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An approach to modelling the random map of hazards to assess the navigational safety

Koncepcja modelowania losowej mapy zagrożeń do oceny bezpieczeństwa nawigacyjnego

Leszek Smolarek, Sambor Guze

Gdynia Maritime University, Faculty of Navigation
Akademia Morska w Gdyni, Wydział Nawigacyjny
81-345 Gdynia, ul. Morska 81–87, e-mail: leszsmol@am.gdynia.pl, sambor@am.gdynia.pl

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Abstract
In the paper the hazard estimation method of assessment of risk on ship routes in terms of the random maps has been proposed. The two-dimensional, multimodal density function of hazard areas has been used. Furthermore, the application to identify the main threats, based on accepted minimum level of safety for particular navigational situation has been proposed.

Słowa kluczowe: obszary zagrożeń, mapa ważności

Abstrakt
W pracy przedstawiono metodę oceny ryzyka na szlaku morskim w kategoriach map losowych. Użyto do tego dwuwymiarowej, multimodalnej funkcji gęstości dla obszarów zagrożeń. Ponadto przedstawiono metody identyfikacji głównych zagrożeń, wykorzystując minimalny poziom bezpieczeństwa.

Introduction

An important aspect of sea transportation is the safety of shipping [1]. It is based primarily on analysis of current situation and depends on the interaction between man, technology and environment [2]. Any error at one of these three components has the great impact on the occurrence of hazardous situations, especially human error [3]. Therefore, an important aspect of navigational safety is the ability to anticipate a hazardous situation and taking the right decision to avoid hazard [4]. There are different methods and criterions which can be used to analysis and evaluate the hazards in terms of shipping safety [5, 6, 7, 8]. Some of them use two basic measures, the CPA and TCPA to estimate the distance between ships, for risk evaluation of collision at the hazard situation at sea [9]. Another important group of method of the risk evaluation is the ship domains analysis. All these methods are used to make the decision or to select a manoeuvre at the hazard situation which leads to less risk.

In the article the risk maps and the projections of a potential threat are described. It is necessary to consider Bayesian approach, due to the subjectivity of hazard evaluation and risk acceptance, for the designation of areas of increased risk [10].

Operational and safety model of ship in the open area

We assume that the analyzed system consists of a navigator, a ship and a part of area in front of a ship. Considered part of the area, is designated at the ship course, has a width depending on the speed of a ship, navigator attitudes towards risk (subjective) and the navigational situation (visibility, the range of observation, other units). This passage is divided into rectangles with sides parallel to the coordinate system associated with the ship, the abscissa is determined by the motion vector of a ship, and the ordinate axis is perpendicular to it. All rectangles are of equal size and their dimensions are defined by the length and breadth of a ship. Because of the subjective sense of navigator danger the function of significance for the individual rectangles is determined. Depending on the speed with which a ship is moving rectangles are grouped into subsets called blocks. The navigator analyzes the hazard of collision for a limited area, which is divided into equal blocks for the operational model, where the shape depends of the measure of significance (Fig. 1). If at the area, defined by the block, is a navigation obstacle (such as another vessel), then we call such block as occupied. Otherwise, the block is unoccupied.

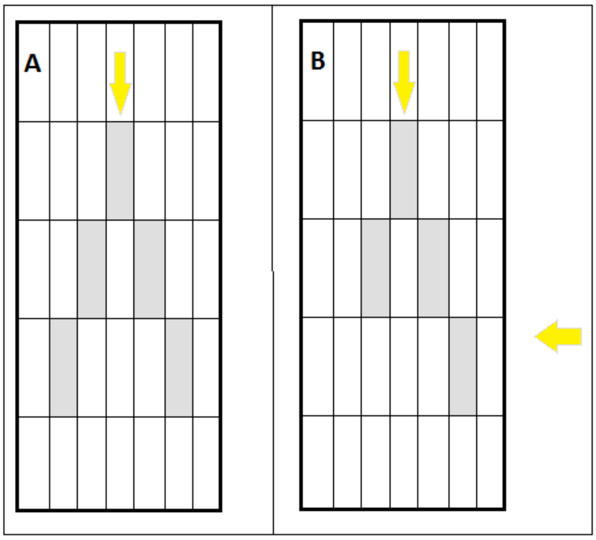

Fig. 1. The example of a block, grey rectangles: A) symmetrical case, B) asymmetrical case, arrow represents a ship's position

Rys. 1. Przykład bloku, szare prostokąty: A) przypadek symetryczny, B) przypadek asymetryczny, strzałka oznacza pozycję statku

Using the measure of significance for rectangles we can compute the measure of significance for blocs [10]. The measure given by formula (1) allows taking into account the level of the navigator's subjective sense of safety [11] (Fig. 2).

$$p(k)=\begin{cases} 1-\dfrac{1}{a^2}\left(\dfrac{k}{n}\right)^2 & k \le [na] \\ 1-\left(\dfrac{k}{n}\right) & [na] < k \le [nb] \\ 1-b-\sqrt{(1-b)\left(\dfrac{k}{n}-b\right)} & k > [nb] \end{cases} \quad (1)$$

for $0 \le a\ b \le 1$, where:

n – number of all blocks at considered area,
k – the number of a block,
a, b – parameters which represents the navigator's approach to risk, accordingly.

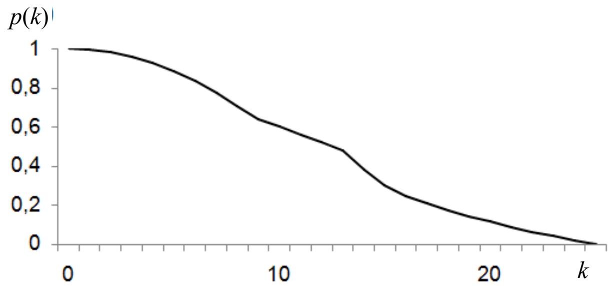

Fig. 2. Measure of significance: n = 30, a = 0.3, b = 0.4

Rys. 2. Wykres miary istotności: n = 30, a = 0,3, b = 0,4

We take into consideration a ship and the set of n equal consecutive blocks in front of a ship. The number of k consecutive unoccupied operational blocks, for the current location of a ship, is used to represent the ship safety in view of collision hazard.

The hazard map

After determining the probabilities of non-occupancy of cells from operational model, we can use it in post-factum analysis. Thus, it was a concept of the risk map based on grid of rectangles.

The map of the hazards of collisions is closely linked to navigation situation (i.e., number and location of ships and their vectors courses). It is two-dimensional multimodal density distributions which is a mixture of two-dimensional density functions:

- normal density functions (where (m_1, m_2) is equal to the position of a ship) – lack of information of ship course,
- product of two unimodal density functions (gamma, Laplace, beta,...) – according to information of ship speed, course and technical parameters,
- uniform density function (on a circle centred at object) – non moving objects like ship at anchor, a rock underwater, etc.

We can use the division into rectangles to count the probability of block occupancy as a measure of the set of the rectangles, where the measure of the rectangle E_{ij} is given by:

$$q_{ij}(t)=\iint_{E_{ij}} q_x(x,t)\cdot q_y(y,t)\,\mathrm{d}x\,\mathrm{d}y \quad (2)$$

where $i, j \in N$, $t \in \langle 0,\infty)$ and the probability measures $q_x(x,t)\times q_y(y,t)$ is a mixture of two-dimensional density functions.

Example of the calculation of hazard map

Let us consider the theoretical example where navigational situation is presented at Fig. 3. We have analysed the safety for the ship S_1 (in circle). All ships are moving with known vectors of velocity.

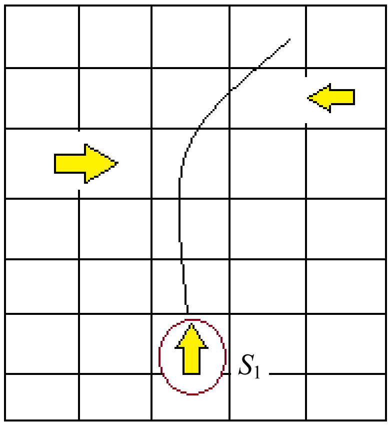

Fig. 3. Navigational situation, arrows represents ship's positions
Rys. 3. Sytuacja nawigacyjna, strzałki określają pozycje statków

In particular case, where we take into consideration the fast ferry, we assume that ship maintains its course with great accuracy and has the ability to change the speed. Therefore, we assume that the course deviation has the Laplace distribution and the speed is described by the gamma distribution. In such case the measure for the rectangle E_{ij} is given by the formula:

$$q_{ij}(t)=\iint_{E_{ij}} \frac{1}{2\lambda(t)} e^{-\frac{|x|}{\lambda(t)}} y^{\alpha(t)-1} \frac{e^{-\left(\frac{y}{\beta_j(t)}\right)}}{\Gamma(\alpha(t))\beta_j(t)^{\alpha(t)}} \,\mathrm{d}x\,\mathrm{d}y \quad (3)$$

where: $\Gamma(y)=\int_0^{+\infty} z^{y-1}e^{-z}\,\mathrm{d}z$ and $i \in I$, $j \in N$, $\alpha(t) > 0$, $\beta(t) > 0$, $\lambda(t) > 0$, $t \in \langle 0,\infty)$ and $E_{ij} = (x_i, x_{i+1}] \times (x_j, x_{j+1}]$

According to (2), (3) we get the following formula for the measures:

$$q_{ij}(t)=$$

$$=0.5\left[\operatorname{sgn} x_{i+1}\left(1-e^{-\frac{x_{i+1}}{1.2}}\right)-\operatorname{sgn} x_{i+1}\left(1-e^{-\frac{x_i}{1.2}}\right)\right]\cdot \quad (4)$$

$$\cdot\left[\Gamma\left(2,\frac{y_{j+1}}{3}\right)-\Gamma\left(2,\frac{y_j}{3}\right)\right]$$

where: $i, j \in N$, $t \in \langle 0, \infty)$, $\lambda = 1.2$, $\alpha = 2$, $\beta = 3$, and $\Gamma(2, y/3)$ and is the lower incomplete gamma function.

From (1) and (4), there are calculated the values of the density functions for $q_{ij}(t)$ in considered situation. Thus, we get following random map for the given moment of time (Fig. 4).

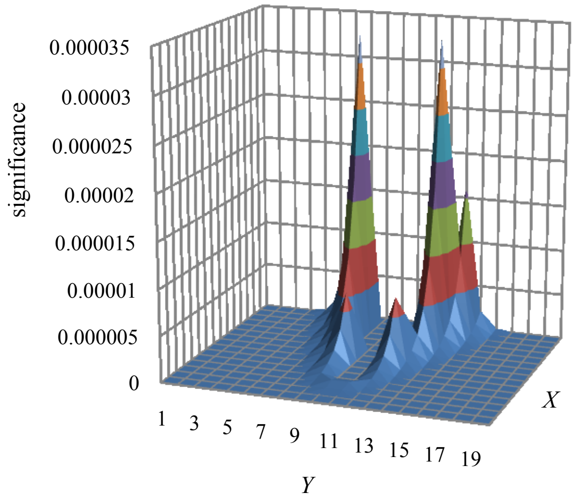

Fig. 4. An example of hazard map
Rys. 4. Przykład mapy ryzyka

Application

The presented hazard map can be used to make the safety model of collision hazard. Let's specify the three state navigational safety model, with B state, ZB state and NB state. The B is a state in which the movement of a vessel shall be continued without a need for unscheduled change of course. The ZB is a state in which there is a need to perform an unplanned manoeuvre change course. The NB is a state in which there are necessary changes in the course of rapid manoeuvre.

These states are determined by the following subsets of consecutive unoccupied blocks:

$S_B = \{s_i;\ i \ge n_{ZB}\}$ for the B state,
$S_{ZB} = \{s_i;\ n_{NB} \le i < n_{ZB}\}$ for the ZB state,
$S_{NB} = \{s_i;\ i < n_{NB}\}$ for the NB state,

where parameters n_{ZB} and n_{NB} are the limits values for numbers of unoccupied blocks, according to taking the decision.

When we assume that the residence times of the system in each state are described by exponential distribution, we can apply Markov approach to this model. Then, we can use the following system of Chapman Kolmogorov equations to count the probability of staying at state B.

$$\begin{cases} P_B'(t)=-\lambda_B P_B(t)+\mu_{ZB}P_{ZB}(t) \\ P_{ZB}'(t)=\lambda_B P_B(t)+\mu_{NB}P_{NB}(t)-(\mu_{ZB}+\lambda_{ZB})P_{ZB}(t) \\ P_{NB}'(t)=\lambda_{ZB}P_{ZB}(t)-\mu_{NB}P_{NB}(t) \end{cases} \quad (5)$$

If the time of occupancy of any block is describes by the nonexponential distribution function, with finite expected value, then, we have to use semimarkov approach [12].

Conclusions

The proposed models taking into account the navigator's subjective level of safety acceptance. These models can be more adequate after applying the semi-Markov model instead of the Markov model.

The map of hazard situations is basic one for the safety model because it has describes dynamic, changing in time, navigational situation. The selected density functions are considered, according to heuristic analysis, to construct the map of hazard. It has taken into account two possible situations:

– lack of information about movement of another ships;
– sufficient but not online information about ships vectors of velocities.

In the exemplary navigational situation the second case is taken to evaluate density functions. Further, these values are used to construct the hazard map for the considered situation.

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Recenzent:
dr hab. inż. Lucjan Gucma, prof. AM
Akademia Morska w Szczecinie