Inference technique based on precedents in knowledge bases of intelligence systems

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Abstract. The problem of a decision of the current problem on the basis of the precedents appears in the engineering and in the medicine. So in the medicine the sick are treated for an illness on the basis of the precedents. In aviations when is using the group of airplanes for decision of the certain problem appears a necessary for the operative choice of strategies of their behaviors.

For formalization of the previous successful experience are using:

- a description of the problem by situational vector (SV); the coordinates of the SV are linguistical variables;
- a presentation of the previous experience through the knowledge matrix - an ensemble of the precedents that was using for the success decisions of the problem.

Under operative use the formalized experience description problems is produced by situational vector with quantitative importance of the coordinates - a result of the measurements - a current situational vector. So in the medicine - current importance result analysis sick, in aviations - a results of the measurements, entering from on-board measuring device. On the current situational vector result by means of proposed mechanism pays the vector a priority precedent, recommended for decision of the concrete problem. The precedent with the maximum priority is recommended for use.

The time of the arrival of the measurements is usually fixed (t1, t2, ,ti,).

Change at time of the condition of the problem and mistakes of the measurement bring about unstable recommendation. For stabilization their is used procedure of the smoothing of the vector of the priorities of the precedents at a certain slithering time lag.

1. **INTRODUCTION.** Onboard operative advising expert systems of typical situations (OOAES TS) of anthropocentric object functioning are intended to solve problems of the second global level of control [Fedunov 1996,1998]. These are the so-called tactical problems; i.e., the problems determining rational ways for the attainment of a current aim of the operation, which is operatively appointed by the crew of the anthropocentric object. For any typical situation (TS) of functioning, a special OOAES should be created.

The structure of the knowledge base of the OOAES is based on a formal model of the object domain [Fedunov1998] in which the general problem of the operation session of the anthropocentric object is represented via the semantic network of problem subsituations (PrS/S).

We briefly dwell on the description of the destination and the form of the inference technique in the knowledge base of an OOAES.

Using the current information from onboard measuring devices, standard algorithms in onboard computers, signals from the information–control field (ICF) of the crew compartment, a situation vector SV(TS–PrS/S) is formed in the knowledge base of the OOAES. This vector describes the state of the outboard and onboard environment for assigning (or identifying) the current PrS/S. We call the technique of such an assignment the inference technique on the set of PrS/S. It is constructed on the basis of results of cooperating with experts who are specialists in the object domain considered.

These mechanisms are implemented in the
OOAES in the form of the rules "if …, then …, else …." Their completeness and consistency is achieved by finalizing the OOAES on systems of imitational modeling (SIM) together with experts.

The inference technique used for (determining) a rational solution to the current PrS/S is represented by three types of mechanisms. The first type is a mechanism identical to the mechanism of PrS/S assignment mentioned above. However, it is constructed for resolving the PrS/S in the knowledge base of an OOAES not
only on the basis of the materials of cooperation with experts, but (and first of all) by the results of mathematical investigation of the optimization problems, whose statement is adequate to the PrS/S considered. In this case, the specific character of a PrS/S prevails over the formal methods for considering it. The first section is devoted to discussing the inference techniques of this type. They are approved practically when designing intelligent systems including designing OOAES knowledge bases.

Among the problem subsituations of operation sessions of anthropocentric objects, there are those that cannot have a completely adequate formal description. As a rule, they are analyzed in detail when the crew is preparing for the forthcoming operation session. As a result of this system analysis, with regard for *a priori*
data about possible conditions for the occurrence of this PrS/S in the forthcoming operation session, some admissible alternatives for its resolution are outlined. This approach is used in the inference technique constructed on the basis of the algorithm for multicriteria choosing of an alternative developed by the American scientist T.

Saaty. The second section contains a description of the inference technique of this (second) type. The technique is approved by constructing a fragment of the knowledge base of an OOAES planned for design.
Finally, the inference techniques of the third type
(which are not currently approved in the practice of OOAES design) are described in Section 3. In discussions with experts and potential users of OOAES, requests are often repeated to develop some mechanisms for presenting to the crew a successful precedent appropriate for the current problem subsituation. For these cases, the most adequate inference technique is the mechanism employing a peculiar knowledge matrix and a description of the problem subsituation by the situation vector SV(PrS/S–solution) whose coordinates are linguistic variables. It seems that these three types of inference techniques do not exhaust all of the possible types inherent in the object domain considered. Of course, their choice for the top-priority investigation is stipulated by the available practice of designing the knowledge bases of the first versions of known OOAES. Below, we dwell only on the inference technique of OOAES TS proposed for use while resolving a problem subsituation.

2. INFERENCE TECHNIQUE BASED ON OPTIMIZATION MODELS

The inference technique of the first type, i.e., the mechanism based on product rules, is most often used in OOAES. In a system of rules (constructed in a certain way), a situation vector SV(PrS/S–solution) that describes the current state of the problem in qualitative coordinates (the left-hand side of the product rule) is associated with the most rational (optimal) way for its resolution (the right-hand side of the product rule). Let us briefly dwell on the methods for constructing the product rules, which are most frequently used in practice when designing OOAES knowledge bases: interviewing experts; constructing the rules on the basis of results of the investigation of optimization models. Constructing the rules on the basis of a preliminary investigation of the problem on its mathematical model is similar to the procedure for constructing the rules on the basis of discussions with experts. In the latter, the model of the problem and the results of its investigation are in the mind of an expert, and the designer of the OOAES should interview some experts and then formalize the knowledge obtained in the form of a totality of rules. The effectiveness and the difficulties of this method for constructing a system of OOAES rules (an
inference procedure) have been discussed in [Gavrilova&others 1992].
Without neglecting the use of this method, we, nevertheless, prefer the second one, namely, the method for constructing the rules on the basis of optimization models. Moreover, we admit the possibility of the joint use of both these methods.
Thus, there is a PrS/S, whose study we are going to initiate. We will describe it by a vector SV(PrS/S–solution) whose coordinates can have only quantitative values. We will create a mathematical model (MM) of this system, which includes the following components: a set of admissible means for its resolution; mechanisms for associating any concrete method for resolving the PrS/S with the result of the action of this method on the PrS/S (the connection “method–outcome”); a mechanism for estimating the quality of every outcome. We state the problem of finding the most preferable method (optimal according to the criterion of the quality estimation) for resolving the PrS/S being studied. We see that this MM is represented in the form of an optimization problem whose solution will be sought in the form of the synthesis of a (situation) control [Pospelov 1986].
Examples of statements of such optimization problems, which we solved while developing the knowledge bases of concrete OOAES, as well as the results of their solution, are presented in [Fedunov 1995, Egorova&others 1996].
On the basis of the obtained solution (synthesis), the rules for rational resolution of the PrS/S being studied are formulated. The right-hand side of the rule contains the values of the coordinates of the vector SV(PrS/S–solution), and the left-hand side contains an appropriate method for resolving the PrS/S for this specific description of the problem. Examples of such rules are given
in [Demkin&others 2001].

3. INFERENCE TECHNIQUE BASED ON ALGORITHMS FOR MULTICRITERIACHOICE.

For a number of anthropocentric objects (for instance, piloted aircraft), problem subsituations are distinguished, whose complexity does not allow one to formulate adequate optimization mathematical problems, but for which, at the stage of preparation for the forthcoming operation session of the anthropocentric object, their crews produce the following:
a set of alternative methods for resolving the PrS/S (alternatives $\{Ai\} = (A1, \ldots, Ai, \ldots, An)$
for resolving the PrS/S);
a set of criteria $\{Kj\} = (K1, \ldots, Kj, \ldots, Kk)$ for estimating the result of applying each of the alternatives (preference criteria).
As a rule, any particular PrS/S realized in the operation session requires a certain adaptation of each alternative Ai and, possibly, operative reestimation of the relative importance of the criteria $\{Kj\}$.We shall make the opera-

tive multicriteria choice of the most preferable alternative using the method of pairwise comparisons proposed by Saaty [Saaty 1991].
An example of implementing the inference technique described is given in [Musarev&others 2001].

4. INFERENCE TECHNIQUE BASED ON PRECEDENTS.

Such inference methods are used in problem subsituations, whose complexity does not allow one to constructively formalize them, but for which there is some experience (precedents) of their successful resolution.
One of difficulties of this approach is the correct choice of the coordinates ($x_1,...,x_i,..., x_n$) of the situational vector SV(PrS/S-solution), both in their number and in the form of representation of each coordinate. The completeness of the description of the situational vector and the connection of a particular vector with a particular precedent is established by long-term cooperation with experts, who are actual bearers of this knowledge [Fedunov 1998].
As a rule, the coordinates of the situational vector are linguistic variables.

4.1. LINGUSTIC VARIABLE AS A COORDINATE OF THE SITUATIONAL VECTOR.

A linguistic variable is defined by Zadeh in [Zadeh 1973] as a variable whose values belong to a specified set of terms or expressions of a natural language. The latter were also called terms.

To work with linguistic variables, one should represent each term via an appropriate fuzzy set [Kaufmann 1977]. The latter, in turn, is represented via a universal set (universe) and the membership function of the elements of the universal set to the considered fuzzy set.

The membership function takes the values in the interval [0, 1]. It quantitatively estimates the grade of membership of an element in a fuzzy set.

Note that both the universal sets and the membership functions on the set are specified on the basis of investigation results (together with experts) of the corresponding object domain.

For a large number of terms, their membership functions are usually specified in a unified form. Most often, this is a piecewise linear function.

4.2. KNOWLEDGE MATRICES BY PRECEDENTS.

Let a state of a problem subsituation be described by a situational vector with coordinates ($x_{1,...,} x_i, .., x_n$) and each coordinate x_i be a linguistic variable with a set of terms $A_i = \{a_i^1,...,a_i^j,...,a_i^{K_i}\}$. For certain realizations of the situational vector, where each linguistic variable takes one of its possible values (a concrete term), there is a precedent of successful resolution of this PrS/S.

Suppose that a set d_j, $j = 1, ..., p$, of precedents is accumulated and each precedent is associated with a set of particular situational vectors, for which this precedent has been selected.

Let us construct the matrix of this correspondence (this matrix have the form of Table 1). We select the rows of the matrix corresponding to a precedent (the block of the precedent). Any row of the matrix is a concrete situational vector for which the corresponding precedent has been successfully realized in the past.

We enumerate the rows of the block of precedent d_j, with two indices: the first index is the number of the precedent (here, it is the number of the block), and the second index is the serial number of the situational vector in this block.

This matrix determines a system of logical propositions of the form *"if..., then..., else..."* For instance, the row j_1 of the matrix encodes the following proposition:

$$\underline{\text{if}}\ x_1 = a_1^{j1}\ \underline{\text{and}}\ x_2 = a_2^{j1}\ \underline{\text{and}} \ldots \underline{\text{and}}\ x_i = a_i^{j1}\ \underline{\text{and}} \ldots \underline{\text{and}}\ x_n = a_n^{j1},\ \underline{\text{then}}\ d_j, \qquad (1.1)$$

else a similar proposition for the next row, etc.

The obtained system of logical propositions ordered in this way is called a fuzzy knowledge matrix or, simply, a knowledge matrix.

4.3. ALGORITHM FOR CALCULATING THE MEMBERSHIP FUNCTION OF PRECEDENT d_t.

First of all, we present an algorithm [Rotshtein 1999] for determining the membership function μ_{dj} (x_1, .. x_i, .. x_n) of the precedent d_j interpreted as a fuzzy set on a universal set $Ud = Ux_1 \times \ldots \times Ux_i \times \ldots \times Ux_n$, where Ux_i is a universal set on which the terms of the linguist! variable x_i are defined, and U_d is the Cartesian product of the universal sets Ux_i .

Any logical proposition of the type (1.1) or, equivalently, any row of the knowledge matrix is a fuzzy relation of the corresponding fuzzy sets. For instance, for (3.1), this is $a_1^{j1} \times a_2^{j2} \times \ldots \times a_n^{jn}$.

Nos.	Coordinates of the situational vector					min	max	d
	x_1		x_i		x_n			
:	:	:	:	:	:	:	:	:
j_1	$(a_1^{j1})^*$	....	$(a_i^{j1})^*$	....	$(a_n^{j1})^*$	$\min_i (a_i^{j1})^*$	$\max_{js} \min_i (a_i^{js})^*$	μ_{d_j}
:	:	:	:	:	:	... ...		
j_s	$(a_1^{js})^*$	....	$(a_i^{js})^*$	....	$(a_n^{js})^*$	$\min_i (a_i^{is})^*$		
:	:	:	:	:	:	... ...		
j_{K_j}	$(a_1^{jK_j})^*$	....	$(a_i^{jK_j})^*$	....	$(a_n^{jK_j})^*$	$\min_i (a_n^{jK_j})^*$		
:	:	....	:	....	:	....	....	:

Table 1. The knowledge matrix.

In accordance with [Zadeh 1973, Kaufmann 1977], the membership function of a fuzzy set generated by this fuzzy relation is $\mu_{a_1^{j1}}(x_1) \wedge \ldots \wedge \mu_{a_i^{j1}}(x_i) \wedge \ldots \wedge \mu_{a_n^{j1}}(x_n)$, where "$\wedge$" we denote the "min" operation.

Analyzing the whole block of logical propositions related with precedent d_j (the block of the corresponding rows of the knowledge matrix), note that they form the union of the corresponding fuzzy sets generated while considering the rows of the selected block. In accordance with [Pospelov 1986, Fedunov 1995], the membership function of this union, which is identified with the membership function of the precedent *dj,* is

$$\mu_{d_j}(x_1,\ldots,x_i,\ldots,x_n) = (\mu_{a_1^{j1}}(x_1) \wedge \ldots \wedge \mu_{a_i^{j1}}(x_i) \wedge \ldots \wedge \mu_{a_n^{j1}}(x_n)) \vee$$
$$\ldots \vee (\mu_{a_1^{jK_j}}(x_1) \wedge \ldots \wedge \mu_{a_i^{jK_j}}(x_i) \wedge \ldots \wedge \mu_{a_i^{jK_j}}(x_n))$$

where by «$\vee$» we denote the "max" operation.

Formally, this algorithm for determining the membership function of the precedent *dj* can be written in the following form:

(a) Fix an arbitrary point $(x_1^*,\ldots,x_i^*,\ldots,x_n^*) \in U_{x_1} \times \ldots \times U_{x_i} \times \ldots \times U_{x_n}$;

(b) for any block of the knowledge matrix corresponding to d_i determine $\mu_{dj}(x_1, .. x_i, .. x_n)$ at this point according to the scheme of Table 1.

Note that, for any fixed point $(x_1^*, \ldots, x_i^*, \ldots, x_n^*)$, the block of the matrix presented in Table 3 is numerical, because each term $\max_{js}$ from this block is replaced with the value of its membership function $(a_i^{js})^*$ calculated at the corresponding x_i^*. The operation $\min_i a_i^{js}$ is performed with the numbers located in rows "i," $1 \le i \le n$, and the minimal number in the corresponding row is placed in the column "min."

The $\max_{jS} \min_i a_i^{js}$ operation selects the greatest of the row minima obtained for $1 \le j_s \le K_J$. This number is the value of the membership function $\mu_{dj}(x_1, \ldots, x_i, \ldots, x_n)$ at the fixed point $(x_1^*, \ldots, x_i^*, \ldots, x_n^*)$. Performing this calculation for every point of the universal set, we obtain the membership functions that interest us.

4.4. ALGORITHM FOR CHOOSING A PRECEDENT WHEN OBSERVING A SITUATIONAL VECTOR WITH QUANTITATIVE COORDINATES.

When observing a situational vector with quantitative coordinates (all coordinates of the vector are measured by numerical scales), in order to select the most preferable precedent, it is not necessary to completely determine the membership functions $\mu_{dj}(x_1, .. x_i, .. x_n)$ on the whole set of points of the universal set. It is sufficient to calculate their values only for fixed numerical values of the coordinates of the vector, which is obtained by us as a result of the observation (table 2). For this purpose, we should use the algorithm from Subsection 4 once, taking the coordinates of the observed situational vector as $(x_1^*, \ldots, x_i^*, \ldots, x_n^*)$.

As a result, for any precedent *dj,* we obtain a number $d_j(x_1^*, \ldots, x_i^*, \ldots, x_n^*)$, which is the grade of membership of d_j to the point $(x_1^*, \ldots, x_i^*, \ldots, x_n^*)$.

Starting from this interpretation, the most preferable precedent for resolving the observed PrS/S is the precedent d_j* such that

$$d_j^*(x_1^*,...,x_i^*,...,x_n^*) = \max_{1\le j\le p} \qquad d_j(x_1^*,...,x_i^*,...,x_n^*).$$

.Nos .	Coordinates of the situational vector					min	max	d
	x_1		x_i		x_n			
:	:	:	:	:	:	:	:	:
j_1	$(a_1^{jl})^*$	…….	$(a_i^{jl})^*$	….	$(a_n^{jl})^*$	$\min_i (a_i^{jl})^*$		
:	:	:	:		:	… …		
j_s	$(a_1^{js})^*$	…….	$(a_i^{js})^*$	….	$(a_n^{js})^*$	$\min_i (a_i^{is})^*$	$\max_{js} \min_i (a_i^{js})^*$	μ_{d_j}
:	:	:	:		:	… …		
j_{K_j}	$(a_1^{jK_j})^*$	…….	$(a_i^{jK_j})^*$	….	$(a_n^{jK_j})^*$	$\min_i (a_n^{jK_j})^*$		
:	:	…	:	…	:	………	………..	:

Table 2. The knowledge matrix for the observed situational vector as $(x_1^*, ..., x_i^*, ..., x_n^*)$

4.5. EXAMPLE.

For formalization of the previous successful experience are using:
- a description of the problem by situational vector (SV); the coordinates of the SV are linguistical variables;
- a presentation of the previous experience through the knowledge matrix - an ensemble of the precedents that was using for the success decisions of the problem.

Under operative use the formalized experience description problems is produced by situational vector with quantitative importances of the coordinates - a result of the measurements - a current situational vector. So in the medicine - current importances result analysis sick, in aviations - a results of the measurements, entering from on-board measuring device. On the current situational vector result by means of proposed mechanism pays the vector a priority precedent, recommended for decision of the concrete problem. The precedent with the maximum priority is recommended for use.

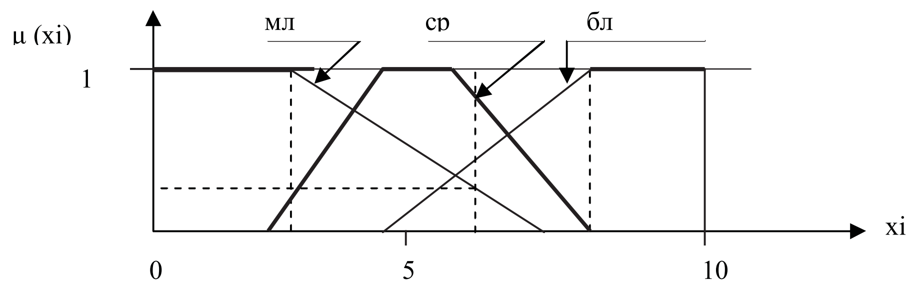

Figure 1: The accesories functions of the fuzzy sets, corresponding therms of linguistical variable xi, i=1,2,3.

The time of the arrival of the measurements is usually fixed (t1, t2, ,ti,).
Change at time of the condition of the problem and mistakes of the measurement bring about unstable recommendation. For stabilization their is used procedure of the smoothing of the vector of the priorities of the precedents at a certain slithering time lag.
Let problem of the application domain is described SV=(x1,x2,x3). Each coordinate of this situational vector is linguistical variable (LP) with set of therms (small (мл), average (ср), big (бл)). Each therm is introduced its fuzzy set. The functions accessories (FP) are determined on universal multitude [0,10] (refer to figure 1).
The importance of the characteristic points each FP (on the left on the right) are accordingly мл1, мл2; ср1, ср.2; бл1, бл2. Their importance are presented in table 3.
Let for considered class of the problems is formed the knowledge matrix for two precedents (the table 4).
The moments of the arrival SV=(x1,x2,x3), taken in sliding interval, the weights of the measurements and quantitative importance of the coordinates of the situational vector are given in table 5.

LP	мл1	мл2	ср.1	ср.2	бл1	Бл2
X1	2	5	3	7	3	9
X2	1	4	3	5	2	8
X3	3	6	4	6	4	7

Table 3 The functions accessories (FP)

Let for considered class of the problems is formed the knowledge matrix for two precedents (the table 4).
The moments of the arrival SV=(x1,x2,x3), taken in sliding interval, the weights of the measurements and quantitative importance of the coordinates of the situational vector are given in table 5.
The moments of time, the vector of the priorities of the precedent for each SV=(x1,x2,x3) and result their averaging on slithering interval are given in table 5.

№ п/п	***Coordinates of the situational vector***					Precedents (Пр)
	x_1	**x_2**	**x_3**			
1.1 1.2	мл мл	ср ср	бл ср			Пр1
2.1 2.2	ср ср	мл мл	ср бл			Пр2

Table 4 The knowledge matrix for two precedents

Moments of time	The weight of the measurements	X1	X2	X3
t1	0.2	2	5	7
t2	0.3	3	3	5
t3	0.4	2	6	4

Table 5 the weights of the measurements and quantitative importance of the coordinates of the situational vector

Moments of time	Situational vector	Пр1	Пр2
t1	SV=(2,5,7)	1	0
t2	SV=(3,3,5)	0.62	0.32
t3	SV=(2,6,4)	0.8	0
Moment of the recommendation issue	On slitherring interval of the observation	0.79	0.09

Table 5 the vector of the priorities of the precedent for each SV=(x1,x2,x3) and result their averaging on slithering interval

The most priority precedent Пр1 is presenting to a user at moment t3.

7. CONCLUSIONS

For decision operative appeared problems, referring to class of the problems, for which on-is accumulated positive experience of their decision (the precedents), is offered:
- fix this experience in form of the matrix of the knowledge with situational vector (vector coordinates are a linguistic variables),
- on the current quantitative description of the appeared problem by means of situational vector with quantitative coordinate using operations fuzzy relations and associations is chosen the most-favored precedent.

This inference technique has been studied only theoretically and has been tested on simple practical examples [Vasil'ev&others 2000]. It is directed to be used in the inference technique of precedents and is based on the algorithms for choosing a solution on the basis of the knowledge matrix. These algorithms are successfully applied in diagnostic problems.

8. REFERENCES

Demkin, M.A. and Fedunov, B.E. 2001. A Frag- ment of the Knowledge Base OOAES TS Ensuring Evasion of theOOAES Carrier from a Pursuer, *Iskusstvennyi intellect* (Artificial Intelligence), NAN Ukrainy, № 3.

Egorova, E.T. and Fedunov B.E.1996. Minimax Problem of Placement and Tracing Points in a Circle and Potential Capabilities of Measurement Devices, Journal of computer and systems sciences international (A Journal of Optimization and Control) ISSN 1064-2307. English Translation of Izvestiya of Rossiiskoi Akademii Nauk. Teoria i Sistemy Upravleniya. № 3.

Fedunov, B.E., 1995. The Optimization Models for Taking the Decision in the Algorithmic and Indicational Support System Designing: Systems, Analysis, Modeling Simulation, J. Mathematical Modeling and Simulation in Systems Analysis, 1995, vols. 18, 19.

Fedunov, B.E. 1996, Problems of the Development of Onboard Operative and Advising Expert Systems for Anthropocentric Objects, . Journal of computer and systems sciences international (A Journal of Optimization and Control) ISSN 1064-2307. English Translation of Izvestiya of Rossiiskoi Akademii Nauk. Teoria i Sistemy Upravleniya,., №. 5.

Fedunov, B.E. 1998. Constructive Semantics of Anthropocentric Systems for Development and Analysis of Specifications for Onboard Intelligent Systems. Journal of computer and systems sciences international (A Journal of Optimization and Control) ISSN 1064-2307. English Translation of Izvestiya of Rossiiskoi Akademii Nauk. Teoria i Sistemy Upravleniya. № 5.

Gavrilova, T.A. and Chervinskaya, K.R. 1992. *Izvlechenie istrukturirovanie znanii dlya ekspertnykh sistem* (Extractionand Structurization of Knowledge for Expert Systems). Moscow: Radio i Svyaz'.

Kaufmann A. 1982. *Introduction a la theorie de sous-ensembles flous*, Paris: Masson, 1977. Translated under the title *Vvedenie v teoriyu nechetkikh mnozhestv*, Moscow: Radio i Svyaz'.

Musarev L.M. and Fedunov B.E.2001. The Structure of Target Allocation Algorithms on Board the Commander of an Aircraft Group. Journal of computer and systems sciences international (A Journal of Optimization and Control) ISSN 1064-2307. English Translation of Izvestiya of Rossiiskoi Akademii Nauk. Teoria i Sistemy Upravleniya. №. 6.

Pospelov, D.A. 1986. *Situatsionnoe upravlenie: teoriya ipraktika* (Situational Control: Theory and Practice). Moscow: Nauka.

Saaty, T. 1991. *The Analytic Hierarchy Process. Planning, Priority Setting, Resource Allocation*, New York: McGraw-Hill, 1980. Translated under the title *Analiticheskoe planirovanie. Organizatsiya sistem*, Moscow: Radio i Svyaz'.

Rotshtein, A.P. 1999. *Intellektual'nye tekhnologii identifikatsii* (Intelligent Technologies of Verification), Vinnitsa:Universum/.

Vasil'ev S.N., Gherlov A.K., Fedosov E.A., Fedunov B.E. 2000. Intelligent control of dynamic systems. Moscow, Fizmatlit, (by Russian).

Zadeh L. 1976. *The Concept of a Linguistic Variable and ItsApplication to Approximate Reasonong*, New York: Elsevier, 1973. Translated under the title Ponyatie lingvisticheskoi peremennoi i ee primenenie k prinyatiyu priblizhennykh reshenii, Moscow: Mir.