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Estimation of rule base quality of fuzzy models of intelligent decision support systems (IDSS)

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Abstract

Some problems of design of the fuzzy system rule base for Intelligent Decision Support System (IDSS) are considered. The fuzzy system rule base used at decision making about an accommodation of industrial and social objects in territories, dangerous from the point of view of hydrometeorological factors, is the object of research. An approach to determining the parameter of the fuzzy model rule base completeness is presented. Influence of the fuzzy model input vector structure on decisions offered by IDSS is investigated. Research is carried out with use of the package Matlab Fuzzy Logic.

Keywords: rule base, fuzzy environment, linguistic variable, intelligent decision support system, hydrometeorological information.

Ocena jakości bazy reguł rozmytych modeli inteligentnych systemów wspomagania decyzji

Streszczenie

W artykule autorka rozpatruje wybrane zagadnienia budowy rozmytej bazy reguł Inteligentnego Systemu Wspomagania Decyzji (ISWD) wykorzystującego informację hydrometeorologiczną. Informację hydrometeorologiczną charakteryzuje niepewność i niepełność. Powoduje to trudności w ocenie skutków decyzji podejmowanych na podstawie tej informacji. Jako narzędzie pomocnicze w tym przypadku może służyć ISWD, w którego strukturze zawarte są systemy rozmyte. Jako obiekt badań występuje baza reguł systemu rozmytego, wspomagającego proces podejmowania decyzji o możliwości rozmieszczenia obiektów socjalnych i przemysłowych na terenach zagrożonych niebezpiecznymi czynnikami hydrometeorologicznymi. W artykule autorka przedstawia podejście do określenia wskaźnika kompletności bazy reguł modelu rozmytego oraz wyniki badań wpływu struktury wektora wejścia modelu rozmytego na rozwiązania proponowane przez ISWD. Badania prowadzono przy wykorzystaniu oprogramowania Matlab Fuzzy Logic.

Słowa kluczowe: baza reguł, środowisko rozmyte, zmienna lingwistyczna, inteligentny system wspomagania decyzji, informacja hydrometeorologiczna.

1. Introduction

In the modern conditions, use of different type of information technologies for management significantly influences significantly the quality of accepted decisions. The special attention is given to creation of *Intelligent Decision Support Systems (IDSS)*. They can be built in a structure of information control systems of regional and local level. The *Intelligent Decision Support Systems* can function as local subsystems, or can be integrated with other information technologies (GIS, OLAP) as well as with internal and external data sources.

Strategic decisions on accommodation and protection of industrial and social objects in territories which are subjected to influence of the dangerous natural phenomena, are always accepted in view of the hydrometeorological information.

It is necessary to note that the hydrometeorological information is usually characterized by incompleteness and illegibility. For this reason, the results of decisions accepted on a basis of this information are difficult to be estimated because of absence of clear algorithms of the decision making. In such cases IDSS can be used to increase the confidence of correctness of the decisions taken. In papers [1,2] the author already presented models of the knowledge base for IDSS, which took into account the hydrometeorological information uncertainty and the subjectivity of decision-making process estimations by experts. In the present paper the author is developing the problem of creating fuzzy models for IDSS knowledge bases in which the hydrometeorological information is used. The author puts the main accent on the estimation quality of fuzzy model rule bases. When creating IDSS, the problem of preparing the contents of the knowledge bases plays the major role. When formatting the knowledge base, the fact that decisions making in view of the hydrometeorological information occurs under fuzzy conditions should be considered. It is achieved by means of accommodation of fuzzy models in the contents of knowledge bases of IDSS. In work [3] approach of Bellman and Zadeh [4] to the description of fuzzy conditions is described. According to this approach, fuzzy conditions are developed from fuzzy purposes, fuzzy restrictions and fuzzy decisions. Thus, fuzzy models should represent the fuzzy purposes (for example, reduction of negative consequences of influence hydrometeorological factors on economic objects) and fuzzy restrictions (for example, force of the hydrometeorological phenomenon etc.).

Also fuzzy decisions (for example, an opportunity of accommodation of object in the given territory) should be presented. When creating fuzzy systems, the important place will be occupied by fuzzy linguistic models containing the fuzzy linguistic variables, the fuzzy sets and the fuzzy rules which take into account input-output functional dependences of the system. The fuzzy model rule base is the central component of this system.

The question of the rule base quality always arises when designing fuzzy models for the IDSS knowledge base. The rule base quality can be estimated with a help of different characteristics, such as the rule base completeness, the fuzzy model input vector characteristics etc. [5]. Analyzing all these characteristics, it is possible to evaluate the quality of the created rule base, and accordingly, of IDSS knowledge bases.

The purpose of this paper is to present the approach to determining the completeness of the fuzzy model rule base in case when terms - sets of linguistic variables are characterized by a different number of elements. In the paper there are also given the analysis results of influence of structural and quantitative characteristics of the fuzzy model input vector on decisions of IDSS. The research was carried out on an example of the fuzzy model IDSS rule base intended for supporting decisions on an opportunity of accommodation of economic objects in territories that are subjected to the influence of dangerous hydrometeorological factors. Such decisions should be considered at a stage of tentative estimation of projects whose financing is supposed to be carried out from the means of regional funds of development. Technology Matlab - Toolbox Fuzzy Logic was used for investigations.

2. Influence of some characteristics of the fuzzy model rule base on the IDSS decisions

When elaborating the fuzzy models of class IDSS systems, the accuracy of decisions offered by them plays the paramount role.

Obviously, the accuracy depends on characteristics of the fuzzy system rule base. These characteristics belong to structural and quantitative characteristics of the fuzzy model input vector: the content and number of input linguistic variables as well as the number of elements of terms - sets of each linguistic variable; the completeness and consistency of inference rules, the structure and parameters of the membership function of input and output linguistic variables, the methods for fuzzification and defuzzification.

The high accuracy of the fuzzy model and the little number of inference rules are quite difficult to obtain. When increasing the fuzzy model accuracy, it is impossible to avoid increase in the number of rules. In this case search for the appropriate compromise is one of the problems which must be decided at design of any fuzzy system.

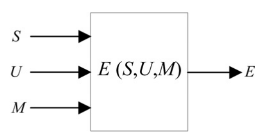
It is possible to assume that there are no objective mathematical ways of grade estimation of such systems. However, comparison of characteristics of different variants of the fuzzy models, such as completeness of the rule base or type of the membership function, allows choosing a rule base variant of necessary quality. In the paper the analysis results of influence of some characteristics of the fuzzy model rule base on IDSS decisions are presented.

2.1. Structure and number of linguistic variables in the fuzzy model

To design the fuzzy model for the IDSS knowledge base, it is necessary to create the rule base in which fuzzy linguistic variables will be used. The structure and number of linguistic variables in the fuzzy model included in the IDSS knowledge base, obviously, influences the system decisions.

According to the aim of the paper, the variants of structure of the fuzzy model are compared for different characteristics, such as the system input vector dimension and the number of elements in terms - sets of input linguistic variables.

The procedure of defuzzification of output linguistic variables is not considered in the paper, as it does not influence essentially the decisions. For example, the following linguistic variables were chosen: *S* - social and economic significance of an economic object for the given region, *U* - useful territory for accommodation of the given object, *M* - influence of hydrometeorological factors on functioning of the economic object situated on the territory, *E* - expedience of the object accommodation on the given territory. The block diagram of the system at whose input there are three linguistic variables *S*, *U* and *M*, and at the output - one linguistic variable *E* is shown in Fig. 1.



Rys. 1. Struktura modelu rozmytego ISWD
Fig. 1. Structure of the IDSS fuzzy model

During inference IDSS should give the answer (linguistic variable *E*) to the question: whether it is possible (and to what degree) to accommodate the given economic object on the given territory when taking into account all input factors. The answer should be given on an universal set T_E of values of this linguistic variable in the form of separate fuzzy variables E_I for which the area of search for values is the universal set $X_E = [0,100]$.

The object of investigations is to find influence of the rule base completeness and structures of the input linguistic variables on the characteristics of IDSS decisions obtained from simulations on the fuzzy model.

Before analysing the investigation results, the approach to estimation of the rule base completeness will be presented.

2.2. Estimation of the fuzzy model rule base completeness

The problem of estimation of the rule base completeness is considered in detail in work [5]. In this work it is emphasized that the rule base is the major part of the fuzzy model. The characteristics of the rule base of this model are presented in the paper.

One of the basic characteristics of the rule base is its completeness. According to the definition given in work [5], the fuzzy model rule base is linguistically complete if to each linguistic state of each input vector corresponds, at least, one linguistic state of the output vector.

Formalizing the process of estimation of the rule base completeness, there will be presented a parameter of completeness as follows:

$$C = \frac{N}{P}, \tag{1}$$

where: C - an index of the rule base completeness, N - number of the rules which are taken into account in the output mechanism, P - the greatest possible number of the consistent rules.

Parameter P is defined by the formula:

$$P = \prod_{j=1}^{m} p_j , \tag{2}$$

where: m - dimension of the fuzzy model input vector, p_j - number of elements of term-sets of an input linguistic variable with the appropriate index "*j*".

In works [5, 6] a little bit different formula for estimation of P is given:

$$P = Z^w , \tag{3}$$

where: w - dimension of the model input vector, Z - number of elements of term - set of each linguistic variable. It is easy to note that results of calculations of size P by formulas (2) and (3) coincide in case when terms - sets of all linguistic variables of the input contain the same number of elements.

Formulas (1), (2) allow carrying out calculations of the completeness index of the rule bases at any number of elements in terms - sets of linguistic variable of the fuzzy model. It is obvious that by development of the rule base it is necessary to aim at obtaining the parameter of completeness C equal to one.

2.3. Influence of the structure of input linguistic variables on IDSS decisions

Investigations were carried out for two variants of the model shown in Fig. 1. As the first variant the structure of terms - sets of the linguistic variables presented in Table 1 was considered.

Tab. 1. Struktura termów - zbiorów warunków zmiennych lingwistycznych w rozmytym modelu ISWD
Tab. 1. Structure of terms - sets of linguistic variables in IDSS fuzzy model

Name of a linguistic variable	Term - sets of linguistic variables			
S - significance	*S1* - high	*S2* - middle	*S3* - small	
U - useful	*U1* - high	*U2* - middle	*U3* - small	
M - meteo	*M1* - small	*M2* - middle	*M3* - high	*M4* - very high
E - expedience	*E1* - certainly possible	*E2* - possible	*E3* - doubtful	*E4* - not recommended

According to formula (2), the maximal number of the rules given in the conjunctive form for the fuzzy model in this case is 36. The limited paper volume does not allow giving the complete report of 36 rules. In Table 2 only 3 of the developed systems of rules are presented.

Tab. 2. Fragment bazy reguł dla pierwszego wariantu modelu rozmytego ISWD
Tab. 2. The rule base fragment for the first variant of IDSS fuzzy model

	S1	*S2*	*S3*	*U1*	*U2*	*U3*	*M1*	*M2*	*M3*	*M4*	*E1*	*E2*	*E3*	*E4*
1	√			√			√				√			
2	√			√				√				√		
	...				…			…					…	
36			√			√				√				√

For example (see Table 2) the rule 1 was entered as: **<**if *S1* and *U1* and *M1* then *E1***>.** Some results of simulations are given in Table 3.

Tab. 3. Wyniki symulacji: warianty możliwych rozwiązań E=f (M, S, U) dla $U1$=5
Tab. 3. Simulation results: variants of probable decisions E=f (M, S, U) for case $U1$=5

Significance S <X_S = [0, 5]>	Meteo *M* <X_M = [0, 100]>					
	0	20	40	60	80	100
High S1 = 5	83,5	68,2	59,8	40,2	33,9	33,7
Middle S2 = 3	63,7	46,3	36,3	36,3	31,5	16,2
Small S3 = 1	62,7	47,8	34,1	25,6	25,6	19,1

In the second simulation variant the number of terms of the input linguistic variables presented in Table1 was reduced:

- for S: T_S = {*S1* - high, *S3* - small},
- for U: T_U = {*U1* - high, *U3* - small}
- for M: T_M = {*M1* - small, *M3* - high}.

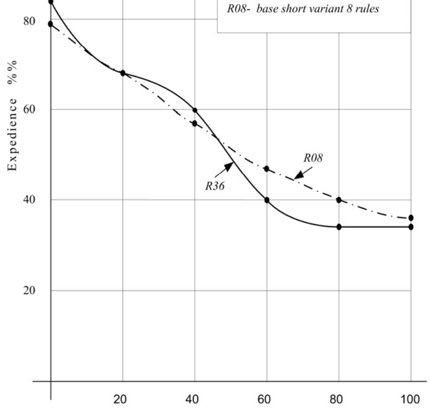
In this variant the maximal number of the rules designed in accordance with formula (2) decreased to 8.

The simulation results of this variant allow comparison with the previous variant as the number of terms of entrance linguistic variables is changed only, thus the structure of system is left without changes. Because of the limited paper volume the rule base is not shown here. Some simulation results for the second variant are presented in Table 4.

Tab. 4. Wyniki symulacji: warianty możliwych rozwiązań E=f (M, S, U) dla $U1$=5 (drugi wariant)
Tab. 4. Simulation results: variants of possible decisions E = f (M, S, U) for case $U1$=5 (the second variant)

Significance *S* <X_S = [0, 5]>	Meteo *M* <X_M = [0, 100]>					
	0	20	40	60	80	100
High S1 = 5	78,8	68,1	56,7	47,1	40,3	36,2
Middle S2 = 3	69,7	63,4	54,7	46,7	39,3	34,7
Small S3 = 1	64,2	59,6	53,1	43,7	32,9	25,1

In Fig. 2 there is shown the dependence E = f(M) for two cases to compare 36 rules with 8 rules (at $S1$ = 5 - the high significance of object and $U1$ = 5 - the territory is highly useful).



Rys. 2. Wpływ liczby termów na charakter decyzji proponowanych przez ISWD
Fig. 2. Influence of number of terms on character of the decisions offered by IDSS

The diagrams in Fig. 2 show evidently influence of the number of elements in terms-sets of linguistic variables on the character of IDSS decisions.

The analysis shows that the quality of received decisions using a smaller number of input linguistic variables in the fuzzy model, as a rule, can be sufficient at a stage of preliminary estimation of projects. Reduction in the number of input linguistic variables allows essentially reducing the labour-intensiveness of creation of the fuzzy model rule base. Thus, the quality of the decision remains at a satisfactory level.

The author of the paper also investigated systems of structure at higher level of complexity in comparison with those presented in the paper. For example, the comparison of two variants of systems with a scalar output and four input linguistic variables were investigated. For the first variant the term-sets of three input linguistic variables contained three elements, and the term-set of one more input linguistic variable contained four elements. In this case the greatest possible number of rules according to formula (2) was 108. For the second variant the term-sets of all input linguistic variables contained two elements. In this case the maximal number of rules was 16. The analysis of the results received from modelling in the Matlab Fuzzy Logic environment showed that the divergence of results did not exceed 15 - 20 %.

3. Conclusions

In the paper the results of investigating the influence of rule base characteristics of the fuzzy model on the decisions offered by IDSS are analysed. The investigations were carried out with use of Matlab Toolbox Fuzzy Logic on an example of the fuzzy model IDSS rule base intended for supporting decisions on possibility of economic object accommodation in the territory subjected to the threat of influence of dangerous hydrometeorological factors. In the paper two variants of the fuzzy models of different structure of input- output linguistic variables are compared. Reduction in the number of terms of the input linguistic variables allows essential reduction in the number of rules in the fuzzy model rule base. As a result, the labour-intensiveness of creation of the rule base can be reduced. The research results demonstrate that the quality of the decisions accepted in the fuzzy environment at the reduced number of rules in the fuzzy model can be sufficient at a stage of acceptance of initial administrative decisions.

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