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AUTOMATION OF DECISION MAKING IN MANAGEMENT SYSTEMS

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A model of decision making aimed at automation of an enterprise management system is presented. On the base of this model a procedure of decision making, taking into account the conditions of dynamically changing environment, was worked out.

1. Introduction

The process of decision making, considered as a problem of selection of the most suitable solution out from among a number of options is, however, inseparable from any human activity. From that results importance and immediate interest of problem of decision making. The reason for this interest lies in a very fast progress of science and technology, as well as in dynamic changes of environment and in mutual interactions of results of many different decisions (Larychev, 1980; Khini and Raifa, 1981).

This is particularly demonstrative in the process of manufacturing automation. Traditionaly basic solutions (decisions) are determined only once on the phase of planning and their realization is then sheduled along the predetermined sequence of stages. The adjustments to the projected decisions in the continuously changing environment, as offered by the conventional approach, are limited and strongly determined by the skill of the project designer (Aizerman and Aleskorov, 1990; Pavlov, 1991).

In this paper, a new approach to the decision making problem is presented. The relevant manufacturing management problems are considered as multicriterial tasks solved by a decision making procedure, taking into account assumption regarding a continuously changing environment. This approach for the process of decision making in dynamically changing environment does not limit the adaptation possibilities of the projected decisions.

The paper is organized as follows. In Section 2 a model of decision making problem is introduced. Then, in Section 3 the concept of elementary solutions is provided in order to state a basis for the formalization of a set of considered criteria in Section 4. The structure of priorities as well as procedure of the i–th solution is provided in Section 5, and Section 6, respectively. The advantages and limitations of the obtained results are discussed in Section 7.

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2. Model of Decision Making

The following sets which define the character of the above cited process are included in the model of the decision making procedure: S is a set of structural units which constitute the company management system, A is a set of work stations, F is a set of functions which could be performed under automatic control, P is a set of utility programs which can perform the functions under automatic control, O is a set of system programs which can operate the functions under automatic control, T is a set of technical means which can complete physical effect of the functions performed under automatic control, K is a set of criteria.

The notion of the elementary solution $\omega \in \Omega$ presents the method of performance of any function under automatic control at any work station. Different systems of automatic control management consist of the elementary solutions grouped to the specified aspects.

Each of the optional solutions meets certain additional requirements of the structural and/or operational nature. A set of criteria K, which include complete information indispensable to make the decisions is formulated for comprehensive appraisal of the options. The decision maker is required to apply his priority scale to the set of criteria in order to declare the policy of this particular decision making procedure.

The first step in the task of gradual implementation of automatic control to both the process and the management systems of a company is to review the existing operation structure. A complete list of the process and the management functions performed by all structural units and at all work stations is prepared in conclusion to the review.

The next step is to draw a layout diagram which will show the relations between individual work stations, functions and structural units. Then from the list of the process and the managing functions with reference to the layout diagram, are selected those functions which can be performed under automatic control.

Let us consider in more details the sets indicated at the begining of this section:

$$S = \{s_1, ...s_i, ...s_n\} \text{ is a set of structural units,}$$

$$A = \{a_1, ...a_i, ...a_n\} \text{ is a set of work stations,}$$

$$F = \{f_1, ...f_i, ...f_n\} \text{ is a set of functions,}$$

$$P = \{p_1, ...p_i, ...p_n\} \text{ is a set of utility programs,}$$

$$O = \{o_1, ...o_i, ...o_n\} \text{ is a set of system programs,}$$

$$T = \{t_1, ...t_i, ...t_n\} \text{ is a set of technical means.}$$

The notion of the elementary solution $\omega \in \Omega_u$ presents the method of performance of any function under automatic control at any work station. In other words it explains which utility programs $p \in P$ under which system programs $o \in O$ will be executed, in connection with which technical means (computers)

$t \in T$ to perform the function $f \in F$ at the work station $a \in A$ located in the structural unit (or department) $s \in S$.

Thus, a set of the output elementary solutions Ω_u makes the subset $S \times A \times F \times P \times O \times T$, with the condition $\Omega_u \subset S \times A \times F \times P \times O \times T$ fulfilled, as only several combinations of the product as will be shown, are accepted for practical application.

3. Elementary Solutions

Let us assume that

$AS \subseteq A \times S$ is an acceptable set of the combinations "structural unit/work station" and $A_s \subset AS$ is a set of work stations in the structural unit (or department) s,

$FAS \subseteq F \times AS$ is an acceptable set of the combinations "function/work station/structural unit" and $F_{AS} \subset FAS$ is a set of functions performed by the automatically controlled work station a in the structural unit (or department) s,

$FP \subseteq F \times P$ is an acceptable set of the combinations "function/utility programs which perform this function",

$OT \subseteq O \times T$ is an acceptable set of the combinations "system programs/technical means",

$FPOT \subseteq FP \times POT$ is an acceptable set of the combinations "function/utility programs which perform this function/system environment/technical means" and F_{pot} is a set of methods by which the function f can be performed.

The set FAS is created by a system engineer, with reference to the structural and functional layouts of the management system.

The set $FPOT$ is created by a specialist with reference to the current state and presumed trends in development of modern computer technology.

Thus, the output set of elementary solutions Ω_u will be determined as follows:

$$\Omega_u = FAS \times FPOT \tag{1}$$

However, it would not be reasonable to consider all elements of the set Ω_u when implementing automatic control of the company, but a practicable set of elementary solutions should be formulated.

Any elementary solution $\omega \in \Omega_u$ is acceptable by its own existence, but when a system is considered it is not the most favourable arrangement when a specific work station in a specific structural unit uses different system programs to perform different functions. In order to select a set of practicable (from the system point of view) elementary solutions Ω out from the set Ω_u, the following conditions are formulated:

i) a system of automatically controlled work stations should operate in the environment of uniform system means,

ii) only one computer is to be installed to effect automatic control of a specific work station in a specific structural unit of a company,

iii) only one method is to be used to perform a specific function by a specific work station in a specific structural unit.

Let us consider the following descriptions: Z_o is Boolean variable given by

$$Z_o = \begin{cases} 1 & \text{if the system means } o \text{ are used} \\ 0 & \text{otherwise} \end{cases}$$

Then the condition (i) will be formalized as

$$\sum_O Z_o = 1 \tag{2}$$

U_{sat} denotes Boolean variable assuming the following values

$$U_{sat} = \begin{cases} 1 & \text{if the computer (or computer model) } t \text{ is used} \\ & \text{on the work station } a \text{ in the structural unit } s \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Then the condition (ii) will be formalized as:

$$\forall s \in S, \quad \forall a \in A_S \qquad \sum_T U_{sat} = 1 \tag{4}$$

Y_{safpot} is Boolean variable assuming the following values

$$Y_{safpot} = \begin{cases} 1 & \text{if the utility programs } p \text{ run under the sy-} \\ & \text{stem means } o \text{ on the computer } t, \text{ are used} \\ & \text{on the work station } a \text{ in the structural unit} \\ & s \text{ to perform the function } f \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

Then the condition (iii) will be formalized as:

$$\forall s \in S, \quad \forall a \in A_S, \quad \forall f \in F_{AS}, \quad \sum_{F_{pot}} Y_{safpot} = 1 \tag{6}$$

The set of practicable elementary solutions Ω makes a subset of the set Ω_u and fulfils the conditions (i), (ii) and (iii).

Thus

$$\Omega = \left\{ \omega \in \Omega_u = FAS \times FPOT \left[\sum_O Z_o = 1 \right] \right.$$

$$\& \forall s \in S, \quad \forall a \in A_S \left[\sum_T U_{sat} = 1 \right] \tag{7}$$

$$\left. \& \forall s \in S, \quad \forall a \in A_S \quad \forall f \in F_{AS} \left[\sum_{F_{pot}} Z_o \, U_{sat} \, Y_{safpot} = 1 \right] \right\}$$

In other words, to describe a set of practicable elementary solutions the system of equations is used

$$\begin{cases} \sum_O Z_o = 1 \\ \forall s \in S, \ \forall a \in A_S \ \sum_T U_{sat} = 1 \\ \forall s \in S, \ \forall a \in A_S, \ \forall f \in F_{AS} \ \sum_{F_{pot}} Z_o \, U_{sat} \, Y_{safpot} = 1 \end{cases} \tag{8}$$

The subset X of the set of practicable elementary solutions Ω represents a method (or an option) of implementation of automatic control. Inherently, the set of options X_u of elements X is a set of subsets of practicable elementary solutions Ω.

4. Collection of Criteria

To estimate optional solutions in a full and comprehensive way, criteria must be formulated, by means of which the decision maker will be able to determine the degree each solution is suitable to the execution of the specified task. Each criterion must be comprehensive, measurable, full (covering all essential aspects of the problem), realistic, indispensable, limited (the problem should be contracted to minimum).

In majority, the criteria can be grouped according to the determinants representing different aspects of the problem. In the process of implementation of automatic control means in a company, the criteria can be grouped to the following aspects: i) economy, ii) production, iii) employment, iv) other, specific aspects.

In the aspect of economy, very important are the price criteria, which demonstrate the value of the program, the system and the technical means used to implement automatic control in a company. Some of these can be applicable in the decision making process related to the pre-selected method of implementation of automatic control, so it becomes necessary that if the most favourable option is to be selected, they should be suitably modified.

Substitute criteria are introduced which only indirectly represent achievement of the relevant target but do not constitute the means of direct valuation of this target. The opinions moulded to these criteria can be graded by means of precise indices or by means of a specifically generated quality scale. Usually the economical and production criteria are of quantitative nature, since the relevant estimation results are expressed in numbers.

On the other hand, the quality criteria reflect personal views on the problem of implementation of automatic control, which require a specifically generated scale for the appraisal. It can be a verbal/digital scale for example. In such case, to appraise a selected parametr, a linguistic variable is used which can be expressed as follows (Aizerman and Aleskorov, 1990):

$$\langle \beta,\ T,\ X \rangle \tag{9}$$

where β is a name of the linguistic variable, T is a term (or a set of linguistic variable), X is a domain of the linguistic variable.

To present quality valuation results in a graphic form, absolute or relative scales can be used. The set of criteria, provided for use the decision maker, should present an easy to operate and adjust instrument of expression of policy, for selection of the most favourable option. It could freely add or remove any criterion, to highlight or to diminish various aspects of his policy, as required.

5. Structure of Priorities

Two most undisputable criteria are non–opposition and transitivity. Non–opposition means that in cases when the assessment or comparison with similar options is similar, the decision maker should undertake similar decision. The general criterion of transitivity consists of the principles which for the three options A, B and C can be expressed as follows (Aizerman and Aleskorov, 1990; Pavlov, 1991)

$$\begin{array}{ll} \text{i)} & \text{if } A > B \text{ and } B > C, \text{ then } A > C \\ \text{ii)} & \text{if } A = B \text{ and } B = C, \text{ then } A = C \end{array} \tag{10}$$

These make the basic principles of logic choice. The decision maker's priorities are determined by means of numerous procedures which provide the means of sufficiently clear formulation of the requirements by the decision maker. The decision maker's priorites can be ranked to the following determinants:

- a selected number of criteries which differ from each other by valuation in the test options (information E),
- method of presentation of the decision maker's priorities (information H),
- nature of the information presented by decision maker's priorities (information Z).

In consequence of the above classification, the set I of all possible types of information of the decision maker's priorities is expressed by the following formula

$$I = E \times H \times Z \tag{11}$$

The decision maker's priorities will be formalized with reference to the structure of priorities in the realm of valuation of the criteria. The structure of priorities R is based on certain priority structure axioms (Larychev, 1980). These are by convention divided into two groups:

- axioms on the structure of priorities in a set of options, irrespective of the criterion of choice,
- axioms on structural peculiarities of the priorities in the space of valuation of criteria E_m.

In the process of analysis of the options often suggested are the following structural peculiarities of the decision maker's system of priorities (Pavlov, 1991):

- independence of each criterion of the priorities,
- mutual dependence of the criteria of the priorities,
- comparability of significance of the criteria,
- comparability of replaceability of the criteria.

Now, let us have a closer look at the axioms showing structural peculiarities of the decision maker's priorities. The axiom of independence of the criteria of the priorities can be formulated as follows: the criterion l will be independent of the priorities of the remaining $(m-1)$ criteria if for each of the following

$$\begin{gathered}(x_1,\dots,x_{l-1},r,x_{l+1},\dots,x_m),\ (x_1,\dots,x_{l-1},s,x_{l+1},\dots,x_m)\\ (x'_1,\dots,x'_{l-1},r,x'_{l+1},\dots,x'_m),\ (x'_1,\dots,x'_{l-1},s,x'_{l+1},\dots,x'_m)\end{gathered} \tag{12}$$

the relation

$$(x_1,\dots,x_{l-1},r,x_{l+1},\dots,x_m)\ R\ (x_1,\dots,x_{l-1},s,x_{l+1},\dots,x_m) \tag{13}$$

will always yield

$$(x'_1,\dots,x'_{l-1},r,x'_{l+1},\dots,x'_m)\ R\ (x'_1,\dots,x'_{l-1},s,x'_{l+1},\dots,x'_m) \tag{14}$$

Comparability of certain criteria means that the options which differ in appraisals under these criteria can be compared with each other. The most general description of comparability can be presented in the following way. The criteria k_r and k_t are considered comparable if any two vector appraisals $x, y \in E_m$ such that $x_i = y_i$ $(i = \overline{1,m},\ i \neq r,\ i \neq t)$ are comparable with respect to their priorities. Similarly, if the criteria k_r and k_t are comparable, then any vector appraisals $x, y \in E_m$ such that $x_i = y_i$ $(i = \overline{1,m},\ i \neq r,\ i \neq t)$ will be comparable with each other with respect to their priorities

A set of matched comparable criteria forms a binary relation of comparability B over the set of criteria. We say, that any two appraisals are comparable with respect to their priorities, if at least one of the following statements

i) x is prior to y (xPy) or
ii) y is prior to x (yPx) or
iii) x is equivalent in priority to y (xIy)

is true.

The above descriptions can be put formally in the following way

$$K_r B K_t \longleftrightarrow \forall x, y \in E_m | x_i = y_i, \quad i = \overline{1,m}, \ i \neq r, \ i \neq t,$$
$$[(xPy)v(yPx)v(xIy)] \tag{15}$$

Each combination of appraisals of the criteria presents for the decision maker a definite option.

Axioms which stipulate properties of the decision maker's priorities are observed if

- options of equal priorities can exist,
- high priority is not cyclic,
- high priority is transitive,
- transitivity is generally applicable.

If the above axioms are fulfilled, the relation of the priorities in a certain task can be assumed to the following

$$R = P \cup I, \quad P \cap I = \emptyset \tag{16}$$

where R is relation of priorities in the space of criteria E_m, P is a linear order, I is equivalency.

6. Selection of Current Solution

The theory of decision making includes a great number of priority relations. Each of these relations is biased to a specific structure of priorities. An approach to solution of the multicriteria tasks, which applies consequent priority relations $R_1, R_2, ..., R_i$ working from "less" to "more" strong relations is possible

Now, we shall consider properties of these relations. Let the relation R_i has proved at the application stage i to be not closing on the presented set of options and would not yield the desired solution. In this case in place of the relation $i+1$, we have to use the "least strong" relation meeting the following requirements:

i) the priority existing between any two options at the stage i should not reverse at the $i+1$ (fulfilling the criterion of non–opposition),

ii) the relation applied at the stage $i+1$ should establish priority between at least two options, which have not been comparable at the stage i (criterion of strengthening).

These requirements are formalized as follows

$$R_1 \subset R_2 \subset \ldots \subset R_i \subset R_{i+1} \subset \ldots \tag{17}$$

If the above requirement is fulfiled, the relations R_i, R_{i+1} are called the inserted relations.

Application of a specific structure of the priority relations for solution of a multicriteria selection task can be diagrammatically revealed as follows.

Stage 1

To formulate a set of options Ω, and a set of criteria K of the desired form of solution.

Stage 2

To formulate partially a system of priorities and to describe in detail its structure.

Stage 3

To apply in sequence the system of inserted relations. This is an iteration stage, which consists in steps to build relation R_1 basing on suitable information of the relations S, first steps to arrange the set of options Ω_1 according to relation R, and steps to review probability of receiving a solution from the prepared arrangement. Shifting to subsequent priority relation is realized when it becomes apparent that the relation R_1 is not closing and the obtained arrangement would not yield the solution. This procedure can be modified, however, which is relatively frequent in the decision making tasks.

Stages 1, 2 and 3 will be repeated with the problem situation changing. Thus, the presented pattern of decision making in the process of implementation of automatic control means in a company in dynamic environment is versatile for the multicriteria selection tasks.

7. Conclusions

Determination of the best possible design solution belongs to the category of the multicriteria selection tasks in which the output set of the options is a set of hypothetically possible design solutions. The set of criteria determines quality of each alternative design with all the aspects considered. Each alternative design can be realized by different programming and physical means or it can be said to induce a set of design solutions. If such induced sets are collected through different alternative designs, an output set of options is created out of which, the decision maker would select the most effective option. It is not feasible to implement automatic control means to all functions in a company at any time. The dynamic environment imply that the selection should be made by stages and thus, selection of a specific design alternative at a certain moment will limit the selection range during subsequent stages.

References

Aizerman M.A. and Aleskorov F.T. (1990): *Selection from Options. Theoretical Basis.*– Moscow: Nauka (in Russian).

Khini R.L. and Raifa K. (1981): *Making a Decision at Many Criteria: Priorities and Substitutions.*– Moscow: Nauka (in Russian).

Kreps D. (1986): *A representation theorem for "Preference for flexibility".*– Econometrica, No.3, pp.7–9.

Larychev O.Y. (1980): *The Science and Art of Decision Making.*– Moscow: Nauka (in Russian).

Larychev O.Y., Mecitov A.Y. and Moshkovitz E.M. (1989): *Expert Science.*– Moscow: Nauka (in Russian).

Pavlov A.A. (1991): *Basis of the System Analysis and the Design of Automatically Controlled Systems.*– Kiev: The High School, (in Russian).