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ANALYTIC HIERARCHY MODEL OF THE SELECTION OF AN OPTIMAL ORGANIZATION VARIANT

Vujadin VEŠOVIĆ, Nebojša J. BOJOVIĆ

Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Yugoslavia

Abstract. In this paper is given a model of selecting an optimal organization variant alternative by using the analytic hierarchy process. The problem is described, its hierarchical structure is recognized, and the theoretical foundation of the method is presented. The proposed model is illustrated by a numerical example which is considered from a practical viewpoint. Further research directions in this field are outlined.

Keywords: Analytic hierarchy process, organization design, decision making

1. INTRODUCTION

Today's business conditions require the organization of a business system (a firm) to be adaptable to environmental requirements. In other words, the organization model must be flexible to allow the business system to respond successfully to a changing market, to competetion, and to benefit as much as possible from information technology. To this end, organization elements: structure, resources (manpower, capital, technologies), culture (beliefs, expectations, behaviour) and systems (control, communications, rewards) should be harmonized with development strategy, and the management's task is to keep the balance of the model, i.e. to direct the complex interactions among the strategy, resources, culture and systems. All this means that firm organization models must permanently be studied, modified and improved so as to make them provide for efficient functioning of a business system under variable operation conditions.

Identification of an existing organization together with the aims of business and development policies, organizational concept and organizational criteria provide a basis for designing organization variants - alternatives. Comparisons and evaluations of these alternatives and the selection of one of them represent in fact the problem of determining the optimal organization. A large number of business efficiency and effectiveness criteria, combined with the difficulties concerning their numerical quantification, make the selection of an appropriate model very complicated.

A task formulated in this way belongs to the class of discrete multicriteria decision-making problems [6]. Such problems are most often handled using the cost/benefit analysis. Apart from its shortcomings in describing the conflicting criteria, this analysis requires macro- and microorganization to be worked out to permit the prediction of income and expenditure; all these efforts are often unnecessary and unreasonable. The ELECTRE method based upon the concept of an 'outranking relationship' was used in solving of the stated problem [10].

This paper is intended to show the applicability of the analytic hierarchy process to the selection of the optimal organization alternative. Under this approach the problem is decomposed into smaller component parts and pairwise comparisons are then made for each hierarchical level. Problem decomposition into a hierarchical structure, the measurement methodology developed for purposes of establishing priorities at each hierarchical level (a typical scale of measurement of importance ranges from one to nine), and the calculation of priority and consistency index represent the three basic components of the analytic hierarchy approach [5], [7].

The following Section gives the formulation of the problem of selecting the optimal organization alternative, describes the organization alternatives and defines organization criteria and subcriteria. Section 3 presents the analytic hierarchy formulation of the problem and Section 4 describes the performed numerical experiments. Concluding remarks including the analysis of the results obtained by experiments and the prospective applications are presented in Section 5.

2. PROBLEM STATEMENT

Efficiency in the operation of transport firms depends on the ever increasing competition and offer of services on the market and requires a higher productivity, decreased operational cost and the development of improved planning tools to permit better utilization of the available resources. Trying to find an organization model that will allow achieving the stated goals is an imperative for all participants in the transportation process.

In trying to formulate the model of organization alternative it is important to know the basic characteristics of each proposed alternative with respect to criteria and subcriteria. Three possible organization alternatives suggested in modern management theory are analyzed here.

The method will be used for selecting the optimal organization alternative for a road transport firm which serves in urban, suburban and inter-city transportation. On this territory there are no conditions for establishing separate firms for urban and suburban transport. The following three alternatives have been included in a close choice:

Alternative 1 - Organizing a firm with centralized functions (research, development, sales, etc.) and centralized decision making. Organizational units - departments have a direct control function only.

Alternative 2 - Organizing firm with profit centers on a territorial principle and with decentralized decision making. Research, acquisition, and other functions that are reasonable to perform at firm level are organized at that level, while sales, manufacture, transport services etc. are organized at profit-center level.

Alternative 3 - Several firms organized on a territorial principle with centralized functions, centralized decision making and limited material, manpower and financial resources.

The proposed criteria important for achieving the global goal are: fulfilment of transport requirements, business results, firm development, adaptation ability and the quality of life (working and living conditions) together with motivation factors. The fulfilment of transport requirements is described in terms of subcriteria such as transport volume, quality and price, while business results are judged according to the amounts of profit and costs. Finally, adaptation ability is classified into structural, strategic and operational. The hierarchy of the model of selecting an organization alternative is illustrated in Fig. 1.

For purposes of comparing the relative importance of criteria and subcriteria with respect to the global goal and with respect to alternatives, a measurement scale has been established [4], [7], [11] and is presented in Table 1.

Table 1. Scale of Measurement for Analytic Hierarchy Process

Intensity of Relative Importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values to reflect compromise
Reciprocals of above nonzero numbers	Used to reflect dominance of the second alternative as compared with the first

This scale allows managers to make pairwise comparisons and form matrices for describing the relationship of criteria and subcriteria to the alternatives as well as the interrelationships between criteria. Data required for computing the priorities of various organization alternatives are collected in this way.

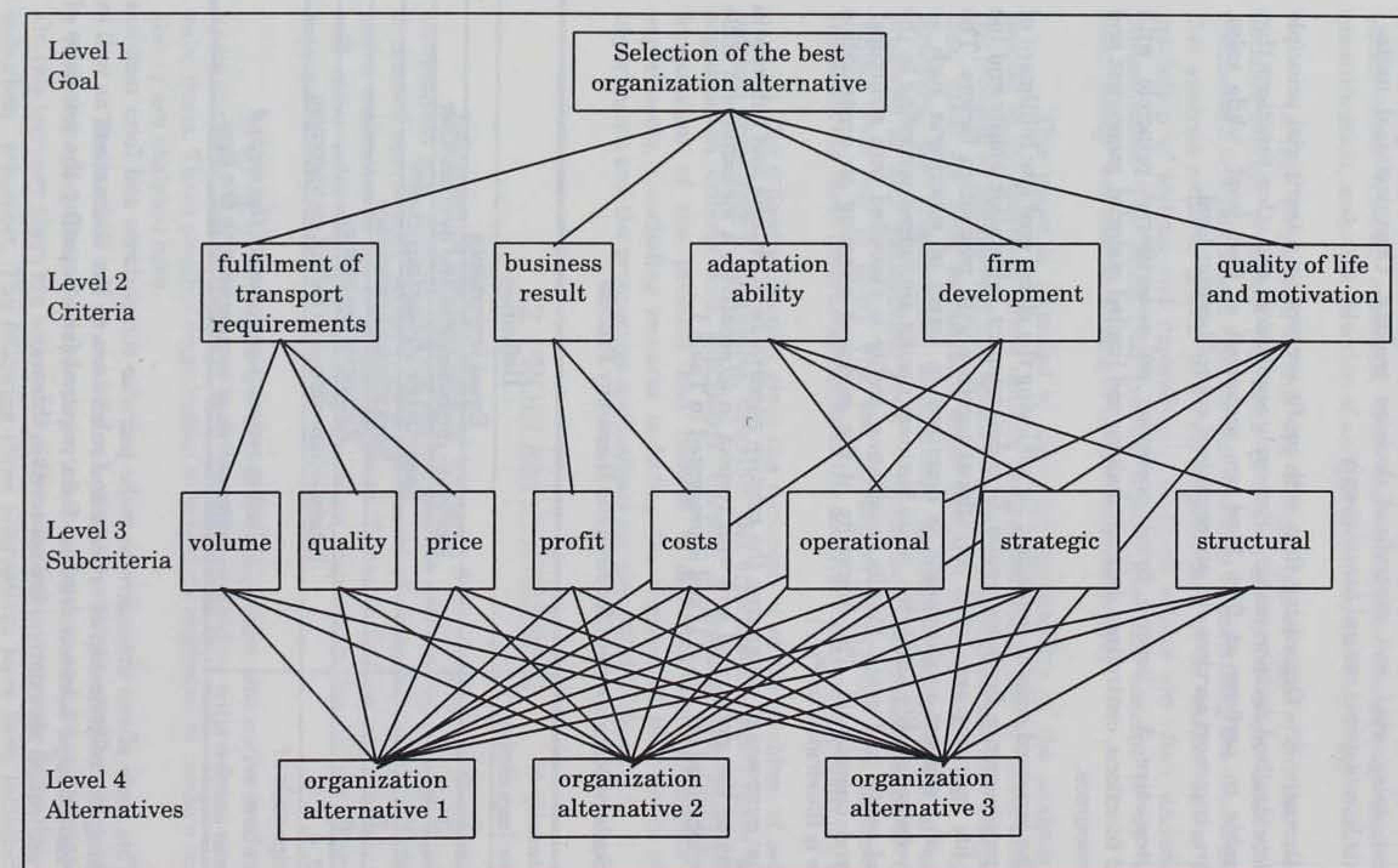

Figure 1. Organization Variants Hierarchical Configuration

3. ANALYTIC HIERARCHY PROCESS

As has been stated in preceding Sections, the analytic hierarchy process provides a framework for selecting the best out of a set of alternatives that were formed using conflicting criteria. The axiomatic statement of this process was given by Saaty [7], and Harker and Vargas [5] demonstrated by examples the inconsistency of the critical remarks directed to Saaty's statement. The first of the four axioms deals with the reciprocity property [4];

Axiom 1: Given any two alternatives i and j in the set of alternatives A, the decision marker is able to provide a pairwise comparison a_{ij} of these alternatives under any criterion c from the set of criteria C on a ratio scale which is reciprocal, i.e.,

$$a_{ij} = \frac{1}{a_{ji}} \text{ for all } i, j \in \mathbf{A}$$

Axiom 2: When comparing any two alternatives $i, j \in \mathbf{A}$, the decision maker never judges one to be infinitely better than another under any criterion $c \in \mathbf{C}$; i.e., $a_{ij} \neq \infty$ for all $a_{ij} \in \mathbf{A}$.

Axiom 3: One can formulate the decision problem as a hierarchy.

Axiom 4: All criteria and alternatives which impact the given decision problem are represented in the hierarchy. That is, all expectations must be represented (or excluded) in terms of criteria and alternatives in the structure and be assigned priorities which are compatible with one's expectations.

Based on the previously made pairwise comparisons and by using the accepted measurement scale, the task is to calculate the elements of a vector of priorities or weights w_i. From the reciprocal matrix

$$A = \begin{bmatrix} a_{11} & a_{12} & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & a_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ a_{n1} & a_{n2} & . & . & a_{nn} \end{bmatrix}$$

these weights can be computed even when the matrix is inconsistent, by applying the eigenvector method [11]

$$A\,w = \lambda_{\max} . w$$

where $\lambda_{\max}$ is the Perron root of the matrix. Consistency is measured by using a consistency ratio ($C.R.$), the ratio of the degree of incosistency in the judgment of w_i / w_j to the consistency obtained if and only if $\lambda_{\max} = n$ and is computed as [2]

$$C.R. = \frac{\lambda_{max} - n}{n-1}$$

Harker [4] has defined a random index (*R.I.*) as the mean *C.R.* value computed for the matrices that were randomly generated for each size of matrix *n*, and has listed these values in a table. The ratio of the consistency ratio (*C.R.*) to the random index (*R.I.*) is referred to as consistency index (*C.I.*) and represents a measure of the probability that the matrix was filed in a random manner. The upper limit of *C.I.* value which can be considered as acceptable with respect to the judgments given in matrix *A* is 0.1.

The principle of hierarchic composition permits the judgments to be synthesized by computing the total priority of an alternative by using a linear additive function [2].

4. A NUMERICAL EXPERIMENT

In this Section the applicability of the model is demonstrated for the judgments given under selected criteria and subcriteria for the 3 proposed organization alternatives, on the basis of the philosophy and theory of the analytic hierarchy process and by using the EXPERT CHOICE [3] software package.

Based on the hierarchical structure shown in Fig. 1, pairwise comparisons of all alternatives have been made according to the measurement scale given Table 1. The results are presented in the form of the reciprocal matrices of each level with respect to all organization alternatives, relationships between levels, and are listed in the following tables.

Table 2: Comparison of Organization Alternatives with respect to Transport Volume

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/6	1/5
Alternative 2	6	1	3
Alternative 3	5	1/3	1
		C.R.=0.090	

Table 3: Comparison of Organization Alternatives with respect to Transport Service Quality

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/2	3
Alternative 2	2	1	5
Alternative 3	1/3	1/5	1
		C.R.=0.004	

Table 4: Comparison of Organization Alternatives with respect to Price

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	5	3
Alternative 2	1/5	1	1
Alternative 3	1/3	1	1
	C.R.=0.028		

Tables 2, 3 and 4 contain data on the criterion: fulfilment of transport requirements.

Table 5: Comparison of Organization Alternatives with respect to Profit Service Quality

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/8	1/4
Alternative 2	8	1	5
Alternative 3	4	1/5	1
	C.R.=0.090		

Table 6: Comparison of Organization Alternatives with respect to Cost

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	4	8
Alternative 2	1/4	1	2
Alternative 3	1/8	1/2	1
	C.R.=0.000		

Tables 5 and 6 include information about the criterion: business results.

Table 7: Comparison of Organization Alternatives with respect to Firm Development

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/9	1/5
Alternative 2	9	1	4
Alternative 3	5	1/4	1
	C.R.=0.068		

Table 8: Comparison of Organization Alternatives with respect to Operational Adaptation Ability

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	3	5
Alternative 2	1/3	1	2
Alternative 3	1/5	1/2	1
	C.R.=0.004		

Table 9: Comparison of Organization Alternatives with respect to Strategic Adaptation Ability

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/4	1/2
Alternative 2	4	1	3
Alternative 3	2	1/3	1
	C.R.=0.017		

Table 10: Comparison of Organization Alternatives with respect to Structural Adaptation Ability

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/3	1/5
Alternative 2	3	1	1/3
Alternative 3	5	3	1
	C.R.=0.037		

Tables 8, 9 and 10 include information about the criterion: adaptation ability.

Table 11: Comparison of Organization Alternatives with respect to Quality of Life and Motivation

	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	1/7	1/3
Alternative 2	7	1	3
Alternative 3	3	1/3	1
	C.R.=0.007		

Table 12: Comparison of Subcriteria

Subcriteria	Relative priority
Transport Volume	0.35
Transport Quality	0.40
Transport Price	0.25
Profit	0.60
Cost	0.40
Operational	0.25
Strategic	0.40
Structural	0.35

Table 13: Comparison of Criteria with respect to Stated Goal

	Fulfilment of Transport Requirements	Business Results	Firm Development	Adaptation Ability	Quality of Life
Fulfilment of Transport Requirements	1	1/9	1/5	1/3	1/4
Business Results	9	1	7	3	5
Firm Development	5	1/7	1	1/4	1/3
Adaptation Ability	3	1/3	4	1	2
Quality of Life	4	1/5	3	1/2	1
	C.R.=0.094				

Table 13 provides an analysis of the interrelationships among criteria. In designing an optimal organization, one has to consider all criteria and take into account the influence of each criterion on each other. Pairwise comparisons have been used here for this purpose.

The calculated C.R. values show that the given judgments are acceptable and that the synthesis can be performed. The stated problem represents an analytic hierarchy process and can be solved successfully by using the EC (EXPERT CHOICE) software package for personal computers.

This package has been employed for solving the previously stated problem of selecting an optimal organization alternative. The package permits solving problems with no more than five hierarchical levels and offers extensive capabilities for the numerical and graphical interpretation of results.

Output results are given in Tables 14, 15, 16 and 17. The first 3 tables refer to the mixed priority of subcriteria with respect to each organization alternative. A mixed consistency index has been calculated in a similar way by using the relative priorities of subcriteria, i.e. their single C.R. values. Table 17 presents the final results obtained by associating all criteria for all organization alternatives.

Table 14: Mixed Priority for Fulfilment of Transport Requirements

	Volume (0.35)	Quality (0.40)	Price (0.25)	Mixed Priority
Alternative 1	0.078	0.309	0.659	0.316
Alternative 2	0.635	0.582	0.156	0.494
Alternative 3	0.287	0.109	0.185	0.190
C.R.	**0.090**	**0.004**	**0.028**	**0.040**

Table 15: Mixed Priority for Business Results

	Profit (0.60)	Cost (0.40)	Mixed Priority
Alternative 1	0.068	0.727	0.331
Alternative 2	0.733	0.182	0.513
Alternative 3	0.199	0.091	0.156
C.R.	**0.090**	**0.000**	**0.054**

Table 16: Mixed Priority for Adaptation Ability

	Operational (0.25)	Strategic (0.40)	Structural (0.35)	Mixed Priority
Alternative 1	0.648	0.136	0.105	0.253
Alternative 2	0.230	0.625	0.258	0.398
Alternative 3	0.122	0.238	0.637	0.349
C.R.	**0.004**	**0.017**	**0.037**	**0.021**

Table 17: Mixed Priority for Organization Alternatives

	Fulfilment of Transport Requirements (0.049)	Business Results (0.421)	Develop-ment (0.104)	Adaptation Ability (0.253)	Quality of Life and Motivation (0.172)	Mixed Priority
Alternative 1	0.316	0.331	0.060	0.253	0.088	0.241
Alternative 2	0.494	0.513	0.709	0.398	0.669	0.530
Alternative 3	0.190	0.156	0.231	0.349	0.243	0.229
	C.I.=0.070					

These tables contain a considerable amount of information the following of which should be emphasized:

a)	relative importance of criteria;	
	business results	0.421
	adaptation ability	0.253
	quality of life and motivation	0.172
	firm development	0.104
	fulfilment of transport requirements	0.049
b)	total mixed priority;	
	organization alternative 1	0.241
	organization alternative 2	0.530
	organization alternative 3	0.229

As can be seen, the performed analysis gives priority to the second organization alternative - organizing a firm with profit centers on a teritorial principle and with decentralized decision making.

c) Of all the output indicators shown in the tables in this Section, the consistency ratio (C.R.) and the consistency index (C.I.) are the only that tell us whether and to what extent the decision maker was consistent in judging the reciprocity matrix elements. In a general case, the C.I. values equal to zero indicate the decision maker's perfect consistency, whereas C.I. values larger than 0.1 show that it necessary to revise some judgements. In our case, the values of C.R. and the total C.I. of 0.07 reflect acceptable consistency.

5. CONCLUSIONS

As stated in the Introduction, the main aim of this paper has been to provide an analytic hierarchy formulation of the problem of selecting an optimal organization alternative. We believe we have shown by experiments that the analytic hierarchy process is a simple yet elegant method for solving this type of problems. The model presented here takes into consideration the most important criteria and subcriteria as well as organization alternatives suggested by modern management theory.

Organization alternative selection has to be formulated in a hierarchical manner. The interrelationships among criteria that are important for proper functioning of transportation are described in the paper. The model proposed here appears to be a very powerful tool for selecting organization alternatives and it represents a valuable aid to a firm's managerial staff in making decisions on their firm's organization.

Analytic hierarchy processes can also be used in solving some other multicriteria decision-making problems (marketing mix decision making [11], selecting subsystem automation options [1], motorcycle design [8]), etc.

Incorporating stochastic elements into the reciprocal matrix of evaluations and studying the influence of uncertainty on the stability of the rank order of alternatives will be one of the important areas of future research. Some attempts of expressing the evaluations by stochastic values are given in [9].

The author's many-year experience gained through numerous transport organization projects made by using other methods (the Delphi technique, ELECTRE method, TOPSIS, etc.) shows that analytic hierarchy processes have certain advantages.

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