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FUZZY APPROACH TO DIMENSIONING THE NAVIGATIONAL SAFETY IN MARITIME TRANSPORT

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Abstract

The safety of ships involved in the process of transport is one of the most important criteria in the maritime transport. Important factors making up the safety include the technical efficiency of the ship, the qualifications of the people in charge of the ship and the conditions under which the transport process takes a place. The paper focuses on the problems significant and characteristic to the ship traffic safety under uncertainty conditions. The ship safety at supervised traffic requires continuous identification of the navigational situation. Very often safety assessment of the traffic situation is made by examining the relative positions of vessel's domains. A limitation is that under uncertainty conditions and more than two vessels we have to take into consideration dynamic domains according to the situations of conflicts, which is rather difficult to analyse. One way to assess the traffic safety approximation is analysis of the potentially conflicting situation. Safety in maritime transport can be analysed at the micro level (safety of the ship, the safety of navigation in specific situation mobility) and in terms of macro models (evaluation over time).In the article some problems of fuzzy description of traffic safety in maritime transport are presented. Basic definitions and a stochastic approach to concept of traffic safety in transport are given. The fuzzy approach to stochastic method of dimensioning traffic safety, useful in dynamic traffic control, is proposed.

Keywords: *safety dimensioning, stochastic fuzzy models, safety in sea transport*

1. General Introduction

The safety of navigation in the maritime is under influence of many different factors acting on the ship. Therefore, assessing the safety of navigation should be included, depending on the situation of navigational, hydro-meteorological conditions, technical parameters of the vessel, the efficiency of appliances and equipment on board and the conduct of the crew, [3, 11].

Existing methods and criteria to assess a situation such as a navigational parameter of the CPA, TCPA, the domain of the vessel and others leads to define safety in terms of static [11].

The navigation is a dynamic process, which requires a time-varying geometric relationship between the body and floating objects to present a navigational hazard of collision.

The concept of the so-called supervised traffic, Motorways of the Sea requires the development of safety assessment methodologies take into account the variability of the navigation during the navigational situation [6].

The paper presents a fuzzy approach to dynamic model of quantitative evaluation of the safety navigation.

2. Dimensioning in Maritime Transportation

Ship accidents at sea have and will occur despite the use of high-tech equipment so it is necessary to build models, which can help in dimensioning traffic safety at maritime transport. Since 1959, a whole series of international measures, such as ships' routing measures, traffic separation schemes; ship reporting systems; and vessel traffic services, made a significant contribution to the safety of navigation.

Systems, mandatory and recommended, have been established on most of the world's major shipping routes, within a reduction on the number of collisions. But still a number of collisions have occurred recently of which one of the causal factors has been a result of a seamanship non-proper look out, [3, 8].

The ship safety at supervised traffic requires continuous identification of the navigational situation.

The problem of risk measuring for a traffic situation may be divided into two main stages:

- modelling the joint evolution of traffic lane width according to a single ship,
- modelling the hazard map by using traffic and navigational situation.

Safety assessment of the traffic situation can be made by examining the relative positions of vessel's domains. A limitation is the fact that most domain of the vessel is used to describe the preferences of a navigator and subjective risk acceptance and not to define the recommendations dealing with the situations of conflict.

With respect to the ship-to-ship collisions, three different collision scenarios should be examined separately namely [3]:

- head-on collision, in which two vessels collide on a straight leg of a fairway as a result of two-way traffic on the fairway,
- collision, in which two vessels moving in an opposite direction on the same fairway collide on a turn of the fairway as a result of one of the vessels neglecting or missing the turn (error of omission) and thus coming into contact with the other vessel,
- crossing collision, in which two vessels using different fairways collide at the fairway crossing.

The following algorithm for evaluation of safety can be used:

- determining of random maps taking into account the situation of navigational hazards,
- identifying potential areas of conflict,
- determining the relative weights for each area of conflict and mutual interactions of ships,
- determination of aggregate safety factor (using the total probability formula).

The shape and the dimensions of dynamic constrains of the ship domain, as a collision risk area, depend on the assumed safety conditions.

In the paper, we assume that it is the ellipse $E(x_i, y_i)$, which parameters depend on the motion vector of the ship. In this area the two-dimensional cut Gaussian probability measure $f_i(x,y)$, which specifies the location of the ship s_i, is determined by formulae [9, 10]

$$p(w) = \frac{1}{2\pi\left|\Sigma\right|^{1/2}} \exp\left[-\frac{1}{2}(w-\mu)^T \ \Sigma^{-1} \ (w-\mu) \right], \tag{1}$$

$$f_i(x,y) = \frac{p(w)\chi_{E(x_i,y_i)}}{\iint_{E(x_i,y_i)} p(w)\,dw}, \tag{2}$$

where

$\mathbf{w} = [x, y]$,

d_i – distance to the ship s_i,

$\chi_{E(x_i,y_i)}$ – indicator function of ellipse $E(x_i, y_i)$,

φ_i – angle between the axis OX and bearing of the ship s_i from the own ship,

$\boldsymbol{\mu}$ – the mean vector, $\mu_i = [d_i(t)\cos(\varphi_i(t)), d_i(t)\sin(\varphi_i(t))]$,

$\boldsymbol{\Sigma}$ – the covariance matrix, for the Gaussian density.

The general measure of all the collision risk areas is defined as, (4-5):

$$g(x,y)=\sum_{i=1}^{n}\frac{1}{n}f_i(x,y). \tag{3}$$

We take into consideration the coordinate system associated with the ship, where the axis OX is determined by the ship course vector and the axis OY is perpendicular to it, the Cartesian coordinate system, Fig. 3.

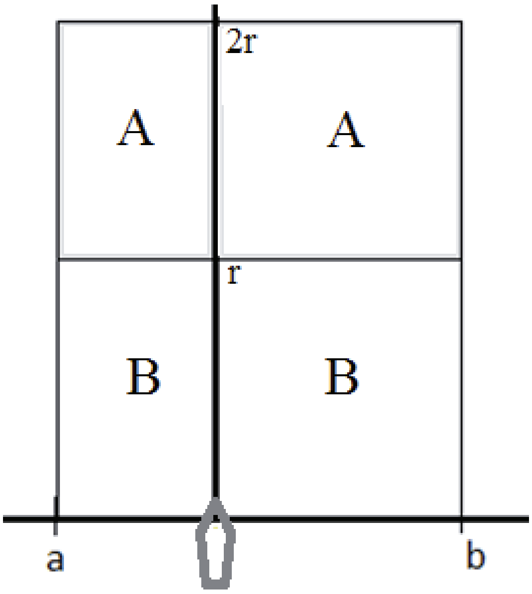

Fig. 1. The coordinate system and the observation area, yellow arrow indicates the position of the ship, [8, 10] (a – width of observation on the port, b – width of observation on the starboard, r – radius of ahead observation

The operational states are defined by:

- *waiting* state is a state in which there is no other ships at observation area,
- *decision* state is a state in which there is a ship at A part of observation area,
- *action* state is a state in which it there is a ship at B part of observation area.

The probabilistic measure of collision is given by the density function of the form:

$$p_r(x,y)=\begin{cases}\left[1-2\left(\frac{x}{r}\right)^2\right]\frac{y+a}{a(a+b)} & \text{for } 0\le x\le 0{,}5r; -a\le y\le 0,\\ \left[1-2\left(\frac{x}{r}\right)^2\right]\frac{b-y}{a(a+b)} & \text{for } 0\le x\le 0.5r; 0\le y\le b,\\ \left[1-\left(0.5+\sqrt{0{,}5\left(\frac{x}{r}-0{,}5\right)}\right)\right]\frac{y+a}{a(a+b)} & \text{for } 0.5r\le x\le r; -a\le y\le 0,\\ \left[1-\left(0.5+\sqrt{0{,}5\left(\frac{x}{r}-0{,}5\right)}\right)\right]\frac{b-y}{a(a+b)} & \text{for } 0.5r\le x\le r; 0\le y\le b.\end{cases} \tag{4}$$

The probabilities of being at each of the operational states are given by the following formulae:

$$\begin{aligned} Pr\{waiting\ state\} &= 1-\int_a^b\int_0^r p_r(x,y)g(x,y)\,dxdy,\\ Pr\{decision\ state\} &= \int_a^b\int_{cr}^r p_r(x,y)g(x,y)\,dxdy,\\ Pr\{action\ state\} &= \int_a^b\int_0^{cr} p_r(x,y)g(x,y)\,dxdy. \end{aligned} \tag{5}$$

3. Hazard Maps By a Cellular Automata Approach

A cellular automaton (CA) may be defined as a complex system made of a finite number of elements, called cells, which are characterized by a number of properties (i.e. a colour, a shape, ecc). A cellular automaton evolves in time by changing the status of all the cells simultaneously; at every time step each cell change its state depending on the state of a set of cells within a certain distance, called vicinity index, according to a particular state function [2].

The basic element of a Cellular Automata is the cell. A cell is a kind of a memory element and stores - to say it with easy words - states. In the simplest case, each cell can have the binary states 1 or 0. In simulation that is more complex the cells can have states that are more different. (It is even thinkable, that each cell has more than one property or attribute and each of these properties or attributes can have two or more states.) These cells are arranged in a spatial web - a lattice. The most common CA´s are built in one or two dimensions. The states of one time step are plotted in a two-dimensional plot, which shows only the state of one time step. These cells arranged in a lattice represent a static state. To introduce dynamic into the system, we have to add rules to define the state of the cells for the next time step. In cellular automata, a rule defines the state of a cell in dependence of the neighbourhood of the cell. Different definition of neighbourhoods is possible. Considering a two-dimensional lattice the Extended Moore Neighbourhood are used, presented at figure.

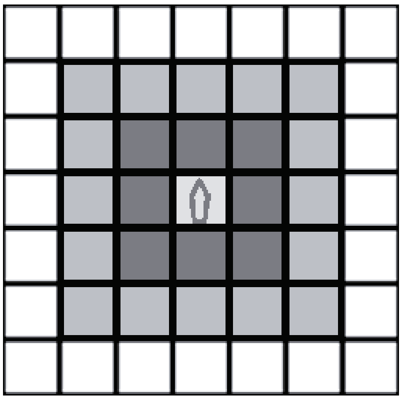

Fig. 2. Extended Moore Neighbourhood

The yellow cell is the centre cell, the grey cells are the neighbourhood cells. The states of these cells are used to calculate the next state of the centre cell according to the defined rule.

We divided the area into cells. Applying Rules are determined by operational states:

- *waiting*-continue moving,
- *decision*-changing parameters of moving (speed, course),
- *action*-rapid changing of course (last chance manoeuvre).

Hazard map is based on grid of probabilities of lattice. The grid of probabilities $q_{ij}(t)$ is introduced for the investigated scenario for the traffic navigational situation. It is determined by the measure of hazard of individual grid cells [7].

The hazard measure is given by the following form.

$$c_{i,j}(t) = \iint_{cellij} p_r(x,y) g(x,y) dxdy\,, \tag{6}$$

where the probability measures $p_r(x,y)$ and $g(x,y)$ are be given by (3), (4) accordingly.

From above formulas the grid of hazard are calculated in considered navigational situation and we get random maps for the given moment of time. Dynamic safety is the stochastic process, which is described, for fixed time moment t_0 by a random variable defining static safety for a given traffic and navigational situation [9].

It is assumed that parameters a, b, r and motion vector characteristics are fuzzy numbers.

A fuzzy subset A of a universe of lactic U is characterized by a membership function $\mu_A : U \to [0,1]$, which associates with each element u of U a number $\mu_A(u)$ in the interval [0, 1].

Memberships functions allow us graphically represent a fuzzy set. The *y*-axis represents the degrees of membership in the [0, 1] interval.

A triangular fuzzy number (TFN) *a* is a fuzzy number with a piecewise linear membership function *fa ,* Fig. 4, defined by:

$$f_a = \begin{cases} 0, x \le \min, \\ (x - \min)/(\mathrm{mid} - \min), x \in (\min, \mathrm{mid}], \\ (\max - x)/(\max - \mathrm{mid}), x \in (\mathrm{mid}, \max), \\ 0, x \ge \max. \end{cases} \tag{7}$$

It has three parameters „minimum“ (min), „middle“ (mid) and „maximum“ (max) that determine the shape of the triangle.

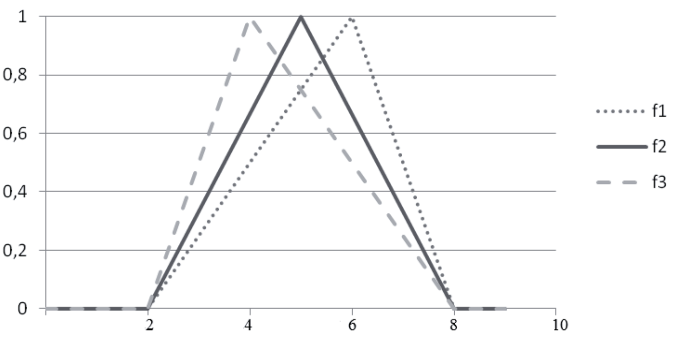

Fig. 3. Examples of triangular membership functions where min=2, mid=8 and max=4,5,6

Another variant of the membership function, which can be used, is trapezoidal function. Given a general shape of a trapezoidal membership function, Fig. 4, as follows:

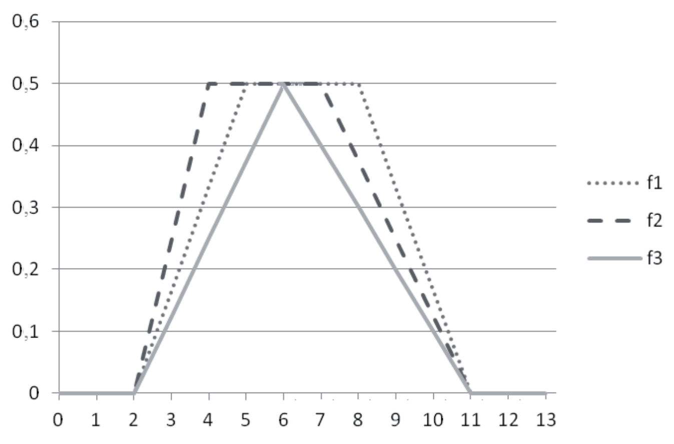

Fig. 4. Examples of trapezoidal membership functions, where min=2, max=11, mid1=4, 5, 6 and mid2=7, 8, 9; formula (8)

The parameters *min* and *max* can be specified by on the same formulas as it is for the triangular membership function, formula (7). According to *mid1* and *mid2* parameters, they based on the lower and upper quartiles.

$$f_a = \begin{cases} 0, & x \le \min, \\ y(x-\min)/(\mathrm{mid1}-\min), & x \in (\min, \mathrm{mid1}], \\ y, & x \in (\mathrm{mid1}, \mathrm{mid2}], \\ y(\mathrm{mid2}-x)/(\mathrm{mid2}-\mathrm{mid1}), & x \in (\mathrm{mid2}, \max], \\ 0, & x > \max. \end{cases} \tag{8}$$

Defining fuzzy concepts, using functions that are more complex does not add more precision so simple functions are used to build membership functions.

Let U be the grid cell, A and B be two fussy subsets of U, and $\overline{A}$ be the complement of A relative to U. Also, let u be an element of U. Then,

$$\begin{aligned} \mu_{\overline{A}}(u) &= 1-\mu_A(u), \\ \mu_{A\cup B}(u) &= \max\{\mu_A(u), \mu_B, \\ \mu_{A\cap B}(u) &= \min\{\mu_A(u), \mu_B. \end{aligned} \tag{9}$$

4. Fuzzy Information Retrieval

Boolean retrieval model is used to interpret the query and retrieve a set of cells ranked based on their similarity to the selected hazard levels, [5]. The similarity between the cell and the query feature is interpreted as the degree of membership of the cell to the fuzzy set of cells that match the query feature. Fuzzy set theory is used to interpret the Boolean query and the cells are ranked based on their degree of membership in the set. The similarity between the cell and the query feature is considered to be the probability that the cell matches the hazard level need. Feature independence is exploited to compute the probability of a cell satisfying the query, which is used to rank the cells.

We take into consideration 3 types of cells:

- Type I –with a ship inside,
- Type II –with potential ships collision point,
- Type 0 – other which not belong to type I or II.

We first set up term-term correlation matrix for terms of type I and type II,

$$c_{i,j} = \frac{n_{i,j}}{n_i + n_j - n_{i,j}}, \quad i,j = I, II. \tag{10}$$

where n_k is the number of cells type k, k=i,j and $n_{i,j}$ is the number of cells type both i and j ($c_{k,k}$=1, k=I, II).

We define a fuzzy set for each term k_i. In the fuzzy set for k, an area d_m has a degree of membership μ_{ij} computed as

$$\mu_{i,m} = 1 - \prod_{k_j \in d_m} (1 - c_{i,j}). \tag{11}$$

Whenever, the cell d_j contains a term that is strongly related to k_i, then the cell d_j is belong to the fuzzy set of term k_i, i.e., $\mu_{i,j}$ is very close to 1.

Safety in maritime transport can be analysed at the micro level (safety of the ship, the safety of navigation in a specific situation mobility, (4),(5)) and in terms of macro models (evaluation over time) using formulas (9-11).

Summary

There are many methods for assessment of the traffic safety under uncertainty conditions. In the paper, fuzzy approach to quantitative evaluation of safety level in marine transport is presented. The necessity to elaborate such methods for safety dimensioning is pointed out. Dynamic model is important for the reduction in the risk of collision by identification of dangerous situation, which may arise at near future.

Safety in maritime transport can be analysed and assessed both at the micro and macro models (evaluation over time). Quantitative assessment of the traffic safety is absolutely necessary as the key criterion for evaluation of traffic control procedures, [5]. Some definitions and ideas of marine traffic safety dimensioning presented in the paper can be used to develop methods that may be useful in practice. Presented methods of safety dimensioning could be used in short-term analysis.

The IMO standards should be used to theoretical estimating of safety without actual details of vessel and crew condition. Analysis of the potentially collision situation is the way to assess traffic safety approximation. The shape of the membership function is important and needs more précised analysis.

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