ANNUAL OF NAVIGATION 3/2001

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ASSESSMENT OF A NAVIGATIONAL SITUATION IN A FAIRWAY USING AN ARTIFICIAL NEURAL NETWORK WITH FUZZY LOGIC

ABSTRACT One of the stages that navigation is composed of is making decisions. One indispensable condition for making adequate decisions is assessment of a navigational situation. This article presents one modern method for supporting the decision-making process. The method consists in assessing a navigational situation with the use of artificial intelligence.

INTRODUCTION

In a broad sense navigation is a complex process of steering a ship along a pre-set trajectory, according to a voyage plan, executed tasks and hydrological and meteorological conditions. In general, the process of navigating a vessel can be divided into the following sub-processes (layers):

- collection and processing of information,
- navigational planning,
- determination of position and vessel velocity vector,
- control of position relative to dangers to navigation and planned trajectory,
- assessment of a navigational situation,
- decision making,
- steering a vessel along a pre-set trajectory.

As one can see, one inherent element of the process of navigation is assessment of a navigational situation. The assessment is often included in the sub-process of decision making it is closely connected with. Inadequate assessment of a navigational situation in relation to reality may reduce the level of navigational safety (increased risk of a navigational accident) or incurring financial loss (conservative measures). That is why the problem of assessment of a navigational situation in certain cases a vital problem that a navigator / decision maker has to face. It goes without saying that a decision should not be made if it is not preceded by situation analysis.

We make decisions in a variety of situations, such as life, economic, social and technical ones. These situations are referred to as decision situations, whereas the person (or system: social, technical) – a decision maker. A decision situation happens when we feel a decision must be taken. Briefly speaking, it can be described as a violation of conformity between the real state and the expected one. The process commencing with becoming aware of a need to change, and terminating with a choice of a specific decision is called the decision making process. However, it rarely happens that any decision can be made. It frequently happens that circumstances of a situation impose certain limitations of taking a decision. The limitations resulting therefore are called restricting conditions. Decisions belonging to a set satisfying restricting conditions are acceptable decisions. It is known that various decisions and various actions usually cause various effects. From the point of view of targets (criteria) that a decision maker aims at, decisions can vary from good to bad ones. Therefore, there appears need for a choice of the decision that would be best with a given criterion, i.e. optimal decision. This criterion is referred to as the criterion of a choice (assessment) of a decision.

According to Roy [Roy, 1990] there are two methodological dangers of describing a decision making process:

- attaching too much importance to imprecise and broad notions, which often diminishes one's motivation for a deeper study of a given problem and encourages one to reject exactness on account of improperly understood anti-reductionism; exaggerated significance is given to the untypical and inessential; this is a frequent fault of a description of a dangerous situation found in social sciences;
- underestimation of what some orthodox scientific conceptions and dogmatic understanding of exactness put aside due to lack of precision, subjectivity, arbitrariness, indefiniteness and inability to being quantified; this, in turn, is a shortcoming of mathematical and engineering sciences.

Another case also includes situations in which immeasurable, subjective magnitudes appear. Hence methods of artificial intelligence are so important in their consideration.

The navigational situation is a specific kind of decision situation. It is characterised by space-and-time variation. In this case, we can use the term dynamic decision making process. The identification of a navigational situation makes up its formalised description making analysis possible, while an assessment of a navigational situation enables us to determine the necessity of making decisions and restricting conditions.

A set of permissible trajectories is the decision field of a given navigational situation. In navigation, a decision often comes down to the choice of heading angle (commonly known as course) and speed. Formally, the choice consists in choosing an adequate trajectory and speed hodographs (sometimes acceleration hodographs as well).

Then the following criteria are used:

- safety,
- economic,
- standard,
- task execution.

Generally, there are a number of limitations; these may include:

- speed (its range: minimum, service, maximum),
- ship's parameters (manoeuvring characteristics, its sea-keeping qualities, ice class, stability),
- depths (safe depth contour),
- proximity of the shore and other dangers to navigation,
- other ships,
- regulations and recommendations,
- hydro-meteorological conditions (wind, current, visibility, ice conditions, waves),
- navigational equipment and assistance (VTS, pilotage),
- crew skills,
- good sea practice.

However, before we start generating a set of permissible decisions and optimising a choice of a specific decision, we should find out whether we deal with a decision situation, that is a necessity of making a decision. An example of this in the field of navigation means an assessment of a navigational situation. Further in the article one computer-aided process of assessing a navigational situation is presented.

A SYSTEM OF NAVIGATIONAL SITUATION ASSESSMENT

Navigation, particularly in navigationally difficult areas, requires from navigators extensive knowledge and greater attention. Thus it has to be executed with utmost care and caution. In such conditions the maintenance of navigational safety is to a large extent dependent upon correct assessment of the situation which has to be adequate to current circumstances. The assessment of a navigational situation is often highly subjective, a fact resulting from knowledge, experience, mental and physical qualities of the navigator and difficult hydro-meteorological conditions. The assessment also depends on one's ability to interpret available navigational information, including the information that cannot be measured. As accuracy and reliability of navigational data may vary, the basic factor of correct assessment of a navigational situation is navigator's knowledge and professional experience. In spite of implementing increasingly improved navigational and navigation-supporting systems (ARPA, GPS, VTS, GMDSS, AIS and others) there still occur accidents due to human errors or improper assessment of navigational situation.

That is why attempts are made to develop new tools for decision support in navigation. Artificial intelligence systems are particularly useful in situations where conditions are not precise enough due to subjectivity. These systems make possible the use of generalised experts' knowledge.

The assessment process consists in comparing a current situation with a model. The task is relatively simple as the model has a measurable or standardised form. Unfortunately, the marine navigation often lacks well-defined models which can make up a reference for assessment. Therefore, we are obliged to use our own model, i.e. knowledge of a phenomenon – situation. The present navigator's experience as well as that of generations of navigators comes to help. It takes the formalised shape as legal acts (e.g. COLREGs) as well as what is called "good sea practice". The assessment is always based on available information concerning a given phenomenon. This task is much more difficult if the available information is linguistic, using descriptive notions such as little, much, close, far away, wide, narrow, safely, dangerously etc., particularly if derived from visual observation. Additional difficulty is the fact that no precisely defined differences exist between these terms. All these facts make the assessment process a complex and troublesome activity. In the case of navigational situation assessment a large number of factors affecting it has to be taken into account, particularly in areas where navigation is difficult, i.e. restricted areas where additional external factors appear.

Correct identification and assessment of navigational situation is a prerequisite for safe navigation. What make the assessment difficult is the determination of a boundary between safe and dangerous navigational situation.
The boundary will be "shifting" depending on numerous factors, such as:

- quantity and reliability of available navigational information,
- navigator's experience,
- time available for assessment,
- parameters of the vessel (size, manoeuvring),
- traffic intensity in a restricted area,
- external (hydro-meteorological) conditions,
- others.

A large number of factors affecting navigational situation assessment in a restricted area practically excludes states of ideally safe navigation in such an area. Navigation is always conducted on a certain level of safety – danger. The navigator has to determine that level and make a decision (accept the risk) allowing to manoeuvre a ship in a given situation through that restricted area. The task is relatively difficult but necessary nowadays for the successful performance of marine navigation. A question remains: what are particular levels of navigational safety, in particular what is the maximum acceptable level - safety boundary? The level usually somewhat varies in the opinion of individual navigators. The navigator acting under pressure resulting from the responsibility for decisions made and the conflict of interests: the safety of crew, vessel, cargo, possible obstruction of traffic due to an accident etc. against financial losses incurred due to a failure to deliver cargo in time may wrongly identify a navigational situation. The erroneous assessment may also result from more down-to-earth reasons, e.g. insufficient experience, fatigue etc. Safe navigation calls for proper identification and assessment of a navigational situation. The right objective assessment of a navigational situation accounting for specific character of a restricted area can be performed by a group – panel of experts. This kind of evaluation is feasible with the application of the theory of fuzzy sets. Experts in assessing a navigational situation can define sets of the assessments of safe and dangerous navigational situations. The sets will take into account the restricted area characteristics which is unknown or only partly known to the navigator. Those sets make up a kind of model for an assessment of a navigational situation, providing at the same time boundary conditions. Thus, the assessment will consist in the determination of the degree of membership of a current navigational situation to an appropriate set of navigational situations. Particular degrees of membership will determine levels of navigational safety. They will become objective, reflecting the resultant assessments of navigational situations by experts.

The solution to a research problem defined as the assessment of a navigational situation requires that a group of conscious actions are taken, i.e. a specific procedure. Generally a chain of research methods is used. In this approach the data from one method are used as input for the subsequent methods. The final result is the assessment of the degree of navigational safety. At present the problems of ship movement in a restricted area, particularly in view of its safety, is a concern of a science known as marine traffic engineering (MTE). It distinguishes the following research methods:

- measuring,
- analytical,
- statistical,
- expert,
- simulation.

Statistical examination of accident rate is a frequent method of navigational safety assessment. The research is conducted on the basis of long observations. In this case, the measure of navigational safety is the number (density) of actual navigational situations characterised by a definite degree of safety (e.g. threats of accident, accidents). The method only allows to perform only a general assessment of navigational safety in an area. This is due to rare occurrence of specific situations and the necessity to perform observations over a long period of time during which parameters of an examined system undergo changes.

While designing a system of the assessment of navigational situation in a restricted area one should apply research methods taking into account all the factors affecting navigational safety. Analytical methods in which certain criteria of assessment are specified, e.g. minimum distance, time to closest point of approach, area parameters, vessel manoeuvring characteristics etc. are insufficient, particularly due to potentially restricted time of assessment in a real situation.

It becomes purposeful in the examined problem of navigational situation assessment to use a number of methods making it possible to find a complex solution, that are as follows:

- computer simulation – the method allows in a relatively short time to simulate navigational situations that may occur (advantage over the statistical method),
- measuring – allows to acquire parameters (during a simulation) affecting navigational situation assessment,
- expert research – the method allows to obtain professional knowledge, experience and skills of navigators (experts) indispensable in the correct process of navigational situation assessment,
- statistical – the method makes it possible to analyse experts' assessments against their suitability in the process of navigational situation assessment,
- artificial intelligence methods.

The above mentioned methods offer a possibility of current situation assessment as well as that of navigational safety. The results obtained during the research applying one method make up input data for the application of another method.

The complexity of navigational situation identification and assessment problem, particularly in view of the numerous factors affecting it, of which many are of linguistic character, forces researchers to seek tools capable of processing such information. One way is the application of artificial intelligence in the form of fuzzy sets theory. The method proposed by Zadeh in 1965 multi-value logic known as fuzzy logic with a system of inference based on it has proved very useful in engineering applications and is commonly used in modern engineering sciences. Fuzzy logic systems have a simple and flexible structure, with their high operating effectiveness being maintained. Thanks to their effectiveness in real data processing, fuzzy inference is used in various expert and decision support systems.

The theory of fuzzy sets is a generalisation of the classical theory of sets. The latter assumes that any element belongs or does not belong to a given set. The theory of fuzzy sets, however, an element may partly belong to a certain set, while its membership may be expressed by means of a real number found in the [0,1] interval. Thus the membership function

$$\mu(x): \quad U \Rightarrow [0,1] \tag{1}$$

Is defined as follows:

$$\forall_{x \in U} \mu_X(x) = \begin{cases} f(x) & , x \in \\ 0 & , x \notin \end{cases} \tag{2}$$

where f(x) is a function obtaining a value – degree of membership – from the [0,1] interval.

Membership functions are usually illustrated graphically - see Figure 1 below.

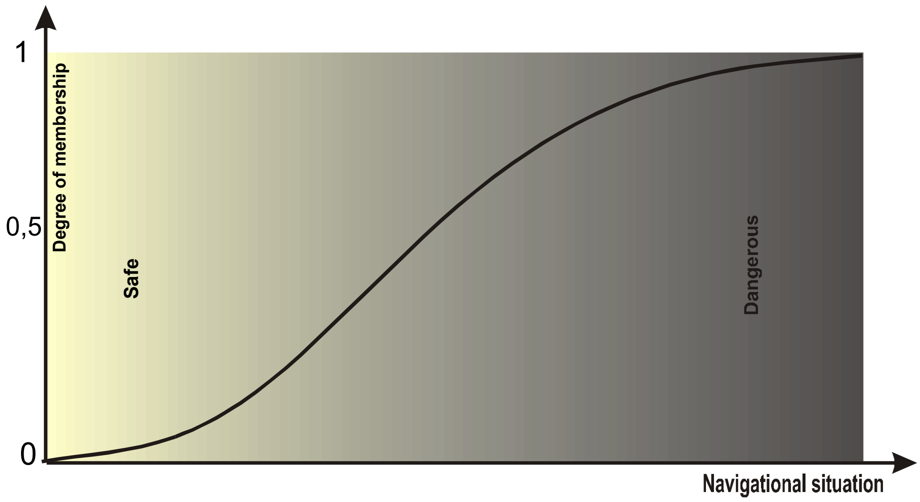

Fig. 1. Graphic interpretation of the function of membership of a navigational situation to fuzzy sets: „safe”, „dangerous”.

Using the laws of fuzzy logic in the problem of navigational situation assessment one can define these fuzzy sets: ‘safe’ navigational situation, ‘dangerous’ navigational situation. Therefore, the process of assessing a navigational situation will consist in determining a degree of membership of a current navigational situation to the fuzzy sets ‘safe’, ‘dangerous’.

The degree of membership is strictly connected with parameters affecting navigational safety. In the event of restricted areas, (difficult for navigation) where possible manoeuvres are limited, as manoeuvring can be carried on only along dedicated traffic lanes or *allocated courses* these parameters are as follows (Fig. 2):

- distance of vessel from fairway centre liner Δy,
- vessel’s deviation from pre-set course $\Delta\varphi$,
- rate of turn ω,
- longitudinal velocity v,
- area size,
- vessel size,
- other traffic,
- external (hydro-meteorological) conditions.

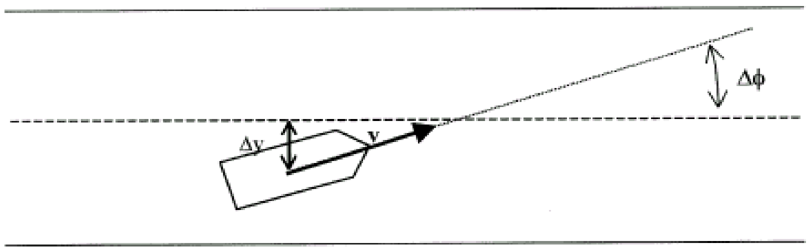

Fig. 2. Graphic display of vessel moving in a restricted area.

The process of proper identification and assessment of a navigational situation has to be based on relevant assessment criteria. Only then the assessment will be correct. Experts in the process of navigational situation assessment take advantage of their own professional experience, use subjective criteria of assessment formed by knowledge and experience acquired over many years of sea service. Thus, the use of experts' criteria in the process of automatic identification and assessment of a navigational situation is an indispensable condition for correct assessment. In order to achieve this, expert knowledge base has to be created. In other words, experts' knowledge has to be acquired. The knowledge can be divided into:

1. Known knowledge about given phenomenon consist of:
   - procedural knowledge (rules, strategies, procedures),
   - declarative knowledge (conceptions, objects, facts),
   - heuristic knowledge (intuition, common sense rules),
   - structural knowledge (relations between conceptions, rules),
   - meta-knowledge (knowledge of knowledge types and methods of their use).
2. Empirical association (professional experience, good sea practice).

The recorded knowledge can be easily used for the identification and assessment of a navigational situation. However, for the assessment to be correct one additionally has to have empirical association. Gaining professional experience is a long process, encompassing the whole period of expert's professional career in the given field. Therefore, it seems purposeful to attempt at seeking methods and tools that could absorb professional knowledge of experts in a short time – tools that use identical assessment criteria. One way of the search is offered by methods of artificial intelligence. Their use make it possible to build a system of automatic identification and assessment of a navigational situation.

Acquisition of experts' knowledge is possible by doing research with experts' participation. A further step in the research the acquired knowledge can be utilised in designing a system of identification and assessment of a navigational situation. During the expert studies simulated navigational situations were evaluated by groups of experts whose professional experience was diversified (different qualifications). Each group consisted of five people.

These were:

- Master mariners;
- Class 2 deck officers;
- Class 3 deck officers;
- Maritime University students after sea training.

Possessing the knowledge of experts with diversified professional experience enables its use in an analysis of assessment criteria of individual experts and the expert groups. In this way experts can be selected to distinguish those with most valuable knowledge and the best physical and mental qualities (do not get tired, are not subject to routine behaviour, do not respond to disturbances from the surroundings, etc.). In a further stage such knowledge can serve as a basis for the verification of other navigators' knowledge and skills. The full knowledge on navigational situation assessment requires that as many facts as possible are gathered. Therefore, research was conducted (as assumed, expert studies were performed in a restricted area, i.e. a fairway) so that a possibly maximum number of navigational situations could be simulated, that is both safe and very dangerous situations were purposefully simulated. The studies dealt with various types of fairway, that is a straight stretch, a bend turning to starboard and port. Additional simulations were performed in fairways of varying width. The studies focused on the assessment of navigational safety of one ship proceeding along the fairway as well as manoeuvres of passing and overtaking. Dangerous situations simulated were those of sudden turns, beaching, collision with another vessel, but there were also absolutely safe, the so called ideal passages. Altogether, 68 simulated passages were conducted. This resulted in gathering about 2000 facts (learning sets).

THE RESEARCH AND RESULTS

In order to verify the method of navigational situation assessment simulated research was done. The research consisted in vessel movement simulation on a fairway. The simulations were performed on the ship handling simulator Norcontrol NMS-90 located at the maritime University of Szczecin. Detailed description of the simulated research with its assumptions are contained in [Pietrzykowski, Uriasz, 1999, Uriasz, Wojniłko, 2001]. Expert studies, complementary to the simulations, consisted in recording the assessments of navigational situations by expert navigators. Examples of the assessments and their analysis are included in [Uriasz, 1999]. Furthermore, learning data for individual observers and for average assessments in expert groups were developed. These formed input data x [Uriasz, Wojniłko, 2001, Uriasz, 1999] and corresponding assessments of a navigational situation, standardised to the [0,1] interval. Learning data were used for the process of network learning, shown in Figure 3. [Tadeusiewicz, 1993, Kacprzyk, 1986]. The same level of network learning was assumed in all analysed cases. Each network represented the knowledge of navigators belonging to expert groups.

An example of network responses - navigational situation assessments is shown in Figure 4. The example illustrates research into an assessment of passing manoeuvre safety in a fairway.

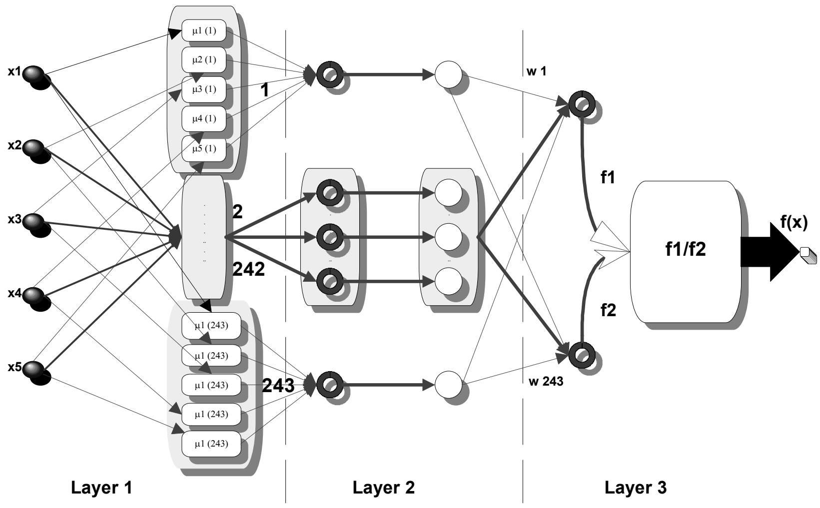

Fig. 3. An example of a neural network with fuzzy logic for 5 input data and 243 inference rules.

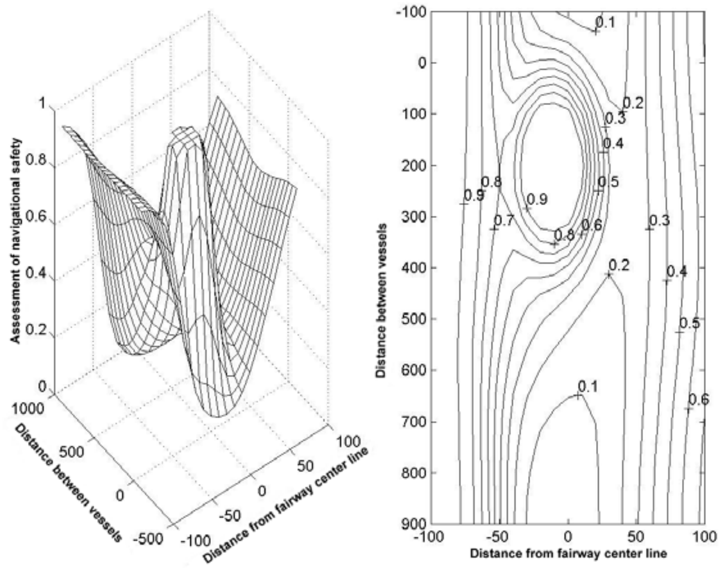

Fig. 4. Assessment of a navigational situation – passing manoeuvre in a fairway for KDd=90^o (course made good), ω=0 (rate of turn), ∢KK=-30^o (heading angle)

The above chart of navigational safety assessment for the presented navigational situation displays a fairway with plotted safety areas, in which a vessel has to be located in order to carry out the passing manoeuvre. The presented situation concerns accurate conditions, i.e. steady speed of the vessel, course 90^o, rate of turn equal to zero, and the bearing relative to the passing vessel -30^o (to port from the vessel's centre line), the vessel being passed does not make any manoeuvres (steady course and speed). Each change of any parameter will cause an automatic change of safety areas (change of a navigational situation). The areas form swept paths for particular safety levels, and the lower the assessment value is the greater the safety is. One can observe increased danger in the vicinity of the passing vessel (narrower paths) and the fairway boundary. It should be noted that this type of assessment of a navigational situation can be obtained in real time (graphic or numerical representation). The studies of overtaking manoeuvre conducted so far [Uriasz, Wojniłko, 2001], including vessel's movement along a straight section of the fairway [Dziedzic, Pietrzykowski, Uriasz, 2000] and in fairway bends [Pietrzykowski, Uriasz, 1999] have confirmed a possibility of navigational situation assessment in a restricted area in which artificial neural network with fuzzy logic can be used.

SUMMARY

The method of navigational situation assessment presented in the article uses the knowledge and experience of experts incorporated in an artificial neural network. The system of navigational situation assessment having a form of artificial neural network with fuzzy logic is a useful tool of computer-aided support of decision-making process. The obtained research results confirm that the method can be applied in navigational situation assessment and its automatic identification.

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Received September 2001
Reviewed November 2001