessary to determine the model parameters (model identification)
- calculation procedures or simulations using a selected algorithm
- qualitative analysis of solutions
- model verification (relevance check, validation)
- implementation of the solution

There are various methods of decision-making. These include [5]:

1. Receptive methods - These are given to every human by nature or acquired in the learning process, for example, instinctive actions, trial and error, habit and routine, standard, experience, personal knowledge, character and experience exchange.
2. Associative methods - Their essence is the intuition of a person or group of people. The methods included in this group are characterized by unfettered thinking, imagination, curiosity and human creativity, such as brainstorming, fictions or thought experiments.
3. Methods of collecting and ordering - They are distinguished by problem presentation in an ordered form by the systematization of structures or concepts, e.g., a decision tree, the search for synonyms, classification, group training and so on.
4. Combined methods - These contain elements of the previous methods. These combinations make it possible to achieve other quality features, which is very useful for very complex decision problems. The methods include psychodrama, thesis-antithesis-synthesis, projection, the “devil’s advocate” method etc.
5. Deductive methods - These are characterized by the tendency to logically organize structures and concepts. The essential ones are strict definition, analysis, abstraction or formula, while other methods in this category are identification of causes, dividing problems into partial ones, decision tables, analysis of costs and restrictions, etc.
6. Mathematical models - These include the “black box”, deterministic models, probabilistic models, fuzzy models, simulation, extrapolation, sociometry, transport algorithms, econometric methods, optimization methods etc.
7. Inductive methods - These include schematic diagrams, matrices of hypotheses, network methods, experiments and SWOT analyses.
8. Integrated methods - These combine some features of the above methods and include value analysis, integrated information management systems, the Kepner-Tregoe method, cost-benefit analysis.

Ship management is based on the autocratic-hierarchical system. As a result, in order to eliminate the human factor, which is the main cause of navigational accidents, decision-making methods, subject to automation, are used; these are mainly mathematical and related modelling and expert methods.

Every decision-making process is based on information. Its quantity, relevance to the present situation, timeliness and other attributes significantly affect the decisions and the consequences.

In line with the nature of the acquired information, we deal with deterministic models, models in terms of randomness (risk) or under conditions of uncertainty. In deterministic models, parameters are known and constant (or change in a known manner). In case of risk models, distributions of random variables are given. In models with uncertainty, input data distributions are not known. These models also refer to rules of enemy behaviour in a conflict (e.g., in game theory).

The navigational situation is a specific kind of a decision situation. The identification of a navigational situation consists of its formal description, thereby enabling an analysis. The navigational situation is characterized by its space-time variability. You can assume that an assessment of a navigational situation is a dynamic change in the decision situation, i.e., limiting conditions, which impose a different set of admissible decisions.

3. INFORMATION AND NAVIGATIONAL SITUATION

A piece of information is a factor with which the receiver (human, another living organism, organization, automatic device) can improve their knowledge of the environment and improve their deliberate actions. It is usually believed that information is directed specifically to someone. That is not quite true because conclusions drawn on the basis of data, obtained from the environment in the process of research, archives (databases) or elsewhere, are also information.

Taking into account the practical considerations, information must have the following characteristics:

- exist
- be credible, not misleading
- withstand disturbances
- be available (able to be transmitted)
- allow for reasoning and making decisions

Maximized use of information is important in decision-making, not just in terms of its storage. When not used, information becomes useless.

Information is knowledge obtained by interpreting data, which in a fixed context have a specific meaning and refer to entities, such as facts, events, phenomena, processes and ideas.

Data are a representation of information, suitable for communication, interpretation and processing. Data take the form of alphanumeric characters, including digits and letters (more generally, literals, which include alphanumeric and special characters), symbols, images and other forms of records comprehensible to humans, or applicable to computer processing or transmission. Computer data frequently occur in the binary form. Data themselves are meaningless, only by interpretation (human or computer) do they become information that can be used to enrich knowledge.

Navigation takes place in a specific physical space (geographical), hence its geospatial reference. Geospatial information is obtained by the interpretation of geospatial data [6].

Navigational information is a special case of geospatial information, which contains essential information about navigating and other objects, the latter either being helpful to or interfering with the movement of the navigating object.

Navigational information can be divided into four subsets associated with the respective objects:

- information related to the ship (its technical parameters and dimensions, manoeuvring characteristics, i.e., the dynamics of the ship, autonomy etc.)
- information about the sailing area and its geometry (geographical location, fairway size, bathymetry, distance to navigational hazards etc.)

- information on hydro-meteorological and climatic conditions (wind, currents, waves, icing etc.)
- information on the infrastructure at sea and on adjacent coastline (including aids to navigation, equipment, communications, logistics, legal status etc.)

Navigation information helps identify a navigational situation, which is understood as a reciprocal space-time location and an interaction of the navigating object, the environment (its state is a hydro-meteorological and an astronomical situation) and other objects affecting navigation (navigational dangers, e.g., collision situation, aids to navigation etc.).

4. ATTRIBUTES OF NAVIGATIONAL INFORMATION

Navigational information has specific characteristics and is characterized by space-time variability. We can identify some of its properties, which enable us to categorize it by quality and quantity. The most widely known are accuracy criteria of navigational information. However, the accuracy measures themselves do not fully reflect the practical or theoretical usability of this information. Navigational information as space-time information has some attributes (properties), the most important of which are given below [3, 4]:

- accuracy
- repeatability
- precision
- resolution
- variability
- timeliness
- reliability
- availability
- completeness
- validity
- cost,
- value

Each of these attributes is described below. The practical role of each attribute is different, but they can be used in multi-criteria analysis of different sources of navigational information.

All measurements, regardless of the conditions and measuring instruments, are characterized by errors, caused by several reasons, which can be divided into the following basic groups:

- imperfection of equipment and measuring instruments
- imperfection of measurement and data-processing methods
- variation of measurement conditions
- imperfection of the observer's senses

The imperfection of equipment and measuring instruments is caused by the difference between the theoretical model (physical or mathematical) of the fabricated device. Variable conditions of performing measurements, as well as both external (environment) and internal changes in physical parameters of measuring devices, are major causes of errors. Continuous changes of the environmental, hydro-meteorological and astronomical conditions significantly affect direct observations and navigational measurements (which take optical bearings, measurement of the height of celestial bodies, horizontal and vertical angles).

Generally defined, accuracy is a distance from the true or real value. This feature applies primarily to attributes of navigational data. Accuracy is determined by random, system and absolute errors. The accuracy of a navigational parameter is characterized in relation to its real value or the average (expected) value.

Repeatability of navigational parameter measurements is understood as the statistical conformance of measurements of the same navigational parameter when measurements are performed:

- using various methods
- with different navigational devices (systems)
- by different observers, in case of non-automated measurements
- under different conditions
- at relatively long time intervals compared to the duration of a single measurement

Repeatability characterizes the possible extent to which we can determine the correct (or real) value of a quantity, regardless of the applied measuring instrument, device or system. It is thus the broadest concept defining the possibility of making measurements of a given quantity and corresponding accuracy. However, we are interested not only in measurement results, but also to what extent they are correct and what their range can be.

The precision of measurements is another concept often confused with accuracy. This is particularly the case when we are not aware of the presence of significant system errors, which hinder assessment.

The repeatability of measurements is therefore the internal measurement conformity of the navigation device (system). It is sometimes called repeatable accuracy. The repeatability of navigational measurements is estimated using average error (or variance) in the case of scalar parameters or error ellipses, circular errors, and covariance matrix determined empirically for the device (the system) under specified measuring conditions. The measurements' precision characterizes repeatability.

In general, precision means accuracy in relation to the average value of a given quantity. Sometimes, however, the term *precision* is viewed as the number of digits that are significant in a numerical record or to read-out accuracy on the measuring scale.

In spatial information systems, including navigational systems, the concept of repeatability also includes mutual conformity of data:

- recorded at the input
- presented at the output

This necessitates elimination of generating errors (disturbances, data distortion) by the data-processing system.

By the term *resolution* (differentiation), we mean the ability to detect or differentiate subsequent levels of the value of data in question. Resolution is also the smallest distinguishable piece of an image, i.e., the pixel, e.g., of a map, or the coordinates calculation unit, e.g., 0.0001' in the DGPS. As we see, this notion can often be confused with the precision of measurements and instrumental errors.

As a measure of variability, we assume the average time frame, after which the value of this attribute changes in reality. The variability of some navigational parameters is relatively easy to determine, such as position coordinates or components of the velocity vector in the case of continuous measurements (or frequently performed). In other cases, we may not be aware of the variability of navigational information, as evidenced by cases of navigational accidents caused by a dredging anchor, i.e., the deviation from a safe position (apart from situations caused by humans, although, in this case, too, we deal with the variability of navigational information). Unlike the data in commonly used geographic information systems, navigational information is highly variable; and, in the case of air and space navigation, the variability is substantially greater.

The concept of information variability is closely linked to its timeliness or validity. The validity time is the interval between the moment of inputting an attribute value change to the system and the time of the next change in attribute value. The data received during that period are valid. The data out of this time span are invalid. The period of variation is the difference of instants of subsequent changes to attribute values; this refers to discrete (step) measurements or to a situation where the parameter itself is a discrete quantity.

The determination of information reliability is related to major terminological problems. These result, for example, from what is commonly understood by the term *reliability*. Navigators are familiar with the term *integrity* associated with the GPS. The reliability, or should we say, integrity of the system is differently understood by IT specialists. Thinking of a human as a source of information, we assume that he is trustworthy if he does not fail our trust; we can just believe him. However, it takes time before we start to trust a man. We deal with a similar type of reliability in the case of nautical publications, which are authorized by hydrographic offices. Such publications require updating by introducing valid information corrections provided by the publishers. However, in relation to navigational equipment and systems, especially to rapidly changing nautical information, the trust ought to be of a different nature and differently justified. Reliability is intuitively associated with the concept of the uncertainty of information.

The uncertainty of information is marked by the following terms: *probable, possible, necessary, plausible* and *credible*. Everything that can be inferred from a collection of factual knowledge is credible. The problem is how to practically verify the trustworthiness of received information. We deal best with probabilistic types of information. It is harder when it comes to the assessment of information, when burdened with system errors or different sources pass around different information, which is often contradictory.

Considering information reliability, we often understand *reliable* to mean correct, within acceptable limits, rather than in the colloquial sense, i.e., information that we have no reason to reject. It is simply possible information. On the other hand, the technical system is reliable when it is operational, performing the tasks that the system was designed to do. Reliability is also conformity, within the limits of measurement errors, of the information from measurements in the system and the real state at the time of data retrieval. Non-conformity may result from invalidity or different kinds of mistakes, including getting wrong data. Acquired navigational information can be tested, often by statistical tests, for instance, by comparing with average values or verifying the conformity with other sources of information. We simply use the fact that reliable information is not completely random and we have some knowledge enabling us to verify it to some extent.

We must also realize that the reliability of navigational information is not only affected by equipment and technical systems from which this information is obtained, but also by its processors: people, algorithms and computer programs.

The concept of reliability is very broadly understood with regard to information systems. *Dependability* is an attribute we rely on in order to trust the services offered by a computer system. Dependability is a high-level attribute. It can be decomposed to lower-level attributes, as follows:

- reliability
- availability
- safety
- security

Reliability determines the ability of a system to deliver continuously expected services, in certain operating conditions. Reliability is well defined with regard to technical systems.

Safety means that, in the event of a failure, the system will not cause danger (accident, disaster etc.). This becomes important, as the process of navigation is subject to widely implemented automation. Automatic collision avoidance systems, intelligent autopilots controlling the trajectory, and similar types of systems and devices must not introduce new risks. This known issue concerns one-man watchkeeping or unmanned vehicles. These problems are scientific, technical, economic and, above all at present, legal in nature.

System security involves access to information being processed, stored or transmitted by the system. This applies in three respects:

- confidentiality - determining the degree of protection against unauthorized access to information (GPS)
- integrity - determining the degree of protection against unauthorized modification (in a different sense to the GPS)
- availability - determining the degree of assurance that the information will be immediately accessible to authorized staff

Factors that may reduce the reliability of the system fall into two categories:

- system failures, which make the system operation deviate from the specification of desired behaviour, including software defects
- defects (errors) of the specification

Therefore, a reliable system must assure:

- detection of failures (errors)
- early warning
- location of failures
- correctness of interpretation

The reliability of a computer system so understood lacks reference to the reliability of the very information processed in this system. It is commonly known that the reliability of output data also depends on:

- the reliability of input data
- the correctness of the software (processing)

The concept of reliability is most prevalent in relation to the GPS, although it applies to all types of systems and navigational information. Previously, it was sometimes considered in the Loran-C system in air navigation applications. Currently, in the more widely developed theory and technology, the integrity of the GPS, formally speaking, is narrowed to mean the “ability to alert that the position given by the receiver is incorrect, because the system is not working properly” [7]. Other definitions are of a similar nature. For example, according to the definition of the US Federal Radionavigation Plan: “Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation". In some cases, it is assumed outright that "the integrity of the system is the ability to provide a pilot with a warning within 10 s of error exceeding 0.3 nautical mile".

However, it should be noted that these definitions of navigation system *integrity* are directed primarily to navigator practitioners and show what practical effects they can expect as a result of appropriate processes and system security. Currently, the concept of GPS integrity is already close to the views presented by IT specialists and comprises the entire navigation measurement and information system, not just measurements.

The availability of data characterizes the percentage of time that the services of the system are usable, provided they are within the specified coverage area. It is a characteristic related to the ease and speed of obtaining data from the system. It may depend on the system, the user or data type. Availability of the navigation system or, more broadly, navigational information, is also spatial in nature. Therefore, the availability of navigational data depends on the region, time and navigation equipment of the ship and the area, as well as the communications systems of the specific vessel. These are reminiscent, in the era of satellite systems, operation zones and ranges, of radio navigation systems. The issue also refers to such navigational information as the determination of the availability of pseudorange corrections from the DGPS.

Completeness is an attribute that can be expressed as the ratio of the number of data stored in the system to the number of data that the system should contain. You can divide completeness by area and content. This attribute is generally difficult to determine. The exceptions are cases when we can precisely define a set of necessary navigational parameters and the range of their values. They are mostly cases determined by specific regulations (SOLAS Convention, presently determined requirements of AIS, port regulations, pilotage requirements etc.).

Relevance expresses the degree to which information demands of the user are satisfied. A precise definition of this characteristic encounters similar difficulties to those of data completeness. Relevance is only well defined in routine situations, while, in other cases, it is difficult to determine, a fact well known to those navies that have had a long experience of planning the navigational and hydrographic security of operations.

Cost is the feature often overlooked, probably because the ship, from the point of view of the crew, usually has specific, fixed navigation equipment already. Similarly, regardless of the ship's navigator, aids to navigation within a specific region currently exist. The only costs of obtaining navigational information at the decision-making level are those of purchasing navigational aids, their updating, pilotage fees etc. Most of the institutions involved in navigation services to ships are the ones that are really aware of the actual costs of nautical information. In general, the cost of navigational data consists of the costs for the following component:

- data acquisition
- data processing
- providing the user with data in a particular form

It is not important who currently incurs these costs. Free navigational warnings received on board have also been paid for: namely, the cost of the shipboard receiver and the cost of the entire system of information acquisition and distribution.

The value of data, or, more precisely, the information obtained from the data, can be determined by:

- the benefit of using the obtained information instead of, or in addition to, the information already possessed

- the loss that the user would suffer if the information was not used

In maritime navigation, especially in what we call the safety of navigation, the value of data is most often associated with possible loss. The exception to this is the optimization of the voyage based on weather routing.

5. CONCLUSION

The article presents the main concepts related to the navigational situation and information, as well as the relations of the latter with the process of navigation. Problems associated with navigation subprocesses, navigational information and its processing have already been dealt with by many authors. From the viewpoint of the entire process of navigation, no comprehensive approach has been taken to date. In practice, studies of navigational and hydrographic security of navy operations are the only exception, in which navigation is viewed as a whole, not as isolated processes and entities, such as the ship, the harbour master's office, VTS and so on. The same applies to the problem of the demand for navigational information from different users and different kinds of navigation, namely, sea, air, land and space.

Analysis of the navigational situation and particular attributes of navigation information imply that the following actions are necessary:

- develop correct and acceptable definitions of the accuracy of navigational parameters (more broadly, nautical information)
- determine the real accuracy of navigational information, not just measurement accuracy
- determine the variability and validity of navigational information (navigational parameters, meteorological and hydrographic data)
- develop a methodology for verifying the reliability of navigational information
- develop consistent and reliable methods of navigational data fusion, in particular, measurement (point) methods with imaging and text (verbal) methods

Quantitative estimates of the other attributes of navigational information would allow for optimizing the selection of nautical information depending on the adopted criteria, i.e., availability, cost, value etc., and the trading regions and tasks performed by vessels. The degree of satisfying the information demand of the navigator (or information relevance) depends on the tasks performed by the vessel, the hydro-meteorological conditions prevailing in the area, the area parameters and the regulations in force (including vessel traffic organization and control). Another issue for consideration is the provision of a wide access to the current situation and navigational information to a large group of non-professional leisure boat users.

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