Application of fuzzy inference to assessment of degree of hazard to ship power plant operator

Tomasz Kowalewski
Antoni Podsiadło
Wiesław Tarełko
Gdynia Maritime University

ABSTRACT

This paper presents application of fuzzy logic to assessment of degree of hazard to ship power plant operator. For the assessment a system of computer-aided identification of hazardous zone within ship power plant, was used. The system's variables representing the subject-matter knowledge in safety design area were transformed into fuzzy sets by means of appropriate linguistic variables and membership functions. The assessing of safety level of operator with the use of fuzzy inference was performed by means of an expert system programmed in the PROLOG LPA language.

Keywords: safety, operator, ship power plant, assessment, fuzzy inference

INTRODUCTION

Complex technical objects (e.g. large transport units, electric power plants and power systems, chemical systems) can create significant hazards to safety of their operators. Sea-going ship is a complex technical object specific from safety point of view. According to many domestic and worldwide elaborations and reports the ship power plant can be deemed the most hazardous place on ship.

In ship power plant many dangerous and noxious factors which constitute various hazards to its operators appear simultaneously. For instance the following can be listed: displacing machines and transported objects, moveable elements, falling elements, pressurized fluids, slippery and uneven surfaces, limited spaces, hot and cold surfaces, caustic and toxic substances. Therefore it would be advisable to indicate, just in early design stages, such places in a ship power plant, which create potential hazards to operators.

The question appears whether it would be possible to limit consideration of ship power plant only to potentially most hazardous zones during designing its safety. In the authors' opinion it is possible provided use will be made of information on structure and function of a power plant, contained in preliminary design documentation, as well as its consideration will be limited only to the zones where an operator (operators) carrying out certain service operations concerning a given technical object, appears. The idea was realized in the computer aided advising system for identification hazardous zones in ship power plant [1]. The system proposes certain safety design strategies for the zones distinguished by it.

The system's concept consists in cooperation between designer and computer where :

- the designer provides appropriate information to the system on the basis of analysis of preliminary design of ship power plant, as well as his own knowledge, intuition and experience
- the computer processes the put-in data, calculates indices and orders distinguished hazardous zones of the power plant taking into account possibility of creating potential hazard to its operator.

The description of the computer-aided identification system of hazardous zones within ship power plant was presented in [2], its elements (variables and functions) as well as a way of modelling the subject-matter knowledge for computer purposes - in [3], and a way of determining its decision variables - in [4] , [5].

In the identification system in question the additive method of estimation of degree of hazard to ship power plant operator, was chosen. A drawback of the method is the linear ranking of potential influence of particular states (symptoms) of distinguished variables, which could not be capable of modelling real influence of endangering and noxious factors on creating a hazard to operator. The drawback can be eliminated by using the fuzzy assessment and inference method. It correctly models the uncertainty associated with the assessment of influence of particular variables on the creating of a hazard to operator.

This work is aimed at consideration of possible application of fuzzy logic to assessing hazardous zones to ship power plant operators.

THE COMPUTER - AIDED IDENTIFICATION SYSTEM OF HAZARDOUS ZONES WITHIN SHIP POWER PLANT

Operation of the computer - aided hazardous zone identification system

The operation of the system in question is realized in such a way that its user – making use of a knowledge base and taking into account various limitations – performs assessment of the system's state, and on this basis he determines a degree of hazard to operator by using a set of measures. The decision

–making procedure consists in choosing the values of input variables, which are capable of causing a definite effect to operator, i.e. hazard to his life or health. Basing on the values of input variables – determined by the system's user – the system calculates value of hazard degree assessment index for considered element of hazardous zone and for n-th identification task, in accordance with the following relationship :

$$I_{H,m}^{(n)} = I_{OF,m}^{(n)} + I_{FF,m} = k_{n,m} w_n c_n + \sum_{j=1}^{J} w_j c_{j,m} \quad (1)$$

where :

- $I_{H,m}^{(n)}$ – index of influence of endangering and noxious factors on the creating of potential hazard to operator, which occur during carrying out service operations realized in compliance with the considered *n-th* procedure concerning *m*-th structural unit
- $I_{OF,m}^{(n)}$ – index of influence of service factors on the creating of potential hazard to operator, which occur during carrying out service operations realized in compliance with the considered *n-th* procedure concerning *m*-th structural unit
- $I_{FF,m}$ – index of influence of functional factors on the creating of potential hazard to operator, which occur during carrying out service operations realized in compliance with the considered *n-th* procedure concerning *m*-th structural unit
- $k_{n,m}$ – number of service operations appearing in *n*-th procedure for *m*-th structural unit
- w_n – weighing factor for *n*-th procedure
- c_n – value of service variable for *n*-th procedure
- w_j – weighing factor for *j*- th functional variable
- $c_{j,m}$ – value of functional variable for *m*-th structural unit
- J – number of functional variables.

If the task of identification of hazardous zone element is considered for a set of service procedures it will be necessary to calculate the hazard index in compliance with the following realtion :

$$I_{OF,m} = \sum_{n=1}^{N} I_{OF,m}^{(n)} \quad (2)$$

where :

- $I_{OF,m}$ – total index of influence of service factors on the creating of potential hazard to operator, which occur during carrying out all service operations distinguished by considered procedures concerning *m*-th structural unit
- N – number of considered procedures.

The assessment index of hazardous zone element – considered according to a set-in criterion (number and kind of service procedures) – is determined by using the following relationship :

$$I_{H,m} = \frac{I_{OF,m}}{\sum_{m=1}^{M} I_{OF,m}} + \frac{I_{FF,m}}{\sum_{m=1}^{M} I_{FF,m}} \quad (3)$$

where :

M – number of structural units distinguished by the considered procedures.

Decision variables of the hazardous zone identification system

As assumed according to [1], ship power plant operator will find himself in a potentially hazardous zone only when he performs definite service operations. Degree of hazard is a function of factors resulting from operation of machines and devices, access to working place, kind of performed operation as well as position of operator. The first two are associated with functional structure of power plant and constructional form of considered unit and its environment, whereas the two remaining – with kind of service task carried out in given external conditions. For this reason the sets of the factors were conventionally split into the group of functional factors and that of service factors. For purposes of the identification system in question both the groups of factors were transformed into the set of input variables for the system.

The performed classification of the factors hazardous and noxious to operator as well as the awareness of main and auxiliary working processes carried out in ship power plant, as well as of service states of ship and its power plant, made it possible to distinguish the set of 10 input variables to the hazardous zone identification system, where 6 of them belong to the group of functional factors, and 4 to that of service factors. The detail description of the procedure for distinguishing the input variables is given in [4] and [5].

In this paper only the group of functional factors is considered. The names and states (symptoms) of functional input variables used for assessing particular structural units are presented in Fig.1.

In the system in question to each of the distinguished variables is attributed the weighing factor $\mathbf{w}_j$ of constant value and five states (symptoms) of the values : 1, 0.75, 0.5, 0.25, respectively, or 0 in the case if a given symptom of considered variable does not involve a hazard to operator.

The task of the system's user is to attribute – on the basis of his knowledge, experience and intuition – appropriate values to the variables during solving a chosen identification problem of zone hazardous to operator. In the case when a variable takes zero value its symptoms are not taken into account on the system's dialogue screens (Fig.1) and then the system's user does not mark any of those symptoms whereas the system automatically attributes zero value to the variable in question.

FUZZY INFERENCE ASSESSMENT OF DEGREE OF HAZARD TO TECHNICAL OBJECT'S OPERATOR

In considering hazard to operator all influencing factors, namely functional and service ones should be taken into account. However for purposes of analysis of possible application of fuzzy inference to assessing degree of hazard to operator the authors' attention was paid only to functional factors, i.e. those associated with realization of operational processes in various service states. To this end, the functional variables were transformed into linguistic ones and fuzzy estimates were attributed to their particular symptoms. Next, to particular linguistic variables appropriate membership functions were attributed. Trapezoid is one of the most often appearing forms of membership functions [7, 8, 9]. Hence the membership functions in question were represented by trapezoids. The assumed form and distribution of membership functions constitutes a preliminary proposal only. In the next phase of the research the properties of the functions will be corrected depending on the knowledge gained from the experienced experts – ship power plant operators. The particular membership functions for the decision variables (V1÷V6) as well as the resulting variable which characterizes level of hazard to operator are presented in Fig.2.

To assess degree of hazard to operator were used the programming language Prolog and software Flint which makes

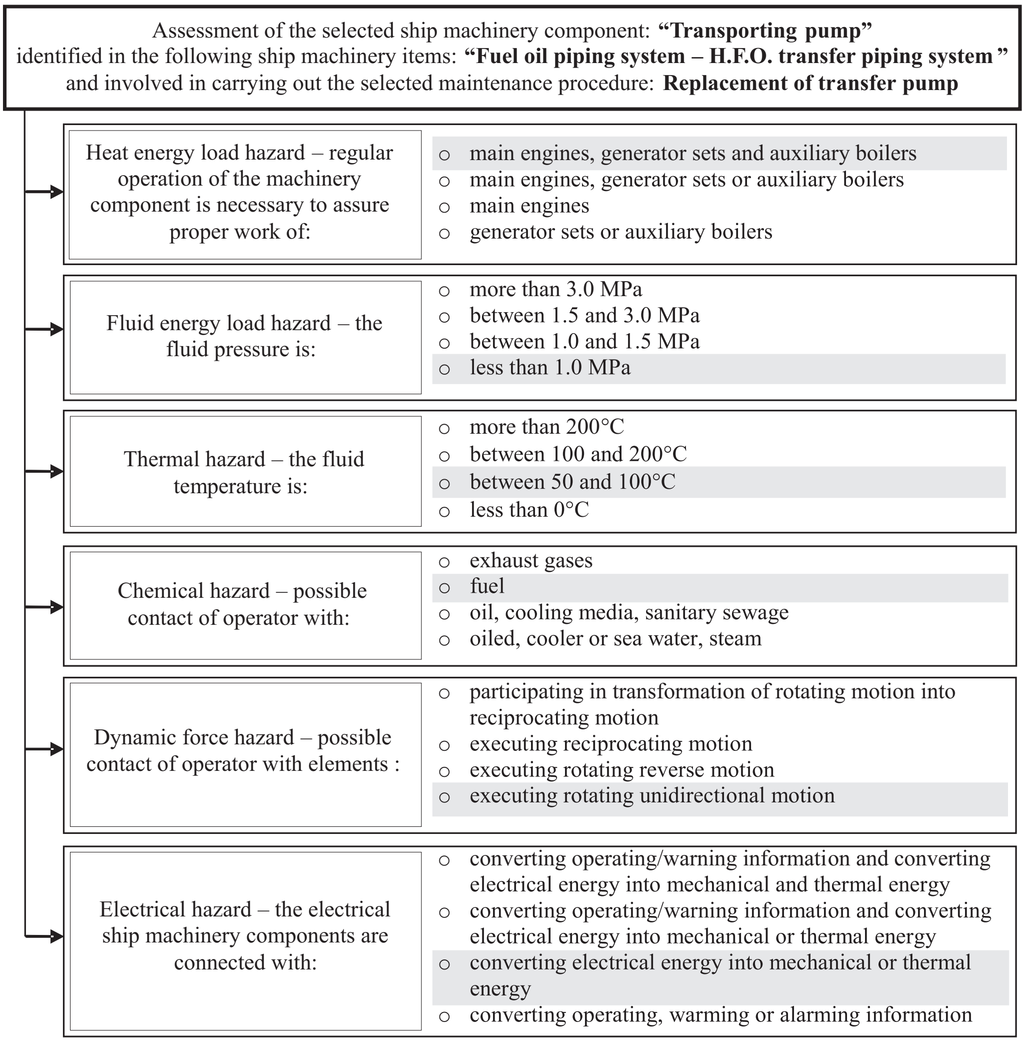

Fig. 1. *Schematic diagram of assessing hazards to operator from the side of the structural unit : "transporting pump" during realization of the procedure: "replacement of transporting pump" .*

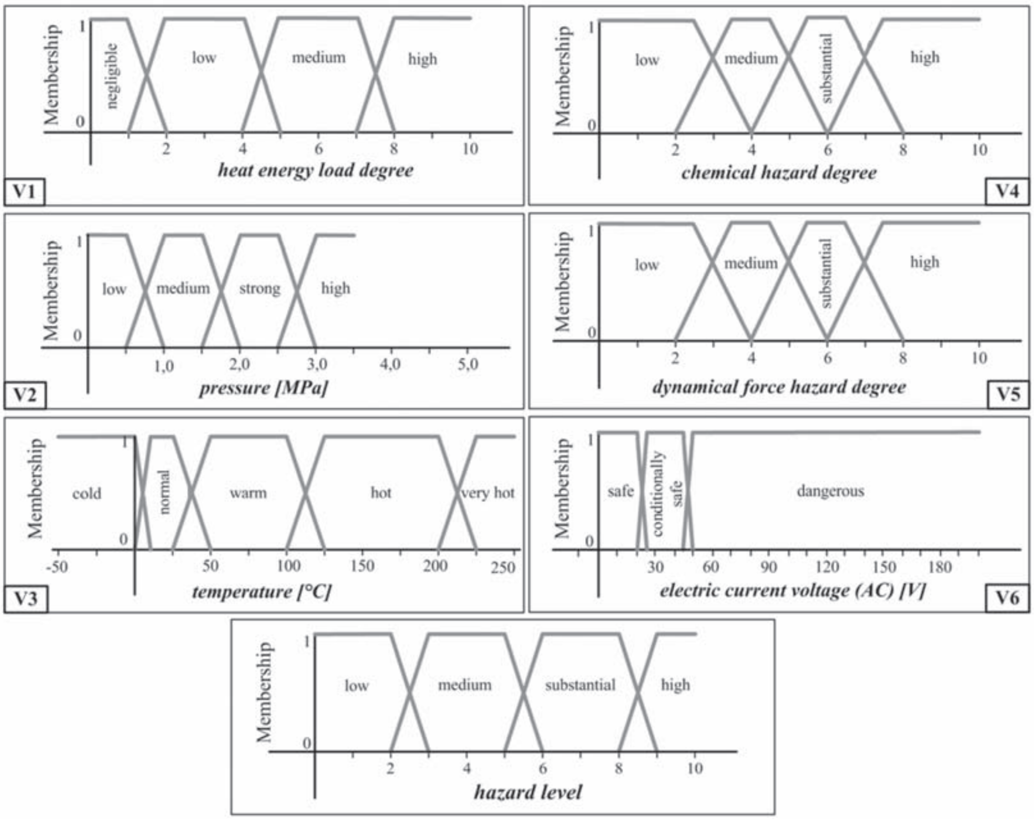

Fig. 2. *Membership functions for functional variables and hazard level .*

fuzzy inference in that language possible. The base of rules in the software Flint, for the distinguished linguistic variables and their values, has the form of the fuzzy matrix as follows :

fuzzy_matrix(t) :-
V1 * V2 * V3 * V4 * V5 * V6 -> hazard level
*small*low*normal*small*small*safe -> low*
…

The notation can be interpreted as follows : „If **V1** is **small** and **V2** is **low** and … and **V6** is **safe**, then the **hazard level** is **low**".

However in this case to fully determine all hazardous situation it was necessary to write as many as 5120 rules. Owing to the great number of variables the base of rules was simplified in such a way that hazard level is considered separately for each of the variables, that significantly decreases size of the base of rules. For instance the rules concerning the variable Z2 will have the following form :

fuzzy_matrix(pressure_reg) :-
pressure -> hazard level
low -> low
medium -> medium
high -> significant
v.high -> high.

Full estimate of hazard to operator by using fuzzy sets, performed by the system's user for a given structural unit, will be based on the estimates of particular functional variables. The partial index of hazard level assessment for the considered hazardous zone element, $\mathbf{I}_{\mathbf{FF,m}}$, will result from the fuzzy inference. The value will be obtained by means of the MAX-MIN inference method with implemented „defuzzification" by using the gravity centre method [7], [9, 10].

As an example the assessment of hazard during replacement of main engine's fuel pump is considered. In Fig.3 the functional variables used for the hazard assessment and the values attributed by the system's user, are presented.

In the considered case, the following values were attributed to the particular functional variables :

- ***V1*** *(range 0÷10) → 3*
- ***V2*** *(range 0÷3.5) →1.25*
- ***V3*** *(range -50÷+250) → 150*
- ***V4*** *(range 0÷10) → 6*
- ***V5*** *(range 0÷10) → 2*
- ***V6*** *(range 0÷380) → 220.*

During fuzzy inference process, due to aggregation of active rules, is obtained the resulting fuzzy set (Fig.4) from which – after its "defuzzification" – the final value of hazard level is achieved.

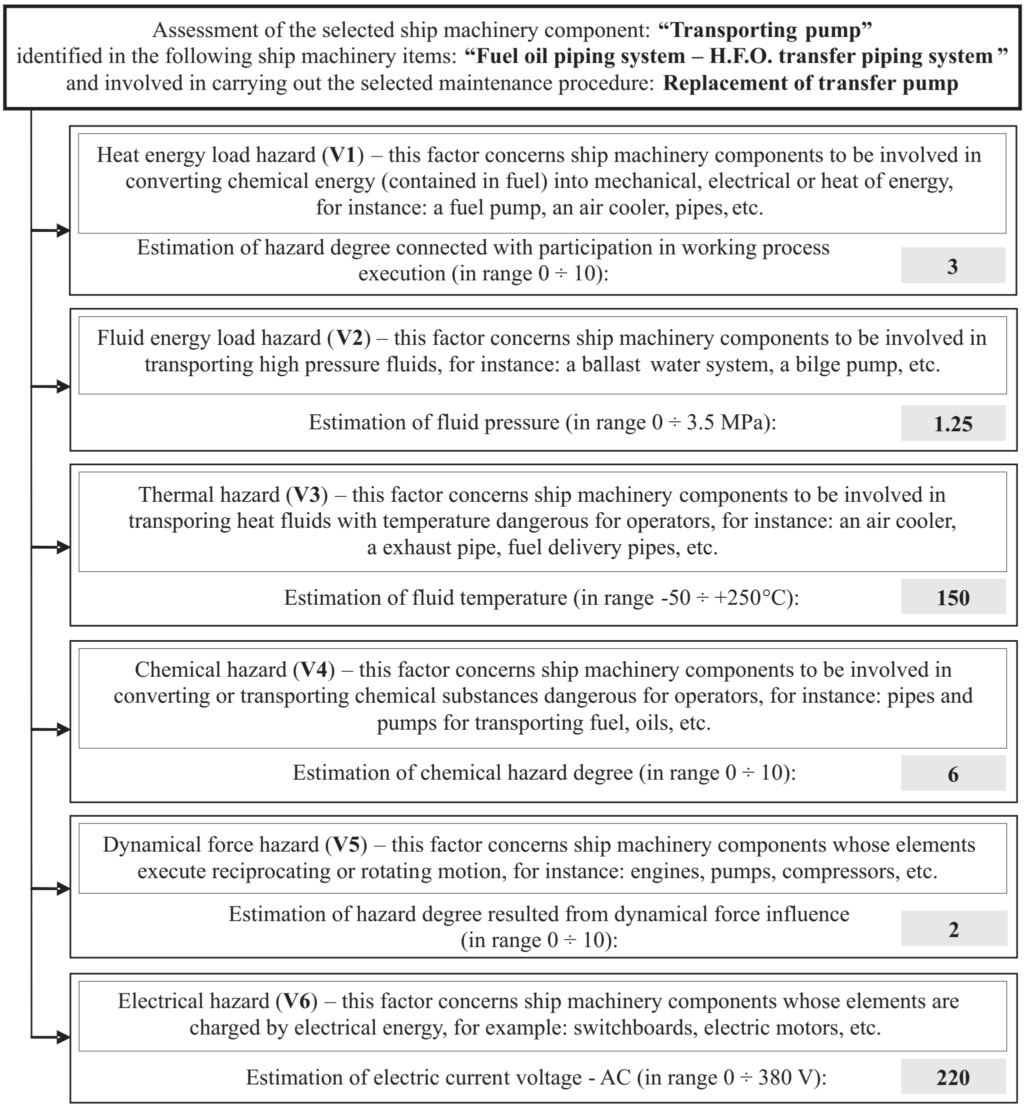

Fig. 3. *Functional variables and estimates involved by the system's user .*

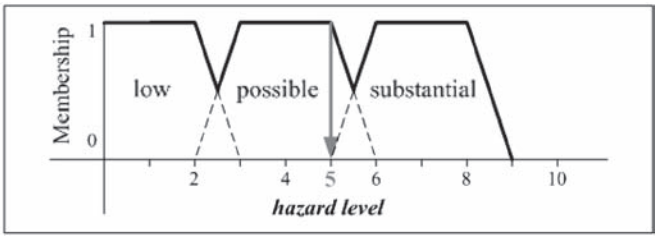

Fig. 4. The resulting fuzzy set and final value of hazard level due to functional factors .

CONCLUSIONS

On the basis of the obtained investigation results the following conclusions can be formulated :

- The application of fuzzy logic makes it possible to estimate operator's safety already during design process of ship power plant, especially in its early stages when information on hazardous and noxious factors to operator are not precise and associated with high uncertainty
- In contrast to the classical solutions the assessment of degree of hazard to operator by using fuzzy logic rules models more realistically qualitative aspects of human knowledge, and the inference process itself does not require performing any quantitative analyses
- The application of the special computer software which helps in using fuzzy inference, to a great extent decreases range of efforts connected with building the base of knowledge, as well as its size within the computer-aided hazardous zone identification system.

NOMENCLATURE

a, b, c – linguistic variables
$c_{j,m}$ – value of functional variable for m-th structural unit
c_n – value of service variable for n-th procedure
f(x) – function providing a membership value in [0,1] fuzzy set
$k_{n,m}$ – number of service operations appearing in n-th procedure for m-th structural unit
w_n – weighing factor for n-th procedure
w_j – weighing factor for j-th functional variable,
$\mu_A(x)$ – membership function of a given element in A fuzzy set
A, A1, A2, B, B1, B2, C1,C2 – fuzzy sets
$I^{(n)}_{H,m}$ – index of influence of endangering and noxious factors on the creating of potential hazard to operator, which occur during carrying out service operations realized in compliance with the considered n-th procedure concerning m-th structural unit
$I^{(n)}_{OF,m}$ – index of influence of service factors on the creating of potential hazard to operator, which occur during carrying out service operations realized in compliance with the considered n-th procedure concerning m-th structural unit
$I_{FF,m}$ – index of influence of functional factors on the creating of potential hazard to operator, which occur during carrying out service operations realized in compliance with the considered n-th procedure concerning m-th structural unit
J – number of functional variables
M – number of structural units distinguished by the considered procedures.
N – number of considered procedures
V1÷V6 – functional variables
X – numerical space of consideration

BIBLIOGRAPHY

1. Tarełko W. *et al.* : *Antropo-technical assumptions for designing safe technical objects – subject-matter report* (in Polish). Report on realization of the research project no. 8T07C 01120 financed by KBN. Bulletin no. 1. Basic Engineering Department, Gdynia Maritime University. Gdynia, 2004
2. Podsiadło A., Tarełko W. : *Identification of hazardous zones in ship power plants*. Proceedings of European Safety & Reliability Conference (ESREL 2005). Advances in Safety and Reliability,Vol. 2, A.A. Balkema Publishers. Gdańsk, June 2005
3. Podsiadło A., Tarełko W. : *Modelling a decision-making process of hazardous zone identification in ship power plants.* Proceedings of European Safety & Reliability Conference (ESREL 2005). Advances in Safety and Reliability, Vol. 2, A.A. Balkema Publishers. Gdańsk, June 2005
4. Tarełko W. : *Machinery function factors triggering off hazards for operators of ship power plants.* Proceedings of the 12th International Congress of the International Maritime Association of the Mediterranean (IMAM 2005),Vol. 1, Lisboa, September 2005
5. Podsiadło A. : *Operational factors triggering off hazards for operators of ship power plants.* Proceedings of the 12th International Congress of the International Maritime Association of the Mediterranean (IMAM 2005). Vol. 1, Lisboa, September 2005
6. Westwood D.: *LPA PROLOG. Version 4.3. Technical Reference.* Logic Programming Associates Ltd. London, 2002
7. Łachwa A. : *Fuzzy world of sets, numbers, relations, facts, rules and decisions* (in Polish). EXIT Academic Publishing House (Akademicka Oficyna Wydawnicza EXIT). Warszawa 2001.
8. Niczyj J. : *Multi-criterion reliability optimization and technical state estimation of bar structures by using theory of fuzzy sets* (in Polish). Scientific Research Reports of Szczecin University of Technology, No. 581. Department of Theory of Structures, issue No. 3. Szczecin, 2003
9. Piegat A. : *Fuzzy modelling and control* (in Polish). EXIT Academic Publishing House (Akademicka Oficyna Wydawnicza EXIT). Warszawa, 2003
10. Piech H. : *Inference based on fuzzy strategies* (in Polish). Publications of Częstochowa University of Technology. Częstochowa, 2005.

CONTACT WITH THE AUTHORS

Tomasz Kowalewski, M.Sc., Eng.
Assoc. Prof. Antoni Podsiadło
Assoc. Prof. Wiesław Tarełko
Faculty of Marine Engineering,
Gdynia Maritime University
Morska 81/87
81-225 Gdynia, POLAND
e-mail : tomkow@am.gdynia.pl

Photo: Cezary Spigarski

Main building of the Gdynia Maritime University .