7. Андрейчиков А. В., Андрейчикова О. Н. Интеллектуальные информационные системы. – М.: Финансы и статистика, 2004. – 424 с.

8. Андрейчиков А. В., Андрейчикова О. Н. Развитие интеллектуальной системы социально-экономического прогнозирования и принятия решений в условиях неопределенности // Информационные технологии. – 1999. – № 2. – С. 14–17.

9. Андрейчиков А. В., Андрейчикова О. Н. Системный анализ и синтез стратегических решений в инноватике: Математические, эвристические, интеллектуальные методы системного анализа и синтеза инноваций. – М.: Либроком, 2012. – 304 с. ●

В построении сетевой аналитической модели для оценки рисков принимала участие профессор О.Н.Андрейчикова.

NETWORK MODELS OF RISK MANAGEMENT

Andreychikov, Alexander V. *– D. Sc. (Tech.), professor of Moscow State University of Railway Engineering (MIIT), Moscow, Russia.*

Maslova, Ksenia A. *– student of Irkutsk State University, Irkutsk, Russia.*

Lelyanova, Susanna V. *– student of Moscow State University of Railway Engineering (MIIT), Moscow, Russia.*

ABSTRACT

The article contains multiple criteria model developed on the basis of analytic networks method (ANM) and the description of this intelligent system for risk management, developed on its basis.

ANM can be used to solve a wide range of decision-making tasks. It allows working with difficultly formalizable, multicriteria problems with mutual influence of criteria and alternatives. ANM is the development of a method of hierarchies' analysis and provides estimates of priority of all elements of network structure with respect to the intended target in the presence of mutual influences and feedbacks.

Intelligent system, developed on the basis of the method of analytic networks includes a database, a set of procedures for processing expert preferences, as well as block of methods of statistical analysis for extracting knowledge. Knowledge in the system is used to solve problems of forecasting, to identify the relationship between criteria and other elements of the problem, as well as expert judgments to check for consistency.

The example under consideration shows analytical multicriteria risk assessment model related to output of different kinds of artificial fiber for products used in transport industry.

ENGLISH SUMMARY

Background

Within the framework of decision-making theory a number of methods have been developed [1–5]. First, they were based on objective quantitative information. Later appeared methods of analysis of statistical decisions, using probabilistic models. In today's rapidly changing socio-economic, technological and political situation, priority was gained by more complex and responsible options for management decisions in which there is no information about the probabilities and forecasting is based on subjective evaluations [6,7]. Such options are close to uncertainty and arise in strategic forecasting, planning, resource allocation, risk assessment.

Objective.

The objective of the article is to investigate multicriteria model to assess risks in functioning of a transport enterprise.

Methods.

The authors use mathematical method, analysis and comparison.

Results.

Analytical networks method (ANM)

ANM [8,9] involves solving a wide range of problems and allows working with difficultly formalizable, multicriteria problems with mutual influence of criteria and alternatives. It is a development of the hierarchies' analysis method (AHP) [6,7], and supports prioritization of all elements of network structure with respect to the intended target in the presence of mutual influences and feedbacks.

Elements of the problem being solved with such an approach are clustered, between which there are arbitrary links. Clustering is an informal procedure and is based on knowledge about the specifics of the given conditions. Combining elements in the clusters reduces the size of the problem and improves the consistency of judgments.

Important moment in ANM is formulation of the main goal of a task and questions to be solved by experts in completing pairwise comparison matrices (PCM). To assess the influence of clusters on each other, PCM are constructed and priorities received after their processing are subsequently used as weighting coefficients in determining and comparing the degree of influence of clusters' elements. The resulting vectors of priorities are written in supermatrix.

An algorithm for constructing analytical network models includes following main steps.

8. Construction of network structure. For this purpose, elements of original hierarchy (containing feedbacks and connections between elements of one level) are clustered: e. g., cluster of purposes, cluster of factors, cluster of criteria, cluster of alternatives etc. Network shows their influence on each other in terms of some global goals, which can be benefits, costs, opportunities, risks, etc. For network binary matrix of influences is built:

$\mathbf{B} = \{b_{ij}\} = 1$, *if i depends on j.*

$\mathbf{B} = \{b_{ij}\} = 0$, *otherwise.*

Matrix **B** *is checked for transitivity. If there are violations, they should be removed and the network should be corrected. To streamline the network, reachability matrix is used, which is obtained by raising the matrix* $(\mathbf{E}+\mathbf{B})$ *to integer degree k until condition* $(\mathbf{E}+\mathbf{B})^{k} \approx (\mathbf{E}+\mathbf{B})^{k+1}$ *is met.*

9. Prioritizing elements of clusters. The elements of each cluster are compared in pairs with respect to each element of cluster affecting it. Main eigenvectors of obtained matrix of paired comparisons are interpreted as priorities clusters' elements.

10. On the basis of the calculated vectors of priorities supermatrix **W** *is constructed. For elements of cluster, not affecting each other, zero values are recorded in supermatrix.*

11. Prioritizing of clusters. If the graph of the network structure is strongly coupled, matrix of pairwise comparisons of all clusters relative to a given target is filled. Values of priorities' vectors of this matrix are then used as weighting coefficients. Otherwise matrices of pairwise comparisons are filled to assess the impact of each cluster on others. In this case it is determined which of the clusters is affected most.

12. Comparison of clusters and their components is conducted with respect to a single purpose or set of elements of a special controlling hierarchy, which detalizes the main goal. In the second case, a set of supermatrices for elements of controlling hierarchy is formed.

13. Bringing supermatrix (or several of them) to a stochastic form is accomplished by multiplying the priority elements of clusters on the priorities of the clusters themselves.

14. Supermatrices structure analysis with a choice of a method for calculating the limiting influence priorities and absolute priorities in the system. Calculating the resulting vectors of priorities is carried out in accordance with the selected method. If the main purpose is detailized by hierarchy, convolution function of obtained priorities' vectors is performed.

To measure the degree of preference nine-point scale of relations is used [6,7]. For each matrix of pairwise comparisons A a principal right eigenvector W is found, which is interpreted as a vector of priorities of compared objects

For positive square matrix A right eigenvector W, corresponding to the maximum eigenvalue λ_{max}, is determined accurate to a constant factor C by the formula

$$\lim_{k\to\infty}\frac{A^k e}{e^T A^k e} = CW \ ,$$

where e = {1, 1, ..., 1}^{T} – unit vector; k = 1, 2, 3, ... – exponent; C – constant; T – stands for transposition.

Computing eigenvector W is made until the specified accuracy is reached:

$$e^T \left| W^{(l)} - W^{(l+1)} \right| \le \xi \ ,$$

where l – number of iteration, when l=1 corresponds to k=1; l=2 – k=2; l=3 – k=3 etc.; ξ – permissible error (ξ =0,01).

Maximum eigenvalue is calculated by the formula: $\lambda_{max} = e^T AW$.

Uniformity of expert judgments, presented in the matrix of pairwise comparisons, is estimated by homogeneity index (ИО) or the ratio of consistency (CR) according to the following expressions:
ИО = (λ_{max} – n) / (n – 1),
CR = ИО/M (ИО),

where M (ИО) – mean value (expectation) of homogeneity index of randomly composed pairwise comparisons matrix A, which is based on experimental data obtained in [7].

Characteristics of intelligent system

Developed on the basis of ANM, intelligent system includes a database, a set of procedures for processing expert preferences, as well as blocks of methods of statistical analysis for extracting knowledge. Knowledge in the system is used in solving tasks of forecasting, identifying relationship between criteria and other elements of the problem, as well as checking the consistency of expert judgments.

The main procedures in ANM are: 1 – generation of alternatives; 2 – formation of a set of criteria for evaluating alternatives, its clustering and representation as a network in which any links are permitted; 3 – identification of experts' preferences on the set of alternatives, criteria and clusters; 4 – determination of relative importance of the impact of clusters on the target selection and other clusters; 5 – getting ranked set of alternatives, criteria and clusters; 6 – assessment of decisions' effects.

At all of these stages the involvement of expert knowledge is required. Thus, in the first phase they generate a set of alternatives, among which it is necessary to select the best one or order the entire set.

Network structure of clusters, criteria and alternatives are models of domain knowledge, which is modified or refined over time. In multi-purposeful task of decision-making several networks are built, each of which corresponds to a particular purpose. For example, in the problems associated with investment projects, it is desirable to consider four types of networks: benefits, costs, opportunities and risks. The overall result here can be obtained by multiplying the priorities of benefits and opportunities, and dividing it by the product of the priorities of the costs and risks.

Intelligent system is designed for two types of users: content providers and consumers of information.

Content providers are involved in completing database (DB) and knowledge base (KB). Content providers are experts, engineers and decision-makers (DMP). When adding new information issues may appear, which relate to the harmonization of the opinions of experts, knowledge transfer, developing collective judgment, resolution of contradictions, etc. To work with DB and KB special modes are introduced, input of new information is available also in the process of solving immediate problems.

Consumers of information use DB and KB, but also information obtained from them can also be entered into DB. Such a role can be played by DMP, experts and analysts. They form the sets of alternatives and criteria, assess preferences, and select methods for solving problems and optimality principles.

Information, entered into system, differs in nature, usage and connectivity. DB stores information on alternatives, criteria, experts, solved problems. Information on criteria, alternatives and experts has an objective nature, i. e. it can exist independently from other categories. Information about tasks is associated with all other categories.

DB of intelligent system contains a set of problems, solved in different conditions, related to the same subject area. There is also general information about alternatives related to the topic, as well as rules, regularities and trends, general for all tasks that can be identified using procedures of mining.

To obtain knowledge, an interface is provided that has a list of possible analysis procedures, means of constructing hypotheses, requests and selection. With the accumulation of information in the database periodically sessions for knowledge extraction are carried out, while the base is replenished with new rules and identified regularities. Adding knowledge may be in the process of direct dialogue with experts and engineers.

The main types of knowledge in KB are rules and functions. Sets of rules reflect the views of optimal variants and show mutual dependence of the elements of information from each other. Functions show set dependencies of preferences and results of selection from time, changes in criteria importance,

etc. Besides functions of time it is important to know dependencies of selection from the number of experts, criteria and alternatives, regularities of change in the set of alternatives, etc. Knowledge processing unit is designed primarily to identify and resolve conflicts, as well as assess decisions' effects.

Network models of risks

Example 1. Forecasting risk of economic crisis of a transport company.

Any enterprise, which is a part of transport infrastructure, faces risky situations. Forecasting economic crisis for it is a task of strategic management because the risks are often the main reason for the decline of the resource potential and competitiveness.

The task of forecasting risk of economic crisis is considered.

Main factors affecting the degree of economic crisis of an enterprise are formed by 12 clusters (Pic. 1). The cluster of alternatives contains five gradations of risk level: very low, low, medium, high and very high. Very low risk corresponds to short-term loss of efficiency, associated, for example, with loss of productivity, slight loss of income, disparity of dynamics of capacity and market share. Very high risk is close to catastrophic threats: major financial losses, comparable to the magnitude of economic means, a complete lack of R & D, etc. Medium risk is associated with short-lived violations of the production cycle. Alternatives to «low» and «high» are designed to provide flexibility in assigning ratings.

Besides alternative variants of risk levels impact of political, social, macro-economic, environmental, management, innovation, production, marketing, personnel, financial, and legal factors are taken into account. Arrows in Pic. 1 indicate the direction of influence.

Task of forecasting comprises 83 risk-forming elements, given in Table 1.

After formation of an analytical network experts filled matrices of pairwise comparisons for clusters and elements, grouped in clusters. For each matrix vector of priorities was calculated. All matrices of pairwise comparisons had good grades of consistency, characterizing the sequence of expert judgments.

Pic. 2 shows the marginal influence priorities of risk-forming factors (clusters) of a forecasting model for the level of risk, and Pic. 3 – value of priority's vector of considered alternatives.

Analysis of the results shows that the most important are factors such as macroeconomic, industrial, market activities, staffing, and financial.

From Pic. 3 it becomes clear that the most probable risk for an enterprise is a low risk of economic crisis.

Example 2. Assessment of output risk.

The example shows an analytical multicriteria risk assessment model for output of different kinds of artificial fibers for products used in transport industry.

Alternatives' cluster consists of four main types of products: tire cord fabric (alternative A_1), nylon textile yarn (A_2), technical nylon thread (A_3), polyurethane spandex yarn (A_4). The entire spectrum of enterprise's products has broad application. Cord fabric is used in transport engineering. Nylon textile yarns are used to make knitted fabrics and haberdashery. Technical nylon threads are used for manufacture of pneumatic tires and packaging fabrics. Polyurethane fibers have become the basis of floor coverings, etc.

Throughout the entire period of its existence, the company constantly increased capacity by commissioning of new and modernization of existing production lines. However, the upgrade process was uneven, as a result of which the level of risk for individual groups of equipment varied.

For the study of a task, an analytical network model was constructed, consisting of eight clusters (Pic. 4). Total number of risk-forming factors, included in clusters, is 31.

Factors associated with the production process (cluster 7), characterize not only technical (7.1, 7.4, 7.5), but also economic aspects (7.2, 7.3) of the company. Specialists pay particular attention to recycling technologies with the release of consumer goods from substandard technical yarns, as they can significantly affect the prime cost reduction of the main products.

Risk analysis relating to the volume of work in progress, should consider the long duration of the process cycle. In the production process of polyamide yarn leading spinning and chemical plants must operate continuously. Temporary stops, for example, due to disruptions in the supply of raw materials, lead to lower quality of products. Its characteristics are clustered in «Supply of an enterprise».

At the time of analysis primary and secondary raw materials were purchased from Russian companies. The presence of four traditional suppliers of caprolactam practically guaranteed uninterrupted supply of production. However, for other materials, in particular dimethylformamide «elbow rooms» are considerably limited. Geographical distance of caprolactam sources increases, however, earnings risk due to rising prime cost of the main product due to increased transportation costs of raw materials. In the analyzed period, stocks of raw materials at the plant have doubled, which is not consistent with the traditional procurement policies and associates part of money. Nevertheless, it significantly reduced the risk of unscheduled stop of production process.

An undoubted threat to the company is its lack of investment opportunities in the development of new models of production or acquisition of patents and licenses. Variety of brands of used nylon yarns and fibers, high consumer properties of polyurethane products make competing companies constantly develop new technologies for their production and improve product characteristics.

Wide range of products produced by the company provides its demand in various market segments. Each of them has unique characteristics of capacity, intensity of competition, susceptibility to the components of the marketing complex. Financial resources of different product groups' consumer also vary. This explains the presence of a feedback model of alternatives to the criteria.

Factors determining the situation in the industry are included in the eponymous cluster 8. Unlike polyamide yarn market, tire cord market has a clear oligopolistic structure. On the market there are large companies of the former Soviet Union. Production capacity of consumers of tire cord (tire plants) are loaded only 30–50%. On more favorable for the enterprise market of nylon filaments slow growth in its share is associated with resistance of partnerships of competitors. However, the potential demand is assessed as «high» for the opportunity to strengthen the company's market presence in Russia, CIS and Baltic countries.

The main risk-forming factor in relation to their customers remains low solvency. High growth rates were the result of receivables providing trade loans

to consumers of enterprise. Barter payment is most often used in relations with producers, procuring technical polyamide fibers and filaments.

Situation at the market of nylon filaments is more favorable for the company. It has unique, modern equipment, providing the best quality of this product. Main efforts are directed to optimizing assortment (for technical brands of fiber) and pricing (for textile brands). Positive role should be played by promotion of textile yarns line. However, its frequency is still insufficient.

To obtain estimates, experts needed to fill 61 matrices of pairwise comparisons. When making judgments, the required degree of their homogeneity was reached. Influence of clusters to perform the main purpose was recognized unequal. In particular, it was stated that in relation to the risks associated with release of the product, the manufacturing process factors affect the quality of the goods more than the state of fixed assets and the procurement process.

When filling the matrices of pairwise comparisons of products in relation to the risk factors expert answered the question: «For what kind of products the degree of threat to the factor under consideration is higher?»

In the reverse comparison (different groups of criteria on alternatives) the expert was asked: «What change in the intensity factor has a stronger risk change?»

Values of limiting influence priorities of network elements on a given target are given in Table 2.

Conclusion.

Research results show that for the given enterprise the highest is the risk associated with the release of cord fabric (value in priorities' vector is 0.1420). For other types of products risk is lower: nylon textile thread – 0.1064; monofilament thread technical – 0.1008; polyurethane thread – 0.1079. Cord fabric received high risk assessment for many important factors: the degree of physical wear and tear, the level of quality and selling prices, procurement policy and the level of used manufacturing technology.

The lowest marginal impact on the risk is conducted by factors such as conservatism in the selection of suppliers, since a small amount on the market forces the company to sign long-term partnership agreements and rare change in sources of raw materials; innovation, because strategy to acquire new licenses and patents prevails; obsolescence, incomparable in its consequences and impacts to physical deterioration; volume of work in progress, the level of which is dependent from technology of longtime cycle; capacity utilization: low volumes reduce to a minimum the risks of deterioration in the quality of products, increase waste and cost of repairs.

The greatest impact on the risk are performed by factors of production process; factors that characterize the properties of the product; marketing factors and factors reflecting the situation in the industry.

Results obtained are consistent with intuitive notions of experts rather loosely interpreted and give a detailed description of the forecast.

Interim results are also of interest because they make it possible to analyze the possible interaction of factors and elements of the system being evaluated.

Compared with traditional models of dynamic systems in the form of systems of differential equations the considered approach has, in the opinion of the authors, some advantages, namely:

– Possibility to use high-quality information to build the model;

– No problems in determining the parameters of dynamic models and finding the initial approximation;

– Significant time savings.

Keywords: transport company, infrastructure, intelligent system, risk management, network models, analysis, assessment, forecast.

REFERENCES

1. Dubrov, A.M., Lagosha, B.A., Hrustalev, E. Yu. Simulation of risk situations in economics and business [*Modelirovanie riskovyh situatsiy v ekonomike i biznese*]. Moscow, Finansy i statistika publ., 1999, 176 p.

2. Dubrov, A. M. Statistical methods in investing activities. Investment and financial portfolio [*Statisticheskie metody v investitsionnoy deyatel'nosti. Investitsionno-finansovyj portfel'*]. Moscow, *Sovintek*, 1993, pp.163–176.

3. Zamkov. O.O., Tolstopyatenko. A.V., Cheremnyh. Yu.N. Mathematical methods in economics [*Matematicheskie metody v ekonomike*]. Moscow, DIS publ., 1997, pp. 245–267.

4. Kleyner, G. B. Risks of industrial enterprises [*Riski promyshlennyh predpriyatiy*]. *Rossiyskiy ekonomicheskiy zhurnal*, 1994, Iss. 5–6, pp. 85–92.

5. Komarova, N.V., Gavrilova, L. V. Company: strategy and tactics of risk management [*Firma: strategiya i taktika upravleniya riskami*]. *Vestnik Sankt-Peterburgskogo universiteta, Seriya 5: Ekonomika*, 1993, Vol. 12, Iss. 2, pp. 92–95.

6. Andreychikov, A.V., Andreychikova, O. N. Strategic management in innovative organizations. System analysis and decision-making [*Strategicheskiy menedzhment v innovatsionnyh organizatsiyah. Sistemnyj analiz i prinyatie resheniy*]. Moscow, Infra-M publ., 2013, 396 p.

7. Andreychikov, A.V., Andreychikova, O. N. Intelligent information systems [*Intellektual'nye informatsionnye sistemy*]. Moscow, Finansy i statistika publ., 2004, 424 p.

8. Andreychikov, A.V., Andreychikova, O. N. Development of intellectual system of socio-economic forecasting and decision-making under uncertainty [*Razvitie intellektual'noy sistemy sotsial'no-ekonomicheskogo prognozirovaniya i prinyatiya resheniy v usloviyah neopredelennosti*]. *Informatsionnye tehnologii,* 1999, Iss.2, pp. 14–17.

9. Andreychikov, A.V., Andreychikova, O. N. System analysis and synthesis of strategic decisions in Innovation: Mathematical, heuristic, intelligent methods of system analysis and synthesis of innovation [*Sistemnyj analiz i sintez strategicheskih resheniy v innovatike. Matematicheskie, evristicheskie, intellektual'nye metody sistemnogo analiza i sinteza innovatsiy*]. Moscow, Librokom publ., 2012, 304 p.

The network analytic model for risk assessment was built with participation of professor O.Andreychikova.

Координаты авторов (contact information): Андрейчиков А. В. (Andreychikov A. V.) – Andreichickov@mail.ru, Лелянова С. В. (Lelyanova S. V.) – ff8926@gmail.com, Маслова К. А. (Maslova K. A.) – risula3333@mail.ru.

Статья поступила в редакцию / article received 06.02.2014
Принята к публикации / article accepted 15.04.2014