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MODEL OF ADAPTATION UNDER INDETERMINACY

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Information retrieval in information systems (IS) with large amounts of data is not only a matter of an effective IS architecture and design and technical parameters of computer technology used for operation of the IS, but also of an easy and intuitive orientation in a number of offers and information provided by the IS. Such retrievals in IS are, however, frequently carried out with indeterminate information, which requires other models of orientation in the environment of the IS.

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Classification: 93E12, 62A10

1. INTRODUCTION

Information retrieval in information systems (IS) with large amounts of data is not only a matter of effective IS architecture and design and technical parameters of computer technology used for operation of the IS, but also easy and intuitive orientation in a number of offers and information provided by the IS. Such retrievals in IS are, however, frequently carried out with indeterminate information, which requires other models of orientation in the environment of the IS. Classical adaptive systems, enabling easier orientation in a huge number of data, are controlled by instant discrete events. However, it is necessary to remark and point out two existing fundamental aspects in such systems:

- their development (evolution) in time,
- uncertainty of information which they deal with.

It concerns known situations of information retrieval on websites in various times when we do not get the same results in various times. Similarly, even the user, for whom we create the web interface, changes in time and a common system of adaptation is not ready for this fact. Another frequent problem is uncertainly – made enquiries or inaccurately obtained parameters of the user and qualities of the elements. In certain cases, this uncertainty can be implemented by insufficiently known information due to its corruption, but also due to their requirements on adaptability and autonomy. Considering this kind of uncertainties, it enables the system to deal with unexpected events which can occur when retrieving information on the web as well as to adapt to new applications installed on the web.

2. DECISION PROCESS MODELLING

When modelling such processes on a computer, it is necessary to have a system that enables knowledge acquisition from reactions of the IS users when retrieving information. It primarily concerns simulation of decision making processes as well as ways of knowledge acquisition.

Generally, human mental behavior may be featured as decision making, planning, coordinating, and communicating, being based on information acquisition, storage, evaluation, and classification. In order that any system could substitute or "support" a human in some of the above mentioned activities, such a system must be primarily able to communicate well with the human as well as to offer him/her tools, which would directly support the activities. Other important features are:

- possibility to apply heuristics (together with formally expressed knowledge),
- capability to provide explanations concerning derivations-in-progress as well as concerning the applied knowledge,
- possibility to simply integrate a new knowledge increment into the existing sum of the system knowledge.

Simulation of decision making processes is featured as follows:

- decision making is not based on analytic information only, but predominantly on the knowledge represented by both cognitive and abstraction processes (which are the privilege of brain activities),
- decision making can be done through various approaches depending on the number of the judging persons,
- it is very difficult to formulate an algorithm of the decision making procedure,
- a lot of information used during decision making is of external origin with respect to the already implemented data base of the decision making problem.

A decision making process can be defined as an organic unity of three phases:

- information (knowledge acquisition),
- planning (considering alternatives),
- selection (variant selection).

In order to identify the structure of a decision making process and thus to establish prerequisites to find effective procedures for its algorithmization, we have to deal with decision making processes from a wider, especially methodological point of view.

3. INDETERMINACIES IN DECISION MAKING PROCESSES

One of the characteristic features of decision making processes is the fact that they often work with indeterminate and non-metric information, which often stems from the fact that the input quantities of these processes are entered by a human on the basis of his/her experience, opinion, etc.

Indeterminacy, or insufficient definition of these processes, also has its own structure enabling the use of corresponding tools for work with a corresponding type of incompleteness. The basic structure of incompleteness in the area of information (we are primarily interested in this area) can be depicted by the following scheme (see Figure 1).

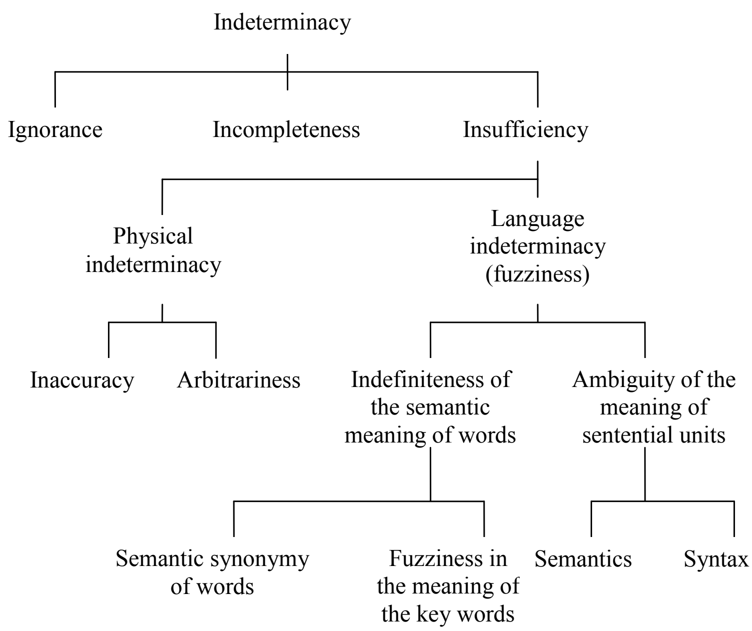

Fig. 1. Structure of indeterminacy.

When analyzing indeterminacies occurring during solving a given decision making process, it often comes out that the indeterminacy is, in fact, represented by insufficient information caused either by external factors (physical indeterminacy) or a language, by means of which a human factor enters the solution. The insufficiency itself is primarily represented by physical indeterminacy caused either by inaccuracies in measuring given quantities and their quantitative expression or in the existence of physical possibilities with more or less accidental occurrence which is impossible to be predicted in advance with a sufficient accuracy. The second type of insufficient information is the use of a natural language, introduced to the decision making process by a human, who then describes the decision making process itself and its functioning. Insufficiency of this information consists in the fact that the human factor is forced to use a finite number of words in a finite time to describe situations, which, in fact, can be of an infinite number. This fact necessarily leads to the fact that most of the words, as well as sentential units, have a considerable variance of their own meaning.

These indeterminacies (indefinitenesses) of the semantic field of words are caused both by semantic synonymies of words and (primarily) by certain fuzziness in the meaning of the key words. The fuzziness then becomes the key cause of the fact that classical mathematics, and exact sciences in general, were not adequately capable enough to work with linguistically defined situations. There was a change in the last period, when so called fuzzy mathematics was created, enabling to work efficiently with such verbally described situations.

4. DECISION PROCESS MODEL

Despite the fact that the decision making process involves numerous indeterminacies, its structure can be defined relatively well. Especially, the elements of this decision making process can be divided into the following groups:

S — a set of situations,

D — a set of all possible solutions,

G — a set of all targets (admissible) for further functioning of a given system,

F — a set of all degrees of existence (probabilities) of a given object,

K — a set of all evaluations for a given solution,

T — time interval.

The decision making process itself is represented by various mappings among these sets. It particularly concerns the following mappings:

1. process of information completion about a given situation and its evaluation, i. e. selection of only the information which has importance for the final solution

$$M_1 : S \times T \times F \to S \times T \times F,$$

2. process of creating a set of admissible solutions, which consists of two partial processes

$$M_2 = M_{22} \circ M_{21},$$

where M_{21} — formulating management targets based on description of a given situation, M_{22} — formulating admissible solutions,

$$M_{21} : S \times T \times F \to G \times S \times T \times F,$$

$$M_{22} : G \times S \times T \times F \to D \times S \times T \times F,$$

3. process of modelling effects of admissible solutions

$$M_3 : D \times S \times T \times F \to D \times S \times T \times (S \times T)^\star \times F,$$

where $(S \times T)^\star$ defines the set of all chains over $(S \times T)$ and each admissible solution is allocated with a set of situations including their time courses, which arise from the given decision,

4. process of acceptance of the solution itself, which consists of two partial processes
$$M_4 = M_{42} \circ M_{41},$$
where M_{41} — evaluating the behaviour of effects of admissible solutions, M_{42} — selection of the best variants,
$$M_{41} : D \times S \times T \times (S \times T)^{\star} \times F \to D \times K \times T \times F,$$
$$M_{42} : D \times K \times T \to D \times T.$$

The whole decision making process is created through gradual composition of these partial processes
$$M = M_4 \circ M_3 \circ M_2 \circ M_1.$$

As we can depict in the following diagram (see Figure 2).

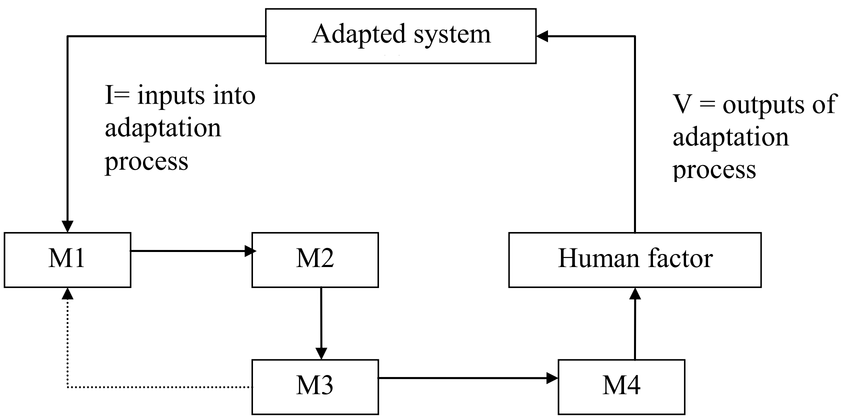

Fig. 2. Decision making process.

Let us note that realization of particular processes $M_1 - M_4$ can be ensured by means of so-called fuzzy algorithms using the results of fuzzy sets theory.

Particular processes $M_1 - M_4$ differ one from another by the character of input and output quantities as well as by other relations being performed within the process.

Generally speaking, each process can be featured by the following sextuplet
$$(T_i, T_v, X_{ch}, T_p, T_k, T_{kk}),$$
where

T_i — type of inputs,

T_v — type of outputs,

X_{ch} — character of outputs,

T_p — type of indeterminacy,

T_k — type of a selection criterion,

T_{kk} — type of particular elements of the criterion.

The particular types may take the values given in the following diagram (see Figure 3)

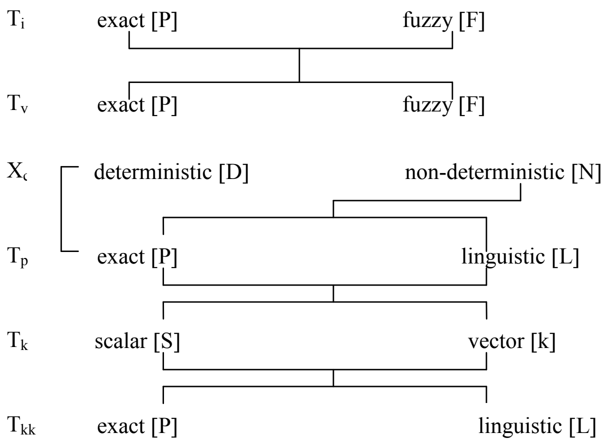

Fig. 3. Process types.

When creating the simulation system, we assumed that it would not be necessary to deal with all processes $M_1 \ldots M_{41}, M_{42}$ because some of them are evident.

We can presume that the process of information completion about a given situation and its evaluation M_1 is a part of acquisition of the input situation evaluation and it is not necessary to explain it in more details.

The key processes in the decision making process can be considered processes M_{22}, M_3, M_{41}, M_{42}.

5. MODEL OF WEB SYSTEM ADAPTATION

The adaptive web system monitors the behaviour and characteristics of an individual user who is then offered adapted information. The basic motivation to create the adaptive web system is variability of individual users. Thus it is necessary to prepare information corresponding to their abilities, preferences, and needs. We can adapt user interface, information content and structure, and other qualities of the provided information. It implies that the users of the adaptive system cannot be anonymous. The adaptive system keeps information about individual users which is continually evaluated and updated [2].

The input information into a decision making process on selection of the most important information visualised on the web can be divided into the following groups:

- data volume;
- information content;
- importance;
- availability;
- credibility;
- cost of information acquisition;
- time for information acquisition;
- size from the point of view of space taken up on disks, etc.

The output of the whole system should be a set of all possible solutions D represented by the following characteristics:

- suitability of the provided information, expressed, e. g., by:
  - real content,
  - comprehensibility,
  - frequency of enquiries about the information,
- recommendation for acquisition of the information from other sources.

The following part will try to indicate how to perform particular processes while stemming from the fact that that some parts of these processes, specific for conditions of retrieval on the web, have been already processed. This particularly concerns processes connected with M_3 — simulating impacts of particular decisions.

Based on this specification, we can define the following general structure of decision making system solving a given problem (see Figure 4).

6. MODEL OF CHOOSING AN OPTIMAL OPTION OF THE MAPPED INFORMATION ON THE WEB

First, let us consider the M_{42} process. From the classification point of view, as depicted in Figure 3, the process of selecting the optimum variant belongs to the following two key categories [1]:

$$\text{I. category} = (P, P, D, P, V, P),$$
$$\text{II. category} = (F, F, N, L, V, L)$$

The two categories correspond to the fact that during the selection of the optimum variant, the input quantities are entered either exactly or verbally, the output quantity is either exact (detailed analysis of the visualization variant) or on the contrary as a verbally described suitability of the given mapping, and a vector criterion entering the selection of mapping can also be described either defined exactly or set verbally.

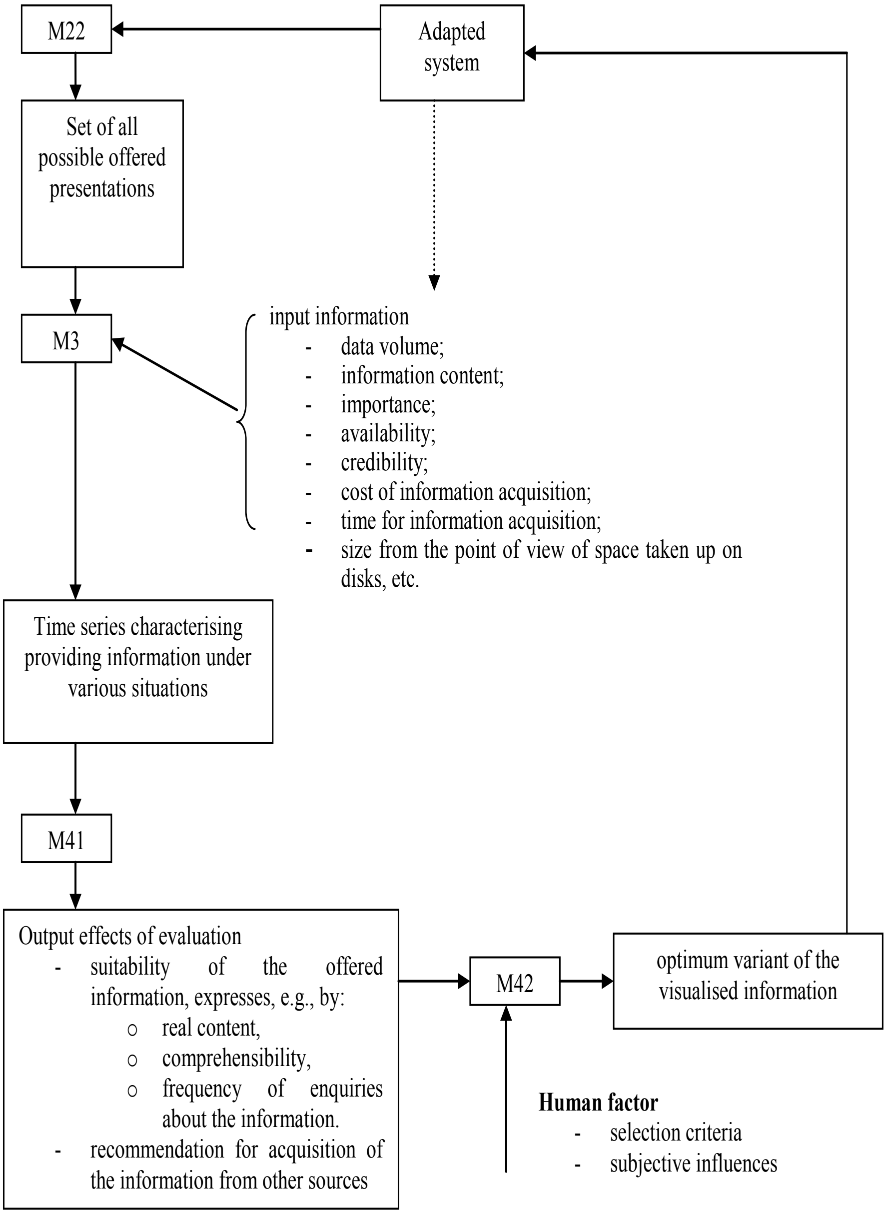

Fig. 4. Structure of decision making system.

It is evident that realisation of both processes M_{42}^{I} and M_{42}^{II} is quite different. While in the case of M_{42}^{I} process it concerns a classic vector optimisation, in the case of M_{42}^{II} process the situation is quite different.

We stem from the fact that the inputs of decision making process M_{42} as well as the decision making algorithm itself can be described uncertainly, primarily by linguistic terms characterising values of specific quantities or by relations between specific quantities. However, to make performance of such inputs and algorithms computerised, it is necessary to use a suitable mathematical apparatus. One of the possibilities how to perform such quantities is the theory of fuzzy sets. We will mention here some descriptions from this theory which are possible to be used in a decision making process [6, 7, 8].

Let U be a set of objects which are concerned in our decision making process (e. g. U is a time interval, or an interval representing average costs to acquire information expressed, e. g. by the amount of database passes, etc.). The fuzzy set in U will be called mapping

$$A : U \to [0, 1]\,,$$

where quantity $A(x),\ x \in U$, is called by the membership level of the element x in A. As each function, we can represent A by the guarantee of the function. For example, if $U = [2000, 10000]$ is the universe representing the quantity of information, then A in U defined by the diagram in Figure 5 represents the verbal term

$$A = \text{HIGHINFORMATIONLEVEL.}$$

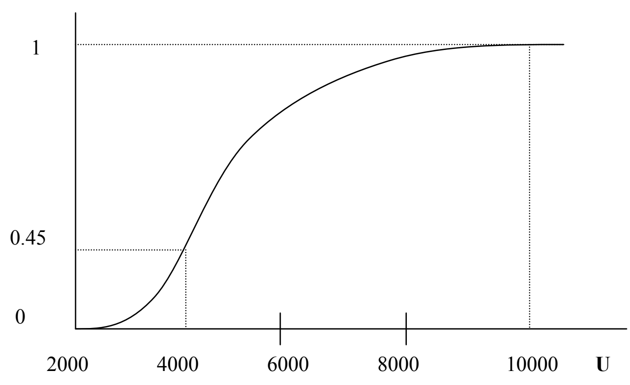

Fig. 5. Fuzzy set diagram.

The fact that A is a fuzzy set in U will be marked as $A \subseteq U$. Furthermore, the term "fuzzy relation" is important for our purposes. If U_1, U_2 are two universes, then fuzzy relation is a fuzzy set in their Cartesian product, i. e. $R \subseteq U_1 \times U_2$. If

e. g. $U_1 = U_2 = U$ in the previous example, then we can define the fuzzy relation $R =$ NEARLY EQUAL to $\subseteq U \times U$ by means of a functional prescription

$$R(x, y) = \mathrm{e}^{-|x-y|};\ x, y \in [2000, 10000]\,.$$

Similarly to classical sets, we can define analogue operations within the class of fuzzy sets. Particularly, if U is a universe, $A, B \subseteq U$, then we define

$$(A \cup B)\,(x) = \max\{A(x), B(x)\}\,,$$

$$(A \cap B)\,(x) = \min\{A(x), B(x)\}\,,$$

$$\neg A = 1 - A(x),$$

$$(A \times B)\,(x, y) = \min\{A(x), B(y)\}\,.$$

For our next objectives, it is important to introduce the term linguistic variable, i. e., the variable χ represented by the following system

$$\chi = \langle X, \tau, M\rangle,$$

where X is a domain of values, τ is a set of terms (i. e., specific words) and M is semantics, i. e., representation assigning a fuzzy set $M(t) \subseteq X$ to each term t.

If we consider the linguistic variable

$$\chi = \text{SIZES.}$$

The set of terms τ of this variable is created, e. g., by words

$$\tau = \{\text{HIGH}, \text{LOW}, \text{MEDIUM}, \text{VERY HIGH}, \ldots\}.$$

Then we can define as a domain of values, e. g., interval $X = \langle 0, 700\rangle$ (e. g., t suitability of the offered information) and function M for particular terms can be defined, e. g., in Figure 6 and

$$\begin{aligned}
M(\text{VERY } t)(x) &= [M(t)(x)]^2; x \in X,\\
M(\text{NOT } t)(x) &= 1 - M(t)(x),\\
M(t_1\text{AND } t_2)(x) &= \min\{M(t_1)(x), M(t_2)(x)\},\\
M(t_1\text{OR } t_2)(x) &= \max\{M(t_1)(x), M(t_2)(x)\}.
\end{aligned}$$

Then for example, the suitability level of the offered information

$$x = 3000t$$

corresponds to the verbal expression

$$t = \text{NOT VERY HIGH AND NOT VERY LOW}$$

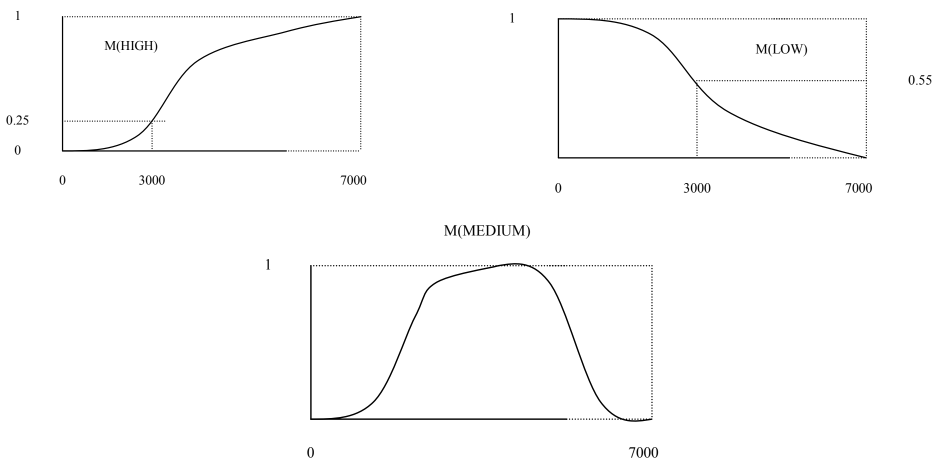

Fig. 6. Fuzzy sets diagrams.

with the membership degree

$$\begin{aligned} M(t)(x) &= \min\{M(\text{NOT VERY HIGH})(x), M(\text{NOT LOW})(x)\} \\ &= \min\{1 - M(\text{VERY HIGH})(x), 1 - M(\text{LOW})(x)\} \\ &= \min\{1 - (M(\text{HIGH})(x))^2, 1 - M(\text{LOW})(x)\} \\ &= \min\{1 - 0.25^2, 1 - 0.55\} = \min\{0.9375, 0.45\} = 0.45 \end{aligned}$$

i. e., only a half.

Using linguistic variables, we are able to set up fuzzy algorithms of certain processes. If the input quantities of a given system are $x = (x_1 \dots x_n)$ and the output ones $y = (y_1 \dots y_m)$, then the fuzzy algorithm means the expression:

$$\textbf{If } \varphi(x_1 \dots x_n), \textbf{then } \sigma(y_1 \dots y_m), \textbf{or } \psi(y_1 \dots y_m),$$

where $\varphi(x_1 \dots x_n)$, $\sigma(y_1 \dots y_m)$, $\psi(y_1 \dots y_m)$ are linguistic expressions concerning the individual mentioned quantities.

For example, in process M_{42}^{II} we consider the following situation. One of the partial decision making rules in this process can concern, e. g. the relations among the importance (e), availability (v), unit costs for information acquisition (j), and the selection of the given mapping (t). Let us suppose that $e \in \langle a_1, b_1 \rangle, v \in \langle 0, 100\% \rangle$. Then the verbal expression of one of the decision making rules can be as follows:

$R_1:$ if $e = \text{MEDIUM}, v = \text{HIGH}, j = \text{MEDIUM}, \text{then } t = \text{HIGH SUITABILITY}$

or

$R_2:$ if $e = \text{HIGH}, v = \text{HIGH}, j = \text{HIGH}, \text{then } t = \text{MEDIUM SUITABILITY}$.We

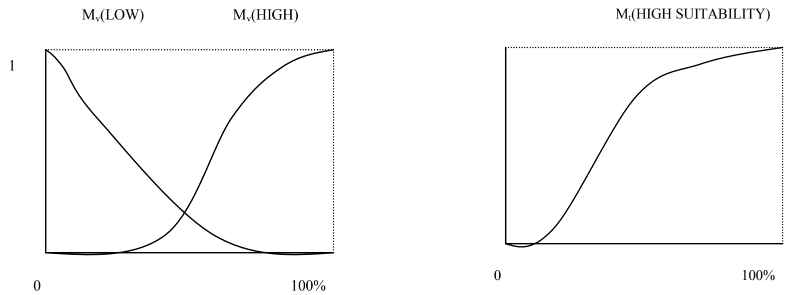

Fig. 7. Fuzzy sets diagrams.

then deal with the relation among 4 linguistic variables

$E = \langle\{\text{LOW, MEDIUM, HIGH, VERY, AND, NOT, OR}\}, \langle a_1, b_1\rangle, M_e\rangle$
$V = \langle\{\text{LOW, MEDIUM, HIGH, VERY, AND, NOT, OR}\}, \langle 0, 100\%\rangle, M_v\rangle$
$J = \langle\{\text{LOW, MEDIUM, HIGH, VERY, AND, NOT, OR}\}, \langle a_2, b_2\rangle, M_{1j}\rangle$
$T = \langle\{\text{LOW SUITABILITY, MEDIUM SUITABILITY, HIGH SUITABILITY, VERY, AND, NOT, OR}\}, \langle 0, 100\%\rangle, M_t\rangle,$

some fuzzy sets of which can be, e. g., as follows in Figure 7.

Generally, we can say that we posses such rules

$R_1:$ if $e = A_1, v = B_1, j = C_1,$ then $t = D_1$

$R_k:$ if $e = A_k, v = B_k, j = C_k,$ then $t = D_k$.

In case we have a specified input vector (e, v, j), we can determine the corresponding value with a corresponding mapping t as follows. Let d_i be an x-coordinate, the gravity center of surface lying above the graph of function D_i, i. e.,

$$d_i = \frac{\int x D_i(x)\,\mathrm{d}x}{\int D_i(x)\,\mathrm{d}x}; \quad i = 1, \dots, k; \; x \in \langle 0, 100\rangle.$$

Let furthermore

$$s_i = \min\{A_i(e), B_i(v), C_i(j)\} \in \langle 0, 1\rangle.$$

Then we can put

$$\text{SUITABILITY}(t) = \frac{\sum_{i=1}^{k} d_i s_i}{\sum_{i=1}^{k} s_i} \cdot 100 \in \langle 0, 100\%\rangle.$$

The set of rules $R_i, \dots, R_k$ can be preferably obtained by using the expert assessments.

One of the problems connected with the application of fuzzy sets in process M_{42} is the problem of constructing the corresponding fuzzy sets $M(t)$, where t denotes the terms of the particular linguistic variables. We will show here several possible approaches to solve the problem.

Let us consider e. g. a linguistic variable $V =$ INFORMATION AVAILABILITY and its term $t =$ HIGH. We need to define functions $M_v(\text{HIGH}) : [0, 100] \to [0, 1]$.

(1) We have m available experts. For any value $x \in [0, 100]$, the experts answer the question whether the value corresponds to the expression HIGH or not. Let n out of these experts confirm that it corresponds, then

$$M_v(\mathrm{HIGH})(x) = \frac{n}{m} \in [0, 1].$$

(2) Let us assume again that we have m experts and only values $x = 0, 1, 2, \ldots, 100$ are being tested. Each of the experts then defines values m_{ij} in such a way that

$M_{ij} = 1$, if he/she considers $M_v(\mathrm{HIGH})(i)$ approximately equals to $M_v(\mathrm{HIGH})(j)$

$M_{ij} = 3$, if he/she considers $M_v(\mathrm{HIGH})(i)$ is a little bigger than $M_v(\mathrm{HIGH})(j)$

$M_{ij} = 5$, if he/she considers $M_v(\mathrm{HIGH})(i)$ is bigger than $M_v(\mathrm{HIGH})(j)$

$M_{ij} = 7$, if he/she considers $M_v(\mathrm{HIGH})(i)$ is a bit bigger than $M_v(\mathrm{HIGH})(j)$

$M_{ij} = 9$, if he/she considers $M_v(\mathrm{HIGH})(i)$ is much bigger than $M_v(\mathrm{HIGH})(j)$.

If it was defined already m_{ij}, $i < j$, it is put $m_{ji} = 1/m_{ij}$.

If the maximum inherent number of the matrix $A = \|m_{ij}\|$, we can find the solution $x = (x_1 \ldots x_{100})$ of the matrix equation

$$(A - \alpha E)X = 0.$$

Then we put

$$M_v(\mathrm{HIGH})(i) = \frac{x_i}{\sum_{j=1}^{100} x_j}.$$

The same situation is also in case of process M_{41}, which can be also decomposed into two parts M_{41}^{I}, M_{41}^{II}. For the deterministic part of M_{41} we can use classical methods for analyzing time series, which are usually available.

CONCLUSION

Working with a decision making modeling system might be divided into two separate parts as follows:

a) creating a model, i. e., constructing appropriate fuzzy sets and establishing decision making rules. This stage is relatively demanding as of the analytic activities requiring close co-operation with experts.

b) applying the model and its recovery, i. e., based on specific input parameters pursuing the calculations of the input values. This stage is demanding as of simple mathematic operations, being mostly done by computers.

Verification of the designed model of adaptation under indeterminacy was carried out using the LFLC 2000 tool [3, 5] with subsequent demonstration of its applicability in information retrieval on the web.

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