THE TECHNIQUE OF EVALUATION OF QUALITY IN TECHNOLOGICAL AND ECONOMIC SYSTEMS IN THE CONDITIONS OF NONSTATISTIC UNCERTAINTY

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ABSTRACT

A technique of multicriteria hierarchic quality evaluation in technological and economic systems in the conditions of nonstatistic uncertainty was worked out and the software realizing the technique was designed. The technique gives a possibility of quantitative evaluation of the quality of different objects on the base of verbal expert opinions.

The examples of using the technique and the software while evaluating the quality of a product, of a contract and of the process of projecting the system of electric engine are represented.

Steady quality growth in technological and economic systems is a result of systematic, well-planned complex measures.

One of the quality management problems concerning products, technical projects, contracts is analysis of the influence of different factors on the quality in the condition of nonstatistic uncertainty. To solve this problem it is necessary to understand clearly the goals of quality management, to know the structure of criteria and parameters which determine it.

Worked out by American scientist T. Saaty "Method of Hierarchy Analysis" (MHA) which gives a possibility to represent main elements of a problem in hierarchic form is used frequently to structurize different problems. The method provides decomposition of a problem into several simple parts and further processing of opinion sequence of deciding person with help of matrices of pair comparison. As a result of matrices processing relative degree of interaction of elements in the hierarchy are calculated and the best alternative from the point of view of the goal is chosen.

Let's consider quite a simple example to illustrate the application of the method. Middle-prosperity family wants to buy a house. After the discussion they defined eight quality criteria which the house must correspond. The problem is to select one of three houses-candidates. The first step includes decomposition and representation of the problem in the hierarchic form.

Then according to MHA it is necessary to form a number of matrices of pair comparisons for every lowest level – one matrix for each criterion of the upper level.

On the next stage of MHA a set of local ranks or priorities is to be formed with help of matrices of pair comparisons. The ranks show relative influence of the lowest level elements set on the corresponding elements of upper level. Priorities are synthesized starting form the second level down according to the additive principle.

Global priority of the element is used for weighting of local priorities of lower level elements. The procedure is to be conducted till the lowest level which is a level of alternatives. Now having the vector of local priorities for the alternatives one can make a final decision.

Considered MHA has two significant disadvantages:

1. When changing the quantity of alternatives it is necessary to form all matrices for the alternative level anew. Unfortunately, it is impossible to use information which was obtained earlier which causes full recalculation of all criteria to choose an alternative. In the case of necessity of work with large and quickly changing set of alternatives (analysis of offers in big trading company) this disadvantage becomes critical.
2. When using initial information about alternatives (either quantitative or qualitative) to form a matrix all data change into qualitative which shows comparative evaluation of one alternative in relation to another. The loss of quantitative information in this case could be fatal. For instance, if one

house costs $10 thousand and the other - $10 million then in the matrix of pair comparisons concerning cost criterion there will be figure 9 which shows strong superiority of the first house over the second form the point of view of price. At the same time the cost of $10 million is not only less preferable, but inadmissible for the middle-prosperity family. But while using MHA it could appear that the second house will be more preferable according to the global criterion due to more favorable values of other factors (in practice it must be so, because the house for $10 million is to be better then the second house in all other criteria).

The technique of multicriteria hierarchic quality evaluation suggested in the article gives a possibility to cope with the disadvantages of MHA and to consider subjective information which could be obtained from the deciding person.

In the process of considering of quality evaluation in technological and economic systems cause and effect diagrams are used widely which are of great convenience to define main and auxiliary factors, to structurize problems.

At the same time when working with cause and effect diagrams a large quantity of useful information concerning the problem is lost. For instance, qualitative and quantitative values of factors, the degree of their preference are not considered as well as the unequal importance of private quality criteria in forming the global quality criterion. Moreover, for the expert who evaluates the efficiency of quality improving measures it is preferable to have a possibility of obtaining quantitative values of global quality criterion.

Quality evaluation is a typical problem of multicriteria decision-making in the conditions of uncertainty. The problem is complicated due to private criteria based on the experience and intuition of deciding person and thus defined qualitatively (verbally) [1]. Moreover, as a rule the objects studied have complicated multilevel hierarchic structure.

Efficient solution of such problems is connected mainly with the necessity of using new mathematical apparatus of interval mathematics and fuzzy sets theory [2].

Let's consider the situation of comparative evaluation of several alternative export contracts. In ideal it is necessary to give qualitative characteristic to each contract which shows its proximity to some ideal contract taking into account all private criteria and constraints. The most obvious private criteria of contract quality are: price, delivery terms, payment terms, business reputation of a buyer.

Private criterion "Delivery terms" has qualitative (non-quantitative) character and is naturally characterized by such linguistic statements like: "satisfactory delivery terms" (DAF), "good delivery terms" (FOB) and so on. Private criterion "Business reputation" could be represented as a set of auxiliary criteria of both qualitative and quantitative nature, such as reliability, accuracy in payments and so on.

In the situation of product quality evaluation next factors influencing its quality could be distinguished: raw material, equipment, personnel. Each of these factors in its turn is defined by a number of measured (quantitative characteristics of metal) or qualitatively defined (personnel experience) parameters.

Thus problem of quantitative quality evaluation is a typical multicriteria problem which is complicated by the next circumstances:

- private criteria are qualitatively different. They reflect different essences and thus they make their comparison difficult. Moreover, some criteria such as "Business reputation", "Personnel experience" could be represented not in quantitative form but as the verbal expert evaluations. In this case the appearance of subjective fuzzy uncertainty which cannot be interpreted adequately in traditional possibility sense is inevitable;
- some criteria are antagonistic. Satisfaction of one criterion leads to the non-satisfaction of others;
- criteria are unequal. They make different contributions to the integrated evaluation.

Moreover, in practice there are too much criteria. The thing is that a man apprehends badly too detailed scales of values. Psycho-physical data say that a man distinguishes no more than 7-9 gradations of the scale of a parameter confidently. If the scale contains more gradations then neighboring gradations start to merge and could not be distinguished confidently. As a result it leads to the loss of significant quantity of actual information which could cause inadequate decisions. Usually the next verbal scale represented in the tabl. 1 is used:

Table 1. Linguistic evaluations of relative importance

Strictly equivalent	1
Almost equivalent	3
Slightly preferable	5
Significantly preferable	7
Strictly preferable	9
Intermediate values of importance	2,4,6,8

Noted difficulties could be overcame by using generalized criterion of quality evaluation as aggregation of all private criteria taking into account the coefficients of their relative importance.

To aggregate all private criteria it is necessary to bring them to the mutual base of comparison. The apparatus of fuzzy sets theory is useful in this situation.

Let's consider certain quantitative quality parameter P. Let P_2 be the best value of the parameter P and P_1 be the worst value. All values of P higher then P_2 are maximally desirable and all values of P less then P_1 are inadmissible. General appearance of the function of preference corresponding to the example is represented in the fig. 1.

It is necessary to mention here, that the linear character of changes of the function is not a dogma and is often used in cases when it is possible only to say that one of the parameters is preferable then other [3].

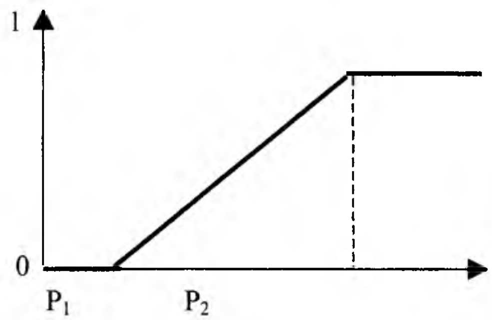

Figure 1. Function of preference

Usually the functions of preference are formed as fuzzy or crisp intervals.

The formalization of quality parameters, which are defined qualitatively, could be realized with the help of the functions of preference. It is convenient to use linguistic evaluations of the degree of expression or preference of the parameter. For instance, "low value of a parameter", "satisfactory", "good", etc.

As the result all qualitative and quantitative parameters are represented with the help of a unified dimensionless scale of the functions of preference.

While ranking the large number of quality criteria the essential methodical problems arise. This is connected with limited human abilities in evaluating the multi-criteria situation. In many cases a man is not able to evaluate directly the numerical value of a parameter or indication (in our case – the coefficient of relative importance, rank of a criterion) with satisfactory small error.

At the same time while comparing two alternatives he is usually able to define adequately which one has more expressed indication, and in some cases – to evaluate roughly (verbally) the difference between the values of two alternatives.

Thus the methods of ranking of criteria must provide the obtaining of quantitative values of coefficients of relative importance on the base of their pairwise comparison which is expressed verbally.

To evaluate the coefficients of relative importance it is proposed to use the above-mentioned methods of T. Saaty.

Let $a_i>0$, $i=1,...,N$ – the absolute ranks of criteria. Let's consider the matrix of relative ranks $A=\{a_i/aj\}$. It is obvious that if one multiplies A on the right by the vector of the required ranks $W=(a_1, a_2,...,a_N)$, he will obtain $AW=NW$. Thus if the matrix A is known the determination of W is reduced to the solution of the system of linear algebraic equations. But in practice the elements of the matrix being the pairwise values of relative importance of criteria are assigned on the base of subjective preferences, i.e. they are inaccurate. That is why T. Saaty proposes to obtain the solution from the equation $AW=\lambda W$, where λ - is the maximal eigenvalue of matrix A [4]. At present it is proved that the task of definition of vector W could be reduced to the problem of minimization of the functional:

$$S=\sum_{i=1}^{N}\sum_{j=1}^{N}(A_{ij}a_j-a_i)^2\rightarrow min;\ \text{with the}$$

$$\text{restriction}\ \sum_{i=1}^{N}a_i=N; \qquad (1)$$

To define the elements of the matrix of pair comparisons it is proposed to connect the linguistic evaluations of pairwise importance of the criteria and positive numerical series. It is interesting to note that the number of gradations does not exceed 9. Due to the above mentioned peculiarities of human mind the same situation could be observed in the languages of other nations.

The process of forming the matrix of pairwise comparisons could be explained with the help of example. There are three criteria X, Y and Z and according to the expert evaluations X is almost equivalent to Y (number 3 in the linguistic evaluations scale), Y is slightly preferable Z (number 5), X is strictly preferable Z (number 9). The resulting matrix is represented in the tabl. 2.

Table 2. Matrix of pair comparisons

	X	Y	Z
X	1	3	9
Y	1/3	1	5
Z	1/9	1/5	1

Specialists have different opinions on relative importance of evaluated criteria and due to this it is reasonable to use weighted evaluations on the base of data obtained from the group of experienced experts and processed with the help of some methods, for instance, Delphi. As practice experience shows it is reasonable to solve arising problems of processing interview data using the syntheses of fuzzy sets theory and traditional methods of mathematical statistics.

The next step is an adequate aggregation of individual criteria, which were formalized with the help of the functions of preference and ranks into some general criteria.

Let $\mu_1(x_1)$, $\mu_2(x_2)$,.., $\mu_N(x_N)$ be the functions of preference of individual criteria; $\{x_i\}$, $i=1,...,N$ – qualitative and quantitative parameters of quality; $a_1,...,a_N$ – coefficients of relative importance of criteria (ranks).

Literature gives the most popular variants of aggregating the unequal individual criteria into general criterion.

$$DD_1 = min(\mu_1(x_1)^{\alpha_1}, \mu_2(x_2)^{\alpha_2}, ..., \mu_N(x_N)^{\alpha_N});$$
$$DD_2 = \sum_{i=1}^{N} \alpha_i \mu_i(x_i); \quad (2)$$
$$DD_3 = \prod_{i=1}^{N} \mu_i(x_i)^{\alpha_i};$$
$$DD_4 = min(\alpha_1\mu_1(x_1), \alpha_2\mu_2(x_2), ..., \alpha_N\mu_N(x_N))$$

Different opinions exist on the comparative efficiency of these methods of forming the general criteria. Variants DD_2 and DD_3 has the property of compensation of small values of some criteria by the others but it is not always desirable [5]. Variants DD_1 and DD_4 are free of this disadvantage but they lead to a very strict evaluation of the situation. That is why they are sometimes called the criteria of maximal pessimism.

As a result on the base of quantitative private criteria and expert evaluations for the object we will get general qualitative evaluation which is changing due to the method of forming from 0 for not satisfactory quality to 1 in ideal case.

On the first stage the initial statistic analysis is conducted with usage of parametric and non-parametric statistics, the dependency between factors is found out, and these dependencies are built with help of multiple linear and adaptive non-linear regression methods.

On the stage of building the functions of preferences of private criteria and their ranking method Delphi is used to process expert evaluations. The combination of methods is defined by the character of the problem.

Suggested technique bases on the quantitative formalization of quality criteria with help of functions of preference. It provides not only complete usage of all initial quantitative information during evaluating but increases the informativity of a problem due to considering the degree of preference of quantitative and qualitative values of the parameters.

Considered example of quality evaluation of houses gives a possibility to make a conclusion that addition of new alternatives in MHA requires the increase and cardinal changing of matrices of preference of the lowest level. Process of changing could not be automatized and it makes necessary the filling of matrices of pair comparison by hand in the case of adding each new alternative. In many practical cases this drawback becomes critical.

In the suggested technique the appearance of a new alternative (one more house) does not change the matrices of pair comparisons and evaluations of already processed alternatives. It requires only the calculation of general quality criterion of new alternative.

At last, the technique gives a possibility to build complex hierarchic structures the generalizes scheme of which is represented in the fig. 2.

Due to the method of forming numerical values of $D_{n-1,i_{n-1}}$ are always in the interval [0; 1] and could be interpreted as the values of certain intermediary private criteria. On the lowest hierarchy level the functions of preference of initial private criteria are used which are defined by basic quality parameters.

$$D_{1,i_{n-1},i_{n-2},...,i_2,k}=f_{1,i_{n-1},i_{n-2},...,i_2,k}(\{\mu_j\}_k,\{\alpha_j\}_k), \quad (4)$$

Basic technique of multicriteria hierarchic quality evaluation in the conditions of uncertainty is realized in the form of software on C and C++ Builder. The general structure of it is represented in fig. 3.

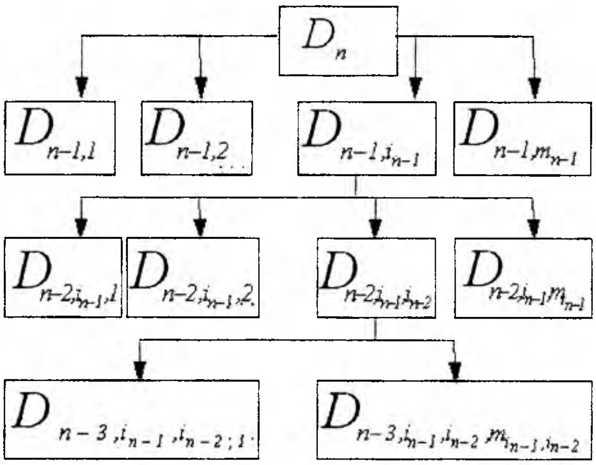

Figure 2. Scheme of building the hierarchic structure

The technique has open character, permit different changes in the set of private criteria of quality evaluation and their ranking which makes it useful in evaluating almost every object [6].

The technique is used on the Mogilev metal works to evaluate the quality of welded seam. After the brainstorming the problem of quality the cause and effect diagram of forming the quality of welded seam was built. Experts defined the next factors which influence the quality of pipes: raw material, personnel, welding process, tools, equipment.

Each of the factors in its turn is defined by the set of quantitative and qualitative parameters.

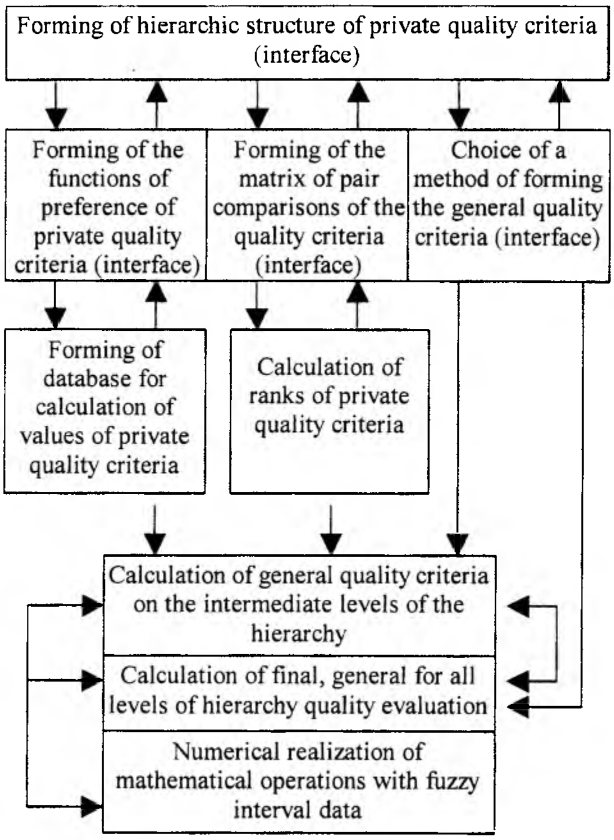

Figure 3. General structure of multucriteria hierarchic quality evaluation software

In tabl. 3 the results of calculations of generalized criteria of the second level according to the technique are represented. Numeric values show the degree of preference of second level factors in providing the general quality criteria.

Table 3. Second level criteria evaluations

Second level factors	D_1	D_2	D_3
Raw materials	0,85	0,86	0,85
Tools	0,97	0,95	0,96
Welding process	0,94	0,95	0,95
Equipment	0,93	0,95	0,92
Personnel	0,36	0,39	0,36

It is necessary to mention that in spite of rather abstract qualitative setting of second level factors the usage of the technique provides quantitative evaluations.

Each of the criteria D_1-D_3 takes values form 0 to 1 and could be considered as the function of preference of the corresponding second level factor. This provides obtaining of quantitative evaluation of generalized criterion by aggregating values D_1-D_3 for the second level criteria taking into account their ranks. The results are represented in the tabl. 4.

Table 4. General evaluation of welded seam quality

The type of aggregation	Value of general criterion
D_1 – criterion of global pessimism	0,848
D_2 – additive criterion	0,878
D_3 – multiplicative criterion	0,848

Described technique was tested on evaluation of the quality of projecting the systems of electric engine. While evaluating the projecting quality the next multilevel groups of demands were defined: obligatory, minimal and desirable. The quality evaluation of regullable electric engine was conducted and the next results were obtained: maximal pessimism criterion and multiplicative criterion– 0.42, additive – 0.78. The results show the incomplete satisfaction of the problem by this type of engine.

While deciding economic problems the technique permits to conduct the quality evaluation of export contracts. The next factors were defined: payment terms, delivery terms, quality of a product, business reputation of a partner, total amount of goods. They depend on a set of auxiliary factors [7]. The results are represented in fig. 4.

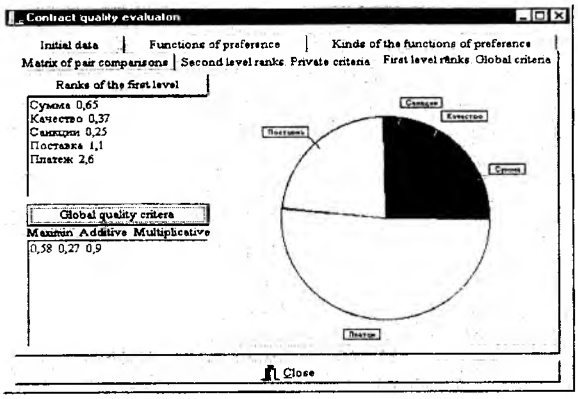

Figure 4. General evaluation of contract quality.

To realize the technique the basic software on C++ Builder with user-friendly standardized interface was worked out. The software could be adopted to the specific problems and used successfully with various quantity of intermediate levels of cause and effect diagram. The technique permits to increase the opportunities of cause and effect diagrams in quality management due to forming of multicriteria quantitative quality evaluations for each intermediate level and in general.

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