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Full Length Research Paper

Organizational design of a rail company using fuzzy ANP

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For development of state policy, railway traffic has great importance, considering necessary reduction of traffic pollution, strengthening and increase of the national rail company. According to the rail market liberalization and deregulation, a rail company has to be flexible and open to the current trends on the market. The organizational design has great importance, since a rail company with an adequate structure can take a better position on the transport market. Organizational structure enables a company to achieve its planned strategic goals and to function effectively and efficiently. In this paper, fuzzy analytic network process was used as a solution for making a decision, which alternative was optimum, considering the variety of data, and their uncertainty, interactions and feedback. This method was applied as a tool for choosing the optimal organizational structure, and it was presented at numerical example based on the data from the Montenegro Railway.

Key words: Organizational design, fuzzy numbers, analytic network process, rail company.

INTRODUCTION

Considering the new trends on the transport market and the government development policy for transport, the rail transport management, organization and company policy become more interesting and important. There are many aspects by which railway system could be influenced and made more efficient and effective. Organizational structure has great importance, because it upholds the aims of a company, whereas an inadequate structure can disturb normal company function. Organizational structure should be defined referring to the temporary trends on the national and international transport market. Selection of organizational structure for a complex and robust system such as the railway is a difficult and delicate process.

The issue of organizational design is one of the main issues within the area of organizations. Largely, this is so because it is possible that organization by altering its design adjusts or adapts according to the changes in environment (Lawrence and Lorsch, 1967). Another reason for the interest in design is that there is some evidence according to which by altering the organizational design we can alter its performance (Burton and Obel, 1984). From practical point of view, the proposed procedure (Ansoff and Brandenburg, 1971) for developing a structure of a purposive organization so as to maximize organizational performance should be considered. Four categories of performance attributes are specified, each contributing to particular objectives an organization pursues in seeking maximum return from the resources it employs. Across the literature there are numerous and not necessarily compatible characterizations of design; examples include the formal structure and task decomposition structure (Mintzberg, 1983), the informal network (Krackhardt and Stern, 1988), the degree of hierarchy, the process of coordination (Pfeffer, 1978) and the information processing characteristics or cost (Carley, 1990). Modern, computational and mathematical approaches to the study of organizations have played an influential, though often overlooked, part in the development of organizational theory. Computational and mathematical organization theory is an inter-disciplinary scientific area focused on developing and testing organizational theory, using formal models. There is a theoretical view of organizations as collections of processes and intelligent adaptive agents that are task oriented, socially situated, technologically bound, and continuously changing (Carley, 1995). Behavior within the organization is seen to affect and be affected by the

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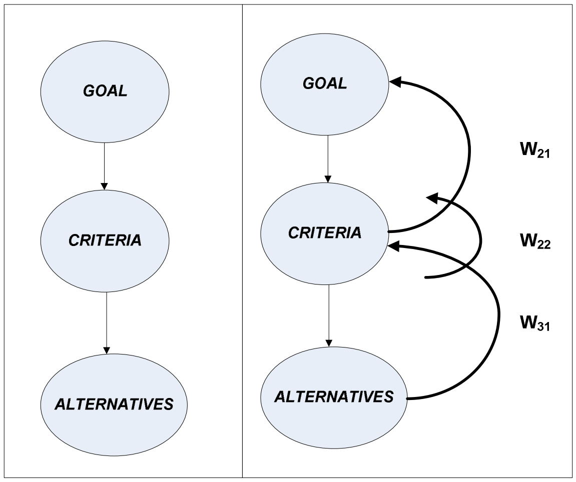

Figure 1. Hierarchical and network structure.

organization's position in the external environment. Newer analysis of organizational structure uses a special metamatrix approach. This approach provides a representational framework and family methods for the analysis of organizational data. This approach builds heavily on recent network-oriented treatments of organizational structure, as well as ideas from the information processing school of organizational theory and operations research. By this approach, organizations are perceived as being composed of a set of elements, each belonging to one of five classes: personnel, knowledge, resources, tasks, organizations. The organization is then defined by the set of elements, together with the dyadic relationship among these elements. It is the analysis of these relationships which lies at the heart of the metamatrix approach. Based on the previously mentioned research, systematic optimization approach uses Dinamic Network Analysis (DNA) metrics for finding the design that more closely meets the ideal (Carley and Kamneva, 2004) .

The subject of this paper is development of the model, which suggests, as a decision support tool, an adequate organizational structure for the rail company, considering the several criteria as relevant inputs for the system. This paper is organized as follows: section 2 presented Fuzzy Analytic Network Process (ANP) as a very efficient tool for making an optimal choice between alternative scenarios, in next section, the problem of determining an optimal organizational structure for a rail company is described and the solution based on fuzzy ANP is proposed. Concluding remarks are given in the last section.

APPLYING THE FUZZY ANP AS A MULTICRITERIA DECISION MAKING METHOD

There are numerous developed models for choosing the organizational structure of a company, and the various methods as well. One specific approach is contingency theory, which is applied in this paper. This theory looks at influences of task environment on the selection of the organizational structure, which could be multidimensionally considered. Lawrence and Lorsch (1967) developed the contingency theory with the main proposition that the choice of the most suitable organizational structure depends on environmental conditions. They emphasized the importance of organizational structure for achieving the organization's goals and objectives. Vesovic and Bojovic (1996) developed a model of selecting an optimal organization variant alternative by using the AHP. Burton and Obel (1998) developed the decision model for the organizational design, using the contingency theory as a theoretical basis. Kujacic and Bojovic (2003) considered the multicriteria nature of organizational design by operating with an environment and organization criteria. They proposed the model for choosing the best organization structure of a post corporation, considering historical data, subjective judgments and expert knowledge.

Taking into consideration the network structure of the model, analytic network process is the most suitable method for solving the considered problem.

Analytic network process (ANP) is a method for making decisions considering the variety of criteria, and their priorities, including the interactions and feedbacks among criteria and alternatives, which have been defined by experts. The ANP was introduced by Saaty (1999) as extended analytic hierarchy process (AHP) and developed also by Saaty (1980). Some of the similarities between AHP and ANP are the three level structures, made by goal, criteria and alternatives; they treat priority degree of the system elements, making the pair wise comparisons and the super matrix. ANP differs from AHP in several characteristics, such as the interactions among elements from the same level, for instance one criterion can influence the other, the feedbacks among the system elements, inner and outer dependences. Figure 1 presents the elements' dependencies valid for AHP (left figure) and ANP (right figure).

Fuzzy ANP has successfully been used to solve different kinds of complex problems, and its application is still in the process of expansion and finding of new fields. After Mikhailov and Singh (1999, 2003) proposed the fuzzy ANP method, later called fuzzy preference programming, FPP, Yu and Cheng (2007) modified this approach. They revised the FPP suggesting the deriving priorities by multiple objective programming. Mikhailov and Singh (2003) proposed a new application of fuzzy analytic network process to the development of decision support systems. With the aim to consider the imprecision and uncertainty of the decision-making problems, they used the fuzzy ANP method, as combination of FPP and ANP. Wu et al. (2006) presented the Porter's diamond model as construction for the location selection of the regional hospital in Taiwan. In their paper, they proposed and presented the solution by using the fuzzy ANP method. Wu et al. (2008) developed a performance measurement model for the hospital's department, applying the previous mentioned method. Liu and Lai (2008) applied the proposed approach, using the FANP method, to the environmental impact assessment of construction projects; the Taiwan high-speed rail project has been used as a case study. The aim of using the analytic network process was to manage dependencies between environmental factors relevant for the considered problem. Using the fuzzy ANP method has been proposed by Guneri et al. (2008) for choosing the shipyard location, considering the current conditions of 2007 in Turkey. Chang et al. (2008) in their paper developed the model for the strategic project selection for the historic Alishan forest railway in Taiwan. The considered problem has been solved by fuzzy Delphi, ANP method and zero-one goal progra-mming. Önüt et al. (2009) presented the FANP and Fuzzy TOPSIS (technique for order performance by similarity to ideal solution) as a solution for the supplier selection problem. The authors emphasized the importance of the selection of the proper supplier, in the condition of very strong competitiveness on the certain market. They used Fuzzy TOPSIS method for supplier selection, and the Fuzzy ANP method for the deriving the criteria weights. The first step in analytic network process is a definition of the priorities among all elements in the system and making the comparison matrixes, which should be done by experts, using the fundamental Saaty scale (Table 1).

Matrix "A" shows comparison among elements a_{ij}, which represents the experts' priority of one element to the others.

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_j \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccccc} A_1 & A_2 & \dots & A_i & \dots & A_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \dots & a_{1i} & \dots & a_{1n} \\ a_{21} & 1 & & & & a_{2n} \\ \vdots & & & & & \vdots \\ a_{j1} & a_{j2} & & 1 & & a_{jn} \\ \vdots & & & & & \vdots \\ a_{n1} & a_{n2} & \dots & a_{ni} & \dots & 1 \end{bmatrix} \end{array}$$

Assume that all priorities are given by fuzzy numbers, using modified Saaty scale (Table 2), the new matrix, which shows priorities among elements, will be "~A". Matrix "A" with fuzzy numbers becomes matrix "~A", the element which is triangle fuzzy number, $\sim a_{ij}$, and there are its left, middle and right limit, a_{ijl}, a_{ijm}, and a_{ijr}, respectively.

$$\sim A = \begin{bmatrix} 1,1,1 & a_{12l},a_{12m},a_{12r} & \dots & a_{1il},a_{1im},a_{1ir} & \dots & a_{1nl},a_{1nm},a_{1nr} \\ 1/a_{12r},1/a_{12m},1/a_{12l} & 1,1,1 & & a_{2il},a_{2im},a_{2ir} & & a_{2nl},a_{2nm},a_{2nr} \\ \vdots & & & & & \vdots \\ 1/a_{1ir},1/a_{1im},1/a_{1il} & 1/a_{2ir},1/a_{2im},1/a_{2il} & & 1,1,1 & & a_{inl},a_{inm},a_{inr} \\ \vdots & & & & & \vdots \\ 1/a_{1nr},1/a_{1nm},1/a_{1nl} & 1/a_{2nr},1/a_{2nm},1/a_{2nl} & \dots & 1/a_{inr},1/a_{inm},1/a_{inl} & \dots & 1,1,1 \end{bmatrix}$$

Table 1. The fundamental Saaty scale.

The importance	Definition
1	Equal
2	Intermediate
3	Moderate importance
4	Intermediate
5	Strong importance
6	Intermediate
7	Very strong importance
8	Intermediate
9	Extreme importance

The eigenvectors are used to calculate the consistency ratio, CR, as a relation of the consistency index, CI, and the random index, RI. This factor should be less then 0.1, otherwise the judgment of a decision maker should be revised.

$$CR = \frac{CI}{RI} \tag{1}$$

The consistency index is calculated using the following equation, where n is the number of the components (Table 3).

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

$$\lambda_{\max} = \sum_{i=1}^{n} \left(w_i \cdot \left(\sum_{j=1}^{n} a_{ij} \right) \right) \tag{3}$$

$$W = \begin{bmatrix} w_1 \\ \dots \\ w_i \\ \dots \\ w_n \end{bmatrix} ; \; w_i = \frac{1}{n} \sum_{j=1}^{n} a'_{ij} \tag{4}$$

After determination of matrix "~A", and checking the value of the CR, defuzzication method is applied. Fuzzy logic is used in different circumstances, which are characterized by uncertainty and imprecision, and in the cases where the linguistic phrases and numerical values can be used for description. Liou and Wang (1992) proposed the deffuzication method, which has been used in this paper. The elements of the single pairwise comparison matrix $g_{\alpha,\beta}(A)$ consider the preference α and risk tole-rance β of decisions makers. These coefficients can have value between 0 and 1. The degree of uncertainty is higher when α is closer to 0. The degree of a decision maker's pessimism is described by β, so that pessimistic decision maker uses value 1 for coefficient *β*.

$$
g_{\alpha\beta}(A)=g_{\alpha\beta}\left[a_{ij}\right]=\begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_i \\ \vdots \\ C_n \end{array}\begin{bmatrix} 1 & g_{\alpha\beta}(a_{12}) & \cdots & g_{\alpha\beta}(a_{1i}) & \cdots & g_{\alpha\beta}(a_{1n}) \\ g_{\alpha\beta}(a_{21}) & 1 & & g_{\alpha\beta}(a_{2i}) & & g_{\alpha\beta}(a_{2n}) \\ \vdots & \vdots & & & & \vdots \\ g_{\alpha\beta}(a_{i1}) & g_{\alpha\beta}(a_{i2}) & & 1 & & g_{\alpha\beta}(a_{in}) \\ \vdots & \vdots & & & & \vdots \\ g_{\alpha\beta}(a_{n1}) & g_{\alpha\beta}(a_{n2}) & \cdots & g_{\alpha\beta}(a_{ni}) & \cdots & 1 \end{bmatrix}
$$

$$
g_{\alpha,\beta}(a_{ij})=\left[\beta\cdot f_{\alpha}(a_{ijl})+(1-\beta)\cdot f_{\alpha}(a_{ijr})\right],\ 0\le\alpha\le 1,\ 0\le\beta\le 1
$$

$$
f_{\alpha}(a_{ijl})=(a_{ijm}-a_{ijl})\cdot\alpha+a_{ijl}
$$

$$
f_{\alpha}(a_{ijr})=a_{ijr}-(a_{ijr}-a_{ijm})\cdot\alpha \tag{5}
$$

The super matrix, "W" is made of several matrices. W_{ij} shows priorities among system elements separately, and represents the importance of some nodes, and clusters, comparing with the others. The components of the system are C_i, i = 1,.., n, and elements of the component are e_{imi}, where m_i is a number of elements.

$$
\begin{array}{cc}
 & \begin{array}{ccc} e_{11}\ e_{12}\ e_{1m1} & e_{21}\ e_{22}\ e_{2m2} & \quad e_{n1}\ e_{n2}\ e_{nmn} \end{array} \\
W= \begin{array}{c} e_{11} \\ e_{12} \\ e_{1m1} \\ e_{21} \\ e_{22} \\ e_{2m2} \\ \vdots \\ \\ \end{array} &
\begin{bmatrix} W_{11} & W_{12} & & W_{1n} \\ & & \cdots & \\ & & & \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix}
\end{array}
$$

If the considered system is composed of three levels, matrix "W" will be as follows.

$$
W=\begin{array}{c} G \\ C \\ A \end{array}\begin{bmatrix} 0 & 0 & 0 \\ W_{21} & 0 & 0 \\ 0 & W_{32} & I \end{bmatrix}
$$

The first column represents the impact of the goal on the goal, criteria and alternatives, respectively. The sub-matrix "W_{21}" shows the impact of the criteria on the goal; the sub-matrix "W_{32}" presents the influences of the alternatives on criteria and the sub-matrix "I" is the identity matrix. Every zero in the matrix means that there are no influences between two components in the system. If there is an influence, for instance, among criteria, then previous matrix "W" will include the sub-matrix "W_{22}".

Table 2. Fuzzy numbers in Saaty scale.

Fuzzy triangle numbers		Fuzzy reciprocal values	
$\tilde{1}$	(1,1,1)	$\widetilde{1/1}$	(1,1,1)
$\tilde{2}$	(1,2,3)	$\widetilde{1/2}$	(1/3,1/2,1)
$\tilde{3}$	(1,3,5)	$\widetilde{1/3}$	(1/5,1/3,1)
$\tilde{4}$	(2,4,6)	$\widetilde{1/4}$	(1/6,1/4,1/2)
$\tilde{5}$	(3,5,7)	$\widetilde{1/5}$	(1/7,1/5,1/3)
$\tilde{6}$	(4,6,8)	$\widetilde{1/6}$	(1/8,1/6,1/4)
$\tilde{7}$	(5,7,9)	$\widetilde{1/7}$	(1/9,1/7,1/5)
$\tilde{8}$	(6,8,9)	$\widetilde{1/8}$	(1/9,1/8,1/6)
$\tilde{9}$	(7,9,9)	$\widetilde{1/9}$	(1/9,1/9,1/7)

$$
W=\begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix}
$$

The next step is making the normalized matrix, and then the limit matrix, which shows the preferences among the alternatives. The limit matrix is made by multiplying the super matrix by itself. When the columns of the matrix become the same, the limit matrix has been reached, and the matrix multiplication process is finished.

For three-level model, the limit matrix is calculated as shown below.

$$
W=\begin{bmatrix} 0 & 0 & 0 \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & I \end{bmatrix} \Rightarrow W^{\infty}=\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ W_{32}(I-W_{22})^{-1}W_{21} & W_{32}(I-W_{22})^{-1} & I \end{bmatrix}
$$

DETERMINING AN OPTIMAL ORGANIZATIONAL STRUCTURE FOR A RAIL COMPANY USING FUZZY ANP

Considering knowledge, experience and intuition of the experts, the structure of the system is developed (Figure 2), using the recommendation by Burton and Obel, which is in harmony with the contingency theory.

According to defined goals and objectives of the company, experts define the potential types of organizational structure for the rail company. In this paper, four

Table 3. The values of the random index, RI, according to the number of the components.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

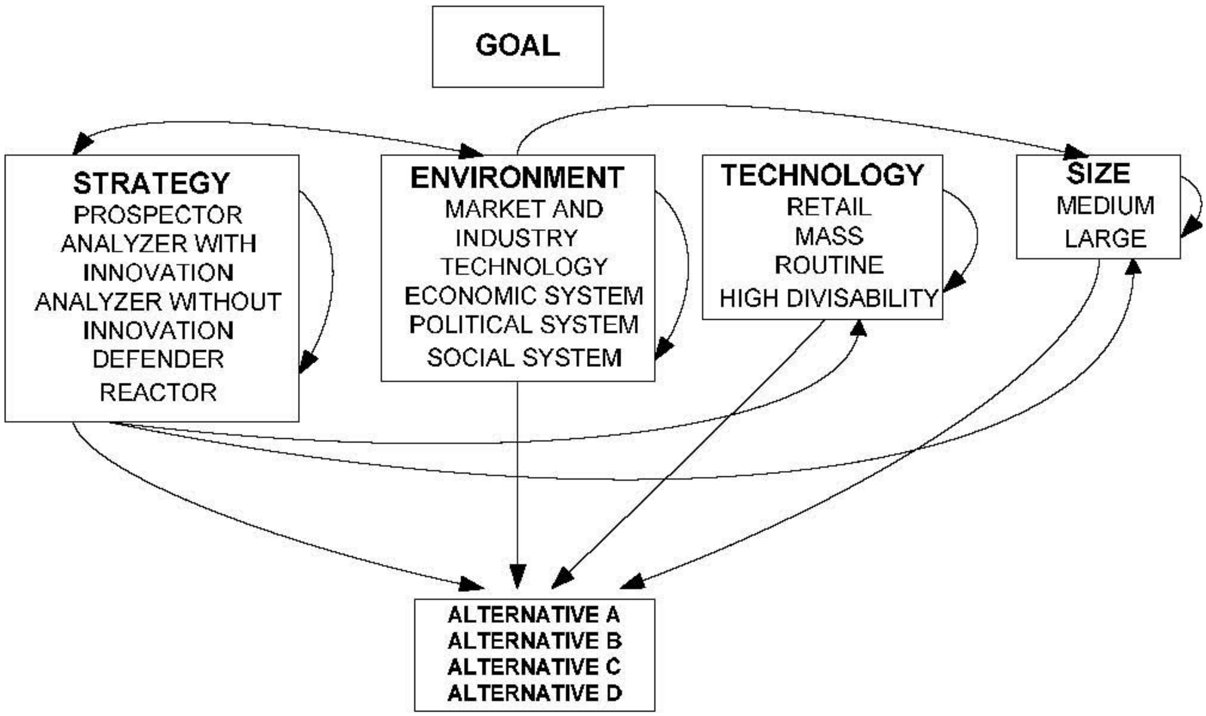

Figure 2. ANP network for the organizational structure selection.

Table 4. The ranking order of alternatives using the fuzzy numbers.

A = 0.1, ß = 0.9		α = 0.9, ß = 0.1		α = 0.5, ß = 0.5		α = 0.1, ß = 0.1		α = 0.9, ß = 0.9	
B	0.326534	B	0.343124	B	0.340111	B	0.344836	B	0.341418
D	0.315882	D	0.285044	D	0.269333	C	0.242396	D	0.301737
C	0.245429	C	0.232257	C	0.2397	D	0.207597	C	0.230005
A	0.112155	A	0.139575	A	0.150856	A	0.205171	A	0.12684

alternatives are defined. The first alternative, A, is a current company structure, which means centralization of all functions in a company. The second alternative, B, is an organization of a company by a territorial principle, which considers four cost centers, according to the regions in the country. The alternative C is similar to the previous, but includes more cost centers, actually nine of them, such as the number of the rail sections in the considered example. The last alternative, D, means decentralizations by functions. Existence of the cost centers enables a company to determine, follow, manage and decrease the company costs.

After developing the model, priorities among all elements should be defined, and presented by the comparison matrices. Based on the super matrix, the normalized and limit matrices are defined. Finally, the result of the considered system is a selection of the alternative.

The final results of considered model are presented in Table 4.

DISCUSSION

From the sensitivity analysis the conclusion is that the same alternative has the priority, and the ranking order is the same as well, except in one case (α = 0.1 and ß = 0.1). The alternative B has the priority, regardless of the coefficients' value *α* and *ß*. Applying proposed decentralized model, all company costs would be the responsibility of each region. Besides this adventage, the decentralization makes it possible to plan, compare and monitor all business results of a company, with the aim to improve its effectiveness and efficiency.

The same model has been tested, but with crisp instead of fuzzy numbers. The ranking order of alternatives has not been changed in this case. Interesting conclusion is that the result using the crisp numbers is very similar as one obtained in condition of very low uncertainty, α = 0.9, and high pessimism of decision maker, ß = 0.9.

CONCLUSION

The relevance of determining an optimal organizational structure for a rail company is especially today great, in regard to the changes on the transport and the rail market. Adaptation and harmonization of the company policy is necessary for existence of the market and increasing the market share. Only adequate organizational structure can make the realisation of the company goal and the objectives possible. With regard to the complexity of describing the system elements and their mutual influences, the fuzzy multicriteria decision making method is used.

In this paper we are concerned with determining an optimal organizational structure of a rail company and we proposed the solution to solve this problem by using the fuzzy analytic network process. The fuzzy ANP is a suitable method for this purpose because of the possibility to consider the system's uncertainty, decision makers' pessimism, the interdependency and feedback among the system's elements. Considering the contingency theory and the influence of several criteria on the organizational structure, the model is formed. The output of the considered model is the suggestion for selecting the optimal organizational structure of a rail company.

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