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# A METHOD FOR SEEKING EXPEDIENT ALTERNATIVES

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## U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

| Block | Italic | Transliteration | Block | Italic | Transliteration |
| --- | --- | --- | --- | --- | --- |
| А а | *А а* | A, a | Р р | *Р р* | R, r |
| Б б | *Б б* | B, b | С с | *С с* | S, s |
| В в | *В в* | V, v | Т т | *Т т* | T, t |
| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

**FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS**

| Russian | English |
|---|---|
| sin | sin |
| cos | cos |
| tg | tan |
| ctg | cot |
| sec | sec |
| cosec | csc |
| sh | sinh |
| ch | cosh |
| th | tanh |
| cth | coth |
| sch | sech |
| csch | csch |
| arc sin | $\sin^{-1}$ |
| arc cos | $\cos^{-1}$ |
| arc tg | $\tan^{-1}$ |
| arc ctg | $\cot^{-1}$ |
| arc sec | $\sec^{-1}$ |
| arc cosec | $\csc^{-1}$ |
| arc sh | $\sinh^{-1}$ |
| arc ch | $\cosh^{-1}$ |
| arc th | $\tanh^{-1}$ |
| arc cth | $\coth^{-1}$ |
| arc sch | $\mathrm{sech}^{-1}$ |
| arc csch | $\mathrm{csch}^{-1}$ |
| rot | curl |
| lg | log |

V. Makhova (Czechoslovakian SSR)

# A METHOD FOR SEEKING EXPEDIENT ALTERNATIVES

Production and consumption should be coordinated with one another at any given moment in time. As is well known, in dynamic regeneration models there are such intensive chronological interconnections, and the state of the system at any given moment is to such a degree determined by its past, that in order to guarantee stability it is necessary to plan appropriate economic measures beforehand.

Of course, operative control is not determined only by technical and economic conditions; they only place certain known limitations on it. However, since rationalization of planning requires that the optimal developmental alternative be selected, it is expedient to evaluate a possible alternative with the aid of computer modeling.

At the same time even precise mathematical calculation cannot guarantee that the development of the economic system over a 10-20 year period is unambiguously determined. The reason for this is that variation in economic parameters can be predicted only with a certain probability. The development of science and technology, and of processes in the natural environment and in the area of international relations, gives rise to the necessity of correcting plans.

A mechanism for continuous planning may be regarded, therefore, as a "self-correcting" mechanism for the economic system, since what is involved here is continuous variation of trajectory toward a preset goal on the basis of clarification of prospects for development.

In Czechoslovakia during the last few years complex (multiple) regulation of the scientific research process has been exercised. Such control, of course, requires that the elements of the productive process, beginning with research and development and continuing through the production of finished products, be coordinated in time and space in such a way that the results of research and development can be introduced into production in the shortest possible time.

A solution algorithm in the regulation of scientific research is limited by the requirements imposed by the goal of the research process. On the basis of the information which has been obtained and processed, a path to the goal must be found which will provide the highest possible probability of its being reached. One of the methods which can be used for this purpose is the generalized PERT approach. The basis of this system is a stochastic line diagram for making decisions. The diagram consists of directed lines whose sequence represents branches and events. Unlike the usual PERT line diagram, the stochastic line diagram contains determinative events. A determinative event is essentially the making of a decision on the basis of previously obtained results.

At the input of the decision structure the following events may be distinguished:

--disjunctive events (an event is disjunctive if one and only one procedure from the aggregate of procedures i entering into it can be realized);

--conjunctive events (an event is conjunctive if all of the procedures i entering into it can be realized); and

--inclusive events (an event is inclusive if any procedure of those entering into it can be realized).

At the output of the decision structure the following events can occur:

--deterministic events (an event is deterministic if all of the procedures which flow from it are realized); and

--stochastic events (an event is stochastic if it is realized through one of several possible means).

The aggregate of these events constitutes the stochastic line diagram.

The variant character of the line diagram is determined by the fact that not all of the operations included in a stochastic line diagram can be realized, since it reflects all possible ways of solving the problem. An a priori probability of occurrence is ascribed to each event in the diagram. The sum of the probabilities of these events on each path should be equal to 1.

$$\sum_{i=1}^{n} p_{i,j} = 1, \quad i = 1, 2, \ldots, n \quad 0 \leqslant p_{is}.$$

In the absence of reliable criteria for determining the probability of events, equal probability is assigned to them.

The entropy of an aggregate of events leading to the goal is characterized by the expression

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i,$$

where $p_i$ is the probability of the i-th final event; and

n is the number of events leading to the goal along a particular path.

Let us introduce the concept of relative entropy:

$$E = \frac{H}{H_{max}},$$

where E designates the degree of indeterminacy of a stochastic line diagram. If E = 1, all alternatives in the line diagram are equally probable. If E = 0, there exists a single effective path ($P_i$ = 1). In this case the stochastic decision line diagram degenerates into a PERT line diagram.

In the regulation of several specific research projects, it is possible to compile a stochastic decision line diagram for each research assignment and to evaluate the time required for completion of the work. However, it is very difficult to compile a diagram which reflects all possible alternatives for the completion of the overall project. At the same time, if the goal of the research assignment is defined, it is not difficult to evaluate the criteria of its completion. The more criteria are taken into account, the larger the number of alternative paths to the goal, and so the line diagram even of relatively simple research assignments becomes large and complex.

For these reasons we have concentrated our attention on the search for a method which would make possible, even at the stage of the planning of a research assignment, the discovery of expedient alternatives for fulfilling it.[1] An alternative is expedient if it satisfies, in a technologically maximal fashion, the conditions of reaching the goal of the research assignment (at the first stage of control of the research process neither time nor resources are taken into account: the expediency of an alternative is evaluated from the "technological" point of view).

Since the probability of successfully fulfilling a research assignment is determined by the values of parameters (for example, the weight of a laser, its type, dimensions, etc.) which do not, as a rule, have equal weight from the point of view of their contribution to the final result, they should be compared and their individual importance determined.

Let us assume that there exist four parameters $x_1$, $x_2$, $x_3$, and $x_4$, the relative importance of which is to be established. Fig. 1 shows the results of an evaluation of their relative importance as assigned by various experts (the relatively more important parameters are placed in parentheses).

$$\begin{array}{ccc} x_1 & x_1 & x_1 \\ (x_2) & (x_3) & (x_4) \\ & & \\ & (x_2) & (x_2) \\ & x_3 & x_3 \\ & & (x_4) \end{array} \qquad \begin{array}{cc} x & f_i \\ \hline x_1 & 0 \\ x_2 & 3 \\ x_3 & 1 \\ x_4 & 2 \end{array} \qquad (1)$$

---

[1]The "expedient alternative" is not, in general, identical to the "optimal alternative."

On the basis of matrix (1) the importance f(x) of parameter x may be determined; f(x) is determined as a function of the preferability of x (by the number of parentheses around x).

It is apparent from matrix (1) that the most important parameter is $x_2$ ($f_2 = 3$), and that the least important is $x_1$ ($f_1 = 0$). In order to exclude as far as possible the subjective element, it is useful to perform these evaluations collectively and to process the individual evaluations statistically.

It has been established empirically that, as the number of parameters and individuals performing the evaluations increases, differences between the most and the least important parameters tend to disappear.

Let us assume that r experts are performing an evaluation of the relative importance of n parameters. Clearly, only rarely will r sequences of n parameters by order of importance coincide fully; in the majority of cases these sequences will differ to a greater or lesser degree. In this regard the following questions arise:

1. Is there even partial coincidence between the series of parameters arranged by order of importance? Do the experimental data indicate that such a sequence actually exists? If the data do not indicate that this is the case, it may be assumed that:

a) there is no objective ordering of the parameters by importance; or

b) there is an objective ordering, but an incorrect selection by experts prevented it from being established.

2. What is the best way of determining the actual ordering of parameters, if it is assumed that it exists?

3. How can it be determined, at least for certain pairs of parameters, that the differences in rank between them which have been found are reliable?

4. How can a general evaluation of the importance of all of the parameters be performed, if an expert is qualified to evaluate only some of them?

5. What is to be done if the experts assign several parameters the same importance?

6. What is the resolving power of each expert, and also of the group of experts as a whole?

A parameter should usually satisfy specific, previously established criteria (for example, a maximum weight of 5 kg, a power rating of 40 hp, etc.; in other cases the criterion might be given as a scale, for example, a weight of up to 4 kg is completely satisfactory, up to 5 kg is satisfactory, up to 6 kg is partially satisfactory, more than 6 kg is unsatisfactory).

A set of criteria should be closed, and individual criteria should be mutually disjunctive.

If there exists a criterion satisfied by each alternative, then this is an absolute criterion. If a criterion serves to evaluate the degree of expediency of individual alternatives, then it is a relative criterion.

Criteria, like parameters, differ in importance. Therefore it is necessary to evaluate them.

This evaluation is given by the number of points on a scale of importance characterizing the reaction of a parameter to a criterion. For example, if the magnitude of a parameter does not satisfy a criterion, then its reaction to that criterion is 0 points; if it partially satisfies it, then its reaction is 1 point; if it satisfies it completely, then its reaction is 9 points. Another way of saying this is that the parameter has a rating, according to the criterion in question, of 0, 1, 5, or 9. It should be kept in mind that with a scale-point evaluation of criteria it is more correct to use a nonuniform scale, since such a scale provides a more precise evaluation. It is expedient after the determination of the importance of the parameters of the research assignment and the point evaluation of criteria to perform a semantic evaluation of the criteria.

Table 1 shows a summary of the evaluations of parameters $x_1$, $x_2$, $x_3$, and $x_4$ according to various criteria.

On the basis of matrix (1) we compile Table 2, in which the parameters are displayed in order of importance, and the criteria according to the number of points in descending order. In this case $x_2$ corresponds to $f_2 = 3$ and $f_2 > f_3 > f_4 > f_1$. Let us assume that $x_2 = x_1$, $x_3 = x_2$, $x_4 = x_3$, $x_1 = x_4$. Since criterion $x_{11}$ corresponds to parameter $x_4$, it should be designated as $x_{41}$. However, since $x_{12} > x_{11}$, it is expedient to take $x_{11} = x_{42}''$ and $x_{22} = x_{11}''$ (Tables 2 and 3).

Let us now introduce the concept of semantic evaluation. Semantic evaluation of criteria takes into account the excluded

TABLE 1

| | | Criterion | | | | | |
|---|---|---|---|---|---|---|---|
| Order | Parameter | Name | Point Evaluation | Name | Point Evaluation | Name | Point Evaluation |
| 1 | $x_1$ | $x_{11}$ | 1 | $x_{12}$ | 9 | | |
| 2 | $x_2$ | $x_{21}$ | 5 | $x_{22}$ | 9 | | |
| 3 | $x_3$ | $x_{31}$ | 9 | $x_{32}$ | 0 | $x_{33}$ | 1 |
| 4 | $x_4$ | $x_{41}$ | 9 | | | | |

TABLE 2

| | | | Criterion | | | | | |
|---|---|---|---|---|---|---|---|---|
| Order | Parameter | Rank by Importance | Name | Point Evaluation | Name | Point Evaluation | Name | Point Evaluation |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | $x_1'$ | 3 | $x_{11}''$ | 9 | $x_{12}''$ | 5 | | |
| 2 | $x_2'$ | 2 | $x_{21}''$ | 9 | $x_{22}''$ | 1 | $x_{23}''$ | 0 |
| 3 | $x_3'$ | 1 | $x_{31}''$ | 9 | | | | |
| 4 | $x_4'$ | 0 | $x_{41}''$ | 9 | $x_{42}''$ | 1 | | |

TABLE 3

| Parameter | Rank by Importance | Criterion | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Name | Point Evaluation | Semantic Evaluation | Name | Point Evaluation | Semantic Evaluation | Name | Point Evaluation | Semantic Evaluation |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| $x_1'$ | 3 | $x_{11}''$ | 9 | 27[1] | $x_{12}''$ | 5 | 12[2] | | | |
| $x_2'$ | 2 | $x_{21}''$ | 9 | 18 | $x_{22}''$ | 1 | 2 | $x_{23}''$ | 0 | 0[3] |
| $x_3'$ | 1 | $x_{31}''$ | 9 | 9 | | | | | | |
| $x_4'$ | 0 | $x_{41}''$ | 9 | 0 | $x_{42}''$ | 1 | 0 | | | |

[1]Obtained by multiplying the values in column (2) and (4).
[2]Obtained by multiplying the values in column (2) and (7).
[3]Obtained by multiplying the values in column (2) and (10).

TABLE 4

| Parameter | Rank by Importance[1] | Criterion | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Name | Point Evaluation | Semantic Evaluation | Name | Point Evaluation | Semantic Evaluation | Name | Point Evaluation | Semantic Evaluation |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| $x'_1$ | 4 | $x'_{11}$ | 9 | 36 | $x'_{12}$ | 5 | 20 | | | |
| $x'_2$ | 3 | $x'_{21}$ | 9 | 27 | $x'_{22}$ | 1 | 3 | $x'_{23}$ | 0 | 0 |
| $x'_3$ | 2 | $x'_{31}$ | 9 | 18 | | | | | | |
| $x'_4$ | 1 | $x'_{41}$ | 9 | 9 | $x'_{42}$ | 1 | 1 | | | |

[1] C = 1.

parameters (in this case $x_*$), which requires the addition of an arbitrary constant c to the individual indicators of importance (in this case c = 1, Table 4).

After the semantic evaluation of the criteria has been carried out the line diagram may be constructed, the decision events of which are the parameters of the assignment, ordered according to importance, with the lines indicating individual criteria, evaluation of which is carried out, as a rule, on the basis of a semantic evaluation of the significance of the criteria. This line diagram may be defined as an ordered stochastic line diagram for decision-making.

The data of Tables 3 and 4 are the basis for the construction of ordered stochastic line diagrams for decision-making.

The process of calculating according to the procedure described above may be computerized, which permits determination of all possible alternatives and of the expedient alternatives, i.e. those with the highest semantic evaluations.

In the first stage we worked out program No. 1 in the MOST-1 language for the Polish digital computer ODRA1003.

The purposes of the program are the creation and testing of an algorithm guaranteeing selection of twenty expedient alternatives, their ranking by importance, and the graphical representation of the line diagram required for the making of decisions.

Program No. 1 permits, on the basis of the evaluation of individual parameters and criteria, selection of the required number of alternatives (in this case 20) with the maximum number of points. If the minimum allowable point evaluation in the selection of alternatives is assigned to a number of alternatives, the program records all of these alternatives.

The program makes it possible to express the results of calculations both numerically and graphically, by means of an automatic graph generator.

After debugging Program No. 1 we established that the algorithm satisfies the requirements, but that the form in which the results of the calculations were presented was difficult to understand. This shortcoming was removed in Program No. 2, written in the COBOL algorithmic language. This program does not have the defects of the first in that it requires only that before the calculation is performed the cards be sorted according to the rank numbers of the parameters, and, for the rank numbers of the criteria, according to their point evaluations. On the basis of the evaluation of individual parameters and criteria Program No. 2 determines the twenty alternatives with the most points, and also the alternatives which received an identical minimum evaluation.

The approach described above not only improves planning, but also reduces planning time.

We consider that this approach may be applied not only in the regulation of individual assignments (research, development, production, etc.), but also in the planning of the development of individual branches of the national economy, in the formulation of state policy with regard to technological development, and in the planning of the national economy as a whole.