ENGINEERING IN UNIVERSITY CURRICULA

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ABSTRACT

The principles and contents of engineering approaches expounded in university curricula and designed to shape students' responsible attitude to quality of final product of their work are considered. They include robust design of advanced systems and management activities, as well as methods of multicriteria evaluation of objects with indicators of different nature to make sound management decisions. Characteristics of software and techniques underlying teaching of disciplines on innovative and strategic management, personnel management of transport organizations is given.

Keywords: transport, higher education, quality management, curricula, engineering, robust design, multi-criteria evaluation of objects, indicators of non-numerical nature, software, methodology.

Background. *The term «engineering» translated from English means «design» as opposed to existing in a number of textbooks and manuals vague definitions such as «engineering is an improvement of an organization, increasing its efficiency by 10–15%, and reengineering is a radical improvement of performance, giving high disruptive effect».*

The need for engineering approaches in modern management (innovation, strategic, quality management, business processes management, etc.) should be of a deep sense of a canonical triad, «quality of products is laid at the stage of its design, is created at production stage and is shown only in operation». Therefore, the attention of experts should be focused primarily on design phase, which lays down basic provisions for expected success (the concept «off-line», in tune with the well-known principle: «Measure seven times, cut once»). And only then it is necessary to concentrate efforts on improvement and control of production itself (concept «on-line»). Unfortunately, the latter prevails, and this to a certain extent explains the fact that domestic appliances (e.g., automobiles) can be relatively cheap, but it is too expensive to operate them. Not by chance in planning of resources in engineering most of them are generally allocated for establishment of repair facilities.

Engineering approaches focus not only on «what to do», but also «how to do it», and it is engineering principles and formalized procedures that are used. Among these procedures are quality function structuring, the use of multifactor experiment and statistical models, robust product design and management with assessment of their effectiveness under a new economic criterion – quality loss function, multi-criteria evaluation of research subjects to make sound management decisions, etc. [1–6].

Objective. *The objective of the author is to consider engineering approaches in relation to university curricula.*

Methods. *The author uses general scientific methods, evaluation approach, analytic hierarchy process, mathematical calculation, statistical analysis, comparison.*

Results.

1.

The program of training of students (bachelors and masters) at the department of Management and personnel management of organization includes a discipline «Quality Management Engineering». Its main innovative elements are techniques of robust design (RD) of advanced systems and management procedures and multicriteria evaluation of control objects with indicators of different nature.

RD methodology is recommended by us, for example, for selection and planning of investment projects (IP) in an uncertain market environment. It involves formalization of control objects by type of cybernetic model of «black box», input factors X of which are investment schemes indicators available for changes by investor in calculation – volume of investments, dynamics of investments, form of investments (in the form of financial flows, supply of equipment, leasing, etc. n.), and causing the values of output parameters Y of projects' efficiency. The causes and sources of uncertainty are destabilizing factors Z, characterizing the state of market environment (changes in demand for projected products, cost of raw materials and components, level of taxation, etc.) and affecting parameters Y.

As one of innovations in quality management the method of so-called «robust» design began to be used for design of technical systems in real experiments for selection of constructive and regime parameters, taking into account the influence of destabilizing factors arising at a post-project stage of production, storage and operation of the final product of collective efforts [9].

Offered and taught at the Department the methodology of choice and study of effectiveness of IP is based on multivariate calculations by changing X factors of investment schemes with regard to intended action of destabilizing factors Z according to the appropriate multifactor plan. The final scheme is a robust design plan, which is a direct product of main factors X and plan of destabilizing factors Z, that is, each option (combination of levels) of main factors is being tested in all options, defined by plan of destabilizing factors.

According to the results of these calculations in addition to the values of the output parameter Y of investment projects efficiency are determined values of Taguchi T-criterion characterizing value of Y indicator, taking into account its variability. Further the dependence of T-criterion on each of the factors X is analyzed and that combination of factors values is fixed, which corresponds to the highest values of T-criterion. Thus obtained an option with the highest values of T-criterion corresponds to the best value of Y and its minimal variability. It minimizes quality loss function, illustrating the cost of the manufacturer for repair

Table 1

The values of RCI index and λ_{max} for paired comparisons matrix of dimension n

n	1	2	3	4	5	6	7	8	9	10	11	12
RCI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49	1,51	1,54
λ_{max}			3,10	4,26	5,44	6,62	7,81	8,98	10,16	11,34	12,51	13,69

of failed in operation during the guarantee period products or their replacement with new [5, 6].

To select a robust embodiment of IP implementation – multivariate calculations the possibility is shown to use well-known packages «Alt-Invest» and «Project Expert», as well as catalogs of multifactor economic plans, the characteristic of which is given in the university course «Quality Engineering Management».

The proposed engineering procedures of multicriteria evaluation of control objects with quantitative indicators of their efficiency or quality are built on multidimensional scaling of objects by principal component analysis [3, 4].

This method provides the transition from original correlated variables (individual indicators of an object) to new formal variables – principal components (PC). The latter are linear combinations of individual parameters; they are orthogonal to each other and are arranged on the magnitude of variability (dispersion) of initial individual indicators, which they explain. And the first two or three of PC may explain 60–90% of total variability. And this transition to a small number of initial indicators corresponds to compression of original multi-dimensional information about objects in a form suitable for further analysis and construction of integral index of multicriteria evaluation.

Projecting sample of data corresponding to the investigated object in the plane of the first PC, it is possible to identify visually whether the analyzed sample of objects decomposes into groups, the number of such groups and how far they are spaced apart from each other. This possibility stems from the fact that in design remains relative position of the points in the analyzed sample. By orthogonality of PC as a measure of distance between the objects common metric of Euclid is quite suitable. In this assignment of objects in different groups is carried out by the value of radii of points corresponding to objects in space of PC.

For example, in the plane of the first two PC, denoted by $z_1$and z_2, to each point (each u-th object) will correspond the radius

$$\rho_u = \sqrt{z_{1u}^2 + z_{2u}^2}\ .$$

Using this measure of distance calculated from the first few PC, explaining the greatest part of total variability of original features, it is possible to carry out an integrated assessment of objects by values of the radius, and also get a fairly complete picture of availability and possibility of grouping the objects into homogeneous groups.

An important addition to this normal data analysis by PC analysis (implemented, for example, in packages Statistica, Stadia, SPSS, etc.) is the presence in the analysis scheme of offered by us module for calculation of radius of points in the space of the first PC, corresponding to analyzed individuals as an integral indicator of their assessment [3].

The effectiveness of methods of multi-criteria evaluation of objects with quantitative indicators was shown on the example of solving a complex of practical problems, including professional selection and certification of personnel, ranking of railway higher education institutions and secondary specialized education institutions, least efficient car-repair enterprises of the industry, etc. [3, 4].

2.

The training program «Quality engineering management» provides a demonstration of the solution of typical problems of multi-criteria evaluation (MCE) using principal components analysis and module for calculating the radius of control object in the space of the first PC using domestic package Stadia.

To solve the tasks of MCE of objects with indicators of non-numerical nature expert approach based on the analytic hierarchy process (AHP) was selected) [7]. According to this approach, proposed by T. Saaty [10] studied object or system is represented as a kind of hierarchy – an abstract structure for study of functional interactions between its elements and an impact on the overall system.

This abstraction is represented by a graph. The top zero level of the hierarchy is a global criterion of a system, reflecting a research purpose. The next (first) level is actors (people and organizations that have an impact on decision making). At the second level there are used criteria (technical-economic, environmental, risk indicators, and so on) for evaluation of objects (compared alternatives). At the third level it is possible to structure criteria at sub-criteria. Finally, at the last level of hierarchy there are alternative options of solutions – scenarios of predicted results, options of project, compared objects, action strategies, etc.

For a selected set of criteria (indicators) of objects experts make their evaluation with a method of paired comparisons in order to get their scales q_i – priorities that characterize the degree of their importance for subsequent determination of final priorities of elements of the next hierarchy level – in our case the objects being compared.

In multi-level hierarchies priorities of elements of each level are used to assess priorities of the elements of the next level. Pairwise comparisons are made using the so-called fundamental relationships scale of nine values of preference degree, including the values 1, 3, 5, 7, 9 and intermediate 2, 4, 6, 8. In this case, if the degree of preference of one index (criterion) over the other is x, i.e. it exceeds it x times, the degree of preference of an index compared with it is 1 / x. Such a range of preferences was offered to T. Saaty, on the basis of its relationship with psychophysical law of Weber-Fechner, and reflects psychometric abilities of a person.

For each of k used criteria in the analysis of n objects being compared by paired comparisons k matrices of size n × n are analyzed to obtain priorities ω_{ij}, i = 1 – k, j = 1 – n of each j-th object in terms of each i-th criterion. At the final stage the *final priorities of each of the objects to be compared are estimated as a linear combination*

$$P_j = \sum_{i=1}^{k} q_i \omega_{ij},\ j = 1 - k.$$

The procedure for obtaining priority using AHP gives meaningful results only in case of consistency of expert judgment – conditions of their transitivity. In order to verify consistency of each matrix of paired comparisons of elements at each level of the hierarchy two characteristics are calculated – consistency index (CI) and consistency ratio (CR) of expert preferences. Consistency index

$$CI = \frac{\lambda_{max} - n}{n-1},$$

where n is dimension of matrix of paired comparisons of elements (criteria or objects), λ_{max} is the largest eigenvalue (number) of such a matrix.

A simple approximate method of calculating λ_{max} for the case when vector of priorities is known $P(P_1, P_2, ..., P_n)$, provides for addition of elements of each column of the matrix of pairwise comparisons and multiplying the resulting vector $a(a_1, a_2, ..., a_n)$ by a normalized vector of priorities $\tilde{P}$:

$$\lambda_{max} = \sum_{j=1}^{n} a_j \tilde{P}_j.$$

Comparing CI with so-called random consistency index (RCI) from Table 1 for the selected number n – dimension of matrix of pairwise comparisons is obtained value CR = CI / RCI, which must be less than or equal to 0,1. Otherwise, an expert should review his priorities or hierarchy itself –structure it in another way [10].

In [7, 8], is considered a formalized approach to the problem of achieving consistency of expert judgment – their adjustment by methods of multivariate optimization to minimize λ_{max} to acceptable values obtained and presented in Table 1. In this case, to adjust the initial preferences of experts that do not meet the condition of consistency, it is permissible to use combinatorial plans of incomplete enumeration of options, direct search for a sought option by «steep climb» method or simplex method of optimization.

We used the developed method of analysis of hierarchies, including the procedure for achieving consistency of expert judgments to make decisions in the study of objects of power supply (boiler compartments in the economy of JSC Russian Railways) from a position of assessing impact of modernization on a range of non-numeric indicators (ecology, social sphere, safety and reliability of work, etc.); when comparing options of location in prospect of string assembly shop to serve Moscow Railway; with professional selection of applicants for the job at LLC Energy-industrial technologies and solving land development problems.

Conclusion. *We emphasize in conclusion once again: the creation of methods of robust design and multicriteria evaluation of control objects with indicators of different nature, as well as experience of their application with participation of students in the organization of rail transport is an integral part of the curriculum «Engineering Quality Management». The possibilities of such approaches, and developed techniques are also considered when teaching academic disciplines on innovation and strategic management as a mandatory area of knowledge for future staff of transport companies.*

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