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MULTICRITERIA PERFORMANCE COMPARISON OF CENTRAL EUROPEAN INDUSTRIAL FIRMS

Abstract

The paper presents a modeling approach for productivity comparison of Central European firms. The approach is based on Data Envelopment Analysis and Analytic Network Process. The proposed model consists of two basic parts. The first one estimates the importance of branches within the countries and the second one evaluates the performance of the firms within branches. The results of both parts are synthesized and the productivity of the countries is estimated. The evaluation is based on the data set resulting from a survey among firms from selected industries.

Keywords

AHP, ANP, data envelopment analysis, multiple criteria decision making, efficiency.

1. Formulation of the problem

The main aim of the paper is to propose a methodological framework for evaluation of performance and identification of productivity gaps between selected Central European countries accessing the European Union and developed industrial western European economies. The paper describes and discusses issues and results of the international project focusing on this subject of study.

The proposed approach starts with efficiency evaluation of selected firms of different industrial branches that are very important for all the countries included into the study. Then the results from the first step are aggregated and the efficiencies of the branches are derived. The last step consists in the aggregation of the results from the previous step according to the economic strength of the branches within the countries; finally, the relative productivity measures for all countries are derived. Due to the hierarchical nature of the process mentioned the problem can be expressed as an AHP or ANP model.

Our aim is to compare the efficiency and performance of Central European firms, branches and countries by different models and to try to identify the sources of inefficiencies of the units evaluated. To receive appropriate data sets for the evaluation, a questionnaire was prepared and distributed to hundreds of firms in the countries participating in the study. Almost one thousand letters with the request to fill out the questionnaire were distributed in each of the participating countries (Czech Republic, Poland, Hungary, East and West Germany) to the firms of selected branches. The most important branches in all of the attending countries (building, meat processing, furniture, freight transport, etc.) have been taken into account. The questionnaire used in our survey has the following structure:

1. General information about the firm
   - turnover,
   - pre-tax profit or loss,
   - fixed and variable costs,
   - estimated market share,
   - information concerning the basic features of the production process, such as number of products or services, rate of automatization of the production process, share of the intermediate consumption, etc.
2. Information related to the personnel and capital of the firm
   - structure of personnel (management, administration, workers),
   - labor costs,
   - qualification of personnel and the cost spent on the improving of qualification,
   - size of floor space,
   - investments into fixed assets.
3. Information related to the management, organization and structure of the firm
   - the number of hierarchies in the organizational structure of the form,
   - the main roles and tasks of the management.

4. Information related to innovations of products and/or production processes
   - the number of hierarchies in the organizational structure of the form,
   - the level of substantial innovations or introductions of new products/ services,
   - costs spent on product/service innovations.
5. Information related to networking activities of the firm
   - the rate of co-operation with the customers and suppliers,
   - the level and importance of the use of current communication technologies (e-mail, www, e-business).

The paper is organized as follows. The next section contains a brief description of the basic models that can be used for performance evaluation by taking into account several characteristics influencing the efficiency. Section 3 describes an AHP model that derives the efficiency scores for firms, branches and countries of the study and presents some results on the reduced data set. Section 4 brings a discussion on the possibilities of modeling the problem by the analytic network process. The last section contains a summary of results and a discussion of future research.

2. Performance evaluation models

Within the process of analysis of performance and productivity of countries it is necessary to take into account the performance of production units operating in these countries. As production units, important firms in different economic branches can be taken. Their productivity depends on many factors that can be divided into two basic groups – inputs and outputs. Inputs can be characterized as sources used by the firm during the process of producing outputs. Then, the measure of productivity of firms can be derived by a comparison of outputs and inputs. Usually it is true that higher outputs and/or lower inputs lead to higher productivity measure. The knowledge of productivity measures of firms can be used for estimation of productivity measures of economic branches (according to the size of the firms including in the survey and other factors). Similarly, the importance of the branches within the selected country together with performance measures of branches can lead to estimation of productivity measure of the country.

One of the important problems within the above mentioned process is the evaluation of productivity (efficiency, performance) of the firms with respect to information about their inputs and outputs substantially influencing the productivity. In this section we will not discuss the selection of main factors (inputs and outputs) for productivity comparison but we will mention some of the basic models and techniques that can be used in the evaluation. It is clear that the evaluation is based on the comparison of multiple inputs and outputs. That is why one of the methodological tools available for this purpose is multiple criteria decision making.

Many multiple criteria decision making methods are available; they are usually based on computation of utility measures of evaluated units by means of weighting of the criteria. The most often used methods are WSA, ELECTRE and PROMETHEE class methods and the AHP. The last method is not only a technique for evaluation of units but it can be also profitably used for hierarchical modeling of large and complex decision situations. That is why it can be a nice tool for our purposes. Our aim is not to describe the methods listed in detail. Below we give just the brief characteristics of the AHP, WSA and PROMETHEE II (one of the methods from the PROMETHEE class methods).

The AHP is based on the possibility to express decision problems as hierarchical structures. The hierarchy representing a decision problem always consists of several levels. The first (topmost) level defines a main goal of the decision problem and the last (lowest) level describes usually the decision units. The levels between the first and the last levels can contain secondary goals, criteria and subcriteria of the decision problem. The number of the levels is not limited, but in the typical case it does not exceed four or five. Figure 1 shows a very simple three-level hierarchy, which can represent the standard decision problem – the evaluation of *n* units X_1, X_2, …, X_n, by *k* criteria Y_1, Y_2, …, Y_k.

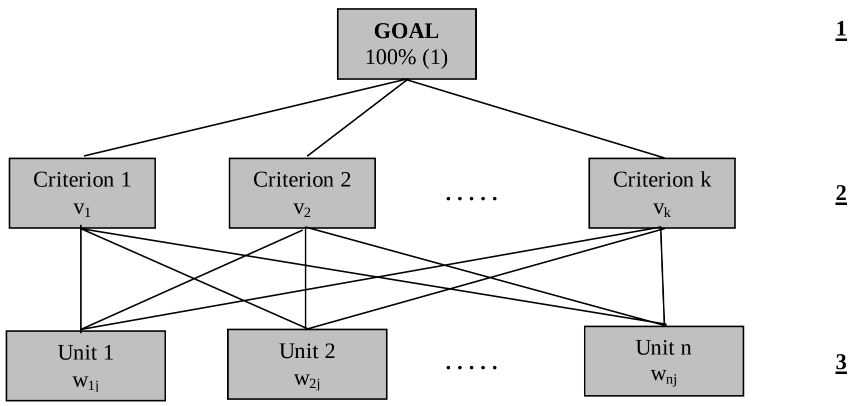

Figure 1. Three-level hierarchy

The decision maker expresses their preferences or compares the importance of the elements on the given level with that of the element on the preceding level. The information resulting from the decision maker's judgements on the given level of the hierarchy is synthesised onto the local priorities. They can express, e.g. the relative importance of the criteria (weight coefficients – in Fig. 1 denoted by v_j, i=1,2,...,k) or preference indices of the units with respect to the given criterion (w_{ij}, i=1,2...,n, j=1,2,...,k). In the standard AHP model the decision maker's judgements are organised into pairwise comparison matrices at each level of the hierarchy. The judgements are point estimates of the preference between two elements of the level. Let us denote the pairwise comparison matrix $A = \{a_{ij} | a_{ji} = 1/a_{ij}, a_{ij}>0, i,j=1,2,...,k \}$, where k is the number of elements of the particular level. Saaty (1990) proposes to use for preference expression a_{ij} integers in the range 1 through 9, where 1 means that the i-th and the j-th elements are equally important and 9 means that the i-th element is absolutely more important than the j-th element. The local priorities are derived by solving the following eigenvector problem

$$A.v = \lambda_{\max} v,$$
$$\sum_{i=1}^{k} v_i = 1,$$

where λ_{max} is the largest eigenvalue of A and v is the normalised right eigenvector belonging to λ_{max}.

The WSA (weighted sum approach) method is based on the principle of utility maximization. The normalized criterion values are aggregated by means of weights and the utility of each evaluated unit is derived. The complete ranking of all the units is received by their utilities.

The PROMETHEE II method works with six basic types of preference functions. They are used for measuring the intensity of preferences of all the pairs of units with respect to the given criterion. The partial pairwise intensities are aggregated by means of weights of the criteria specified by the decision maker and the global preferences between pairs of units are derived. The complete ranking of all the units is obtained by their descending ordering according to their net flows computed from the global preferences.

Multiple criteria decision making techniques are often based on the definition of the utility of units by means of several basic principles, e.g. aggregation of normalized criterion values. Another methodological framework that can be used for the evaluation of performance of decision making units is Data Envelopment Analysis (DEA). The essential characteristic of the DEA model is the reduction of the multiple inputs and multiple outputs using weights computed by the model. This model searches weights that define a virtual unit with the best (not worse) characteristics with respect to the evaluated unit. That means the virtual unit is the unit with lower inputs and higher outputs as compared to the evaluated unit. The unit is called efficient if there does not exist any set of weights that defines the virtual unit with the properties mentioned. Otherwise the unit is not efficient and the virtual inputs and outputs are target values for reaching the efficiency. The formulation of the DEA models leads to a linear fractional programming problem that can be simply transformed into the standard linear programming problem. Data envelopment analysis is a rising area. Many DEA models based on different assumptions have been formulated. Information about them can be found e.g. in Cooper et al. [1].

3. The AHP model

Because of hierarchical structure of the above-discussed problem of the evaluation of performance firms, branches and countries, we propose a simple two step AHP model with the following basic levels:

1. *Countries.* In our study four former Soviet-block countries (Czech Republic, Poland, Hungary and East Germany) on the one hand and one highly developed Western country (West Germany) on the other hand were included on this level. Generally, it is possible to assume we have h items (countries) on this level.
2. *Branches.* The most important branches of industry and services in the region discussed were taken into account (machine building industry, meat processing, freight transport, building industries, furniture, textile industry, etc.). The number of branches in the model will be denoted by m.

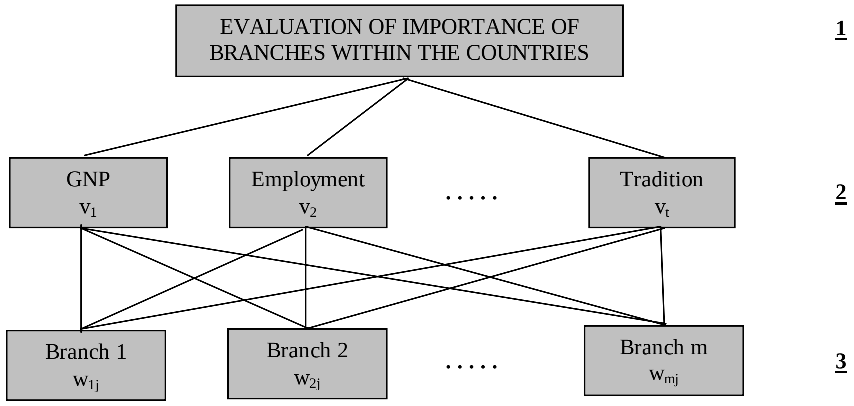

Figure 2. First step – evaluation of importance of branches within the countries

3. *Firms.* Selected more important firms of the branches listed above from all the countries were addressed by the questionnaire (its structure was presented in the introductory section of the paper) and the data from the questionnaires returned were analyzed. An identical number of firms for all the branches and countries was considered. The total number of firms in the study is $m.n$, where n is the number of firms for all the countries from a branch. That means, the number of firms from a branch for the given country is $d=n/h$ (supposing we have h countries).
4. *Criteria influencing the efficiency of firms* (inputs and outputs). The criteria used in the analysis correspond to the items of the questionnaire. As the basic inputs fixed and variable costs, labor costs, available floor space, investments, etc., can be considered, while the output characteristics are turnover, profit, market share, etc. The total number of criteria (r+s) consists of the number of inputs (r) and the number of outputs (s).
5. *Criteria influencing the position of the branches within the countries* (e.g. GNP, employment, tradition of the branch in the country, etc.). The number of elements on this level is t.

The proposed AHP model contains the following three steps:

1. **Estimation of the relative strength of the branches within countries.**
For each country the AHP model presented in Figure 2 is solved. It is the standard three-level AHP model with the units (branches) being evaluated by the criteria influencing their strength. The results of this model assign to the i-th branch its relative importance within the k-th country expressed by the value p_{ik}, i=1,2,...,*m*, k=1,2,...,*h*

$$p_{ik} = \sum_{j=1}^{t} w_{ij}, \; i = 1,2,...,m, k = 1,2,...,h,$$

$$\sum_{i=1}^{m} w_{ij} = v_j, \; j = 1,2,...,t,$$

$$\sum_{j=1}^{t} v_j = 1.$$

These formulas show that the sum of values p_{ik} over all the branches is equal to unity for all the countries k=1,2,...,*h*.

2. **Evaluation of performance of the firms within branches.**
The hierarchical model for this step is presented in Figure 3. This model is solved for all the branches separately, that means we have to analyze *m* similar AHP models. As the result of each of these models we obtain

$$q_{ik} = \sum_{j=1}^{r+s} u_{ij}, \; i = 1,2,...,n, k = 1,2,...,m.$$

The values of q_{ik} express the relative performance of the i-th firm from the k-th branch. Due to the principle of dividing of preferences from the higher hierarchical level to the lower level the sum of the values of q_{ik} over all the firms i=1,2,...,*n* is equal to unity for all the branches k=1,2,...,*m*.

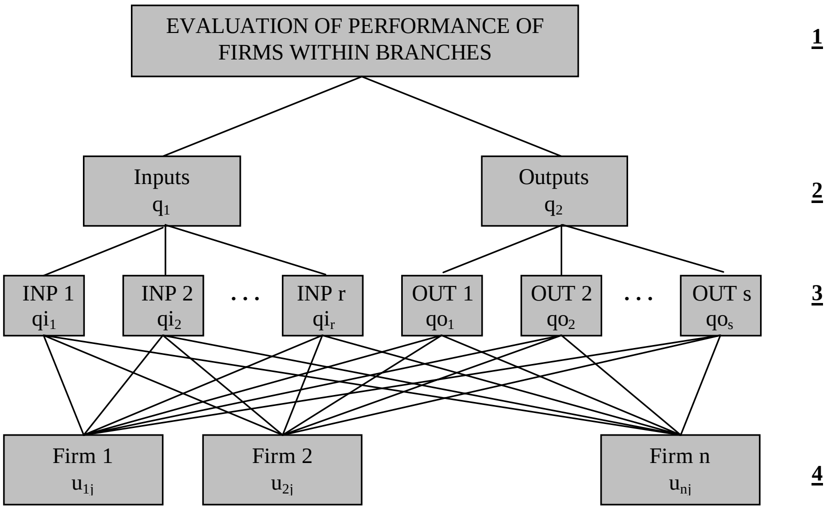

Figure 3. Second step – evaluation of performance of firms

3. **Synthesis of the results from the previous two steps.**

The productivity score for the countries can be derived from the results of the previous two steps. Let us denote the productivity score for the k-th country as P_k, k=1,2,...,*h*. This characteristic can be computed as follows:

$$P_k = \sum_{j \in C_k} \sum_{i=1}^{m} p_{ik} q_{ji}, \quad k = 1,2,...,h,$$

where C_k is the set of indices of firms of the k-th country. The set of indices of firms within any branch is {1,2,...,*n*}. We split this set as follows: $C_1 = \{1,2,...,d\}$, $C_2 = \{d+1, d+2,...,2d\}$,..., $C_h = \{n-d+1, n-d+2,...,n\}$. Because of the relations presented above the sum of P_k over all the countries equals unity.

Table 1

Input and output characteristics of the firms

Branch	Country	Fixed costs	# of workers	Floor space	Investments	Turnover	Market share
		mil. Euro	#	sq. m	mil. Euro	mil. Euro	%
Weights of inp/outp		0.33676	0.14181	0.06124	0.08301	0.29733	0.07986
Building	CZ	11.743	164	6600	0.171	12.314	55
Building	CZ	2.257	308	10000	0.486	11.571	10
Meat	CZ	5.468	458	20129	0.010	12.943	10
Meat	CZ	3.657	316	27000	0.914	6.229	80
Transport	CZ	9.143	80	5000	0.600	14.543	10
Transport	CZ	5.743	421	18652	0.286	16.029	10
Building	PL	2.251	37	8537	0.184	9.043	2
Building	PL	0.285	85	29400	0.284	6.599	80
Meat	PL	1.000	100	3000	0.168	13.233	100
Meat	PL	1.611	95	3000	0.057	3.771	10
Transport	PL	2.281	366	18848	0.258	15.288	2
Transport	PL	3.544	235	24000	0.204	5.724	5
Building	HU	2.789	49	1101	0.974	30.567	2
Building	HU	1.800	198	2500	0.818	22.362	18
Meat	HU	3.047	559	40000	2.493	21.817	3
Meat	HU	2.376	74	4385	0.074	2.645	80
Transport	HU	1.886	316	14300	1.800	13.800	5
Transport	HU	1.000	79	45000	0.010	8.114	60
Building	GW	12.271	220	11000	1.534	86.920	40
Building	GW	1.790	78	1200	0.041	17.282	15
Meat	GW	7.005	85	22000	0.562	16.873	30
Meat	GW	0.665	75	5600	0.153	11.248	5
Transport	GW	6.136	80	3500	0.511	13.294	10
Transport	GW	0.782	57	1400	0.818	8.896	20
Building	GE	1.023	62	1500	0.015	3.272	20
Building	GE	1.841	111	2900	0.010	5.317	35
Meat	GE	6.382	88	21000	0.662	12.976	20
Meat	GE	4.244	77	19000	3.375	31.189	30
Transport	GE	4.286	65	1600	0.162	4.421	30
Transport	GE	2.301	132	5900	3.630	11.862	40

Our approach will be illustrated on the small example with 5 countries (Czech Republic, Poland, Hungary, Germany East and West), 3 branches (building industries, meat processing industry and freight transport) and 2 firms from each branch and country, i.e. the total number of firms in this example is 30. Each firm is described by 4 inputs (fixed costs, number of workers, floor space and investments) and 2 outputs (turnover and market share). The inputs and outputs specific for all the firms are listed in Table 1. The results of the AHP model will be compared to the DEA analysis and results of the WSA and PROMETHEE II methods.

The first step of our approach consists in the evaluation of the importance of branches within the countries. For each of the five countries we applied the model in Figure 2 with three criteria (GNP, employment, tradition) and three branches and asked an expert to perform pairwise comparisons in this model. The results (p_{ik}, i=1,2,3, j=1,2,...,5) are summarized in Table 2.

Table 2

National importance coefficients of branches

	CZ	PL	HU	GW	GE
Building	0.425	0.508	0.343	0.447	0.447
Meat proc	0.212	0.242	0.442	0.191	0.191
Transport	0.363	0.250	0.215	0.352	0.352

In the second step we compute the performance scores for all the firms within their branches according to the model presented in Figure 3. The input and output weights derived by pairwise comparisons are listed in the second row of Table 1. These values are used for the computation of performance scores q_{ik} of firms i=1,2,...,10, j=1,2,3 in Table 4. For computational reasons we show in Table 3 the pairwise comparison matrix for fixed costs of building industry firms together with the preferences u_{ij} only.

Table 3

Pairwise comparisons of building firms with respect to fixed costs

	CZ1	CZ2	PL1	PL2	HU1	HU2	GW1	GW2	GE1	GE2	u_{ij}
CZ1	1.000	0.200	0.200	0.111	0.250	0.167	1.000	0.167	0.125	0.167	0.0174
CZ2	5.000	1.000	1.000	0.333	2.000	0.500	6.000	0.500	0.333	0.500	0.0712
PL1	5.000	1.000	1.000	0.333	2.000	0.500	6.000	0.500	0.333	0.500	0.0712
PL2	9.000	3.000	3.000	1.000	5.000	4.000	9.000	4.000	3.000	4.000	0.2924
HU1	4.000	0.500	0.500	0.200	1.000	0.500	5.000	0.500	0.333	0.500	0.0523
HU2	6.000	2.000	2.000	0.250	2.000	1.000	8.000	1.000	0.500	1.000	0.1050
GW1	1.000	0.167	0.167	0.111	0.200	0.125	1.000	0.143	0.125	0.143	0.0158
GW2	6.000	2.000	2.000	0.250	2.000	1.000	7.000	1.000	0.500	1.000	0.1035
GE1	8.000	3.000	3.000	0.333	3.000	2.000	8.000	2.000	1.000	2.000	0.1677
GE2	6.000	2.000	2.000	0.250	2.000	1.000	7.000	1.000	0.500	1.000	0.1035

The values q_{ik}, i=1,2,...,10, j=1,2,3 in Table 4 express the relative performance of the firms from one of the selected branches. We can see that the most efficient among building firms is the second Polish firm whereas the least efficient are both the Czech firms. Similar conclusions can be drawn from other columns of the following table (meat processing industry and freight transport):

Table 4

Performance of the firms

	Building	Meat pr.	Transport
CZ1	0.06038	0.05839	0.07977
CZ2	0.05753	0.05904	0.07770
PL1	0.08527	0.15543	0.08517
PL2	0.15189	0.09211	0.05227
HU1	0.11389	0.07912	0.10182
HU2	0.09178	0.10589	0.16178
GW1	0.11803	0.08534	0.08972
GW2	0.11382	0.16481	0.16562
GE1	0.11814	0.06439	0.09490
GE2	0.08928	0.13547	0.09124

The results contained in Table 4 can be synthesized by branch weights in Table 2. The final results are presented in the first column of Table 5. The AHP model shows that the West Germany firms reach highest performance whereas the Czech firms reach the lowest one. Apart from the results given by the AHP model, Table 5 contains the average performance scores of the countries computed by other approaches – DEA, WSA and PROMETHEE II. All the results were standardized to the unity sum. By comparison of all the results it can be seen that the AHP model is very close to the DEA, which is a special technique for efficiency evaluation. Other approaches more or less differ in their results as compared to the AHP and DEA models.

Table 5

Productivity scores of the countries

	AHP	**DEA**	**WSA**	**PROM**
CZ	0.13217	0.12419	0.15532	0.14959
PL	0.21474	0.20700	0.22017	0.19244
HU	0.20899	0.21585	0.20483	0.23229
GW	0.24130	0.23245	0.21123	0.23249
GE	0.19641	0.22051	0.20845	0.19319

4. The generalized ANP model

The generalized model for productivity measurement of Central European countries is based on the Analytic Network Process (ANP) approach. The ANP approach [6], Saaty [7] is used for the local performance measuring of units and also for comparison of the global performance of units. The structure of the ANP model is described by clusters of elements connected by their dependence on one another. A cluster groups elements that share a set of attributes. At least one element in each of the clusters is connected to some element in another cluster. These connections indicate the flow of influence between the elements (Figure 4).

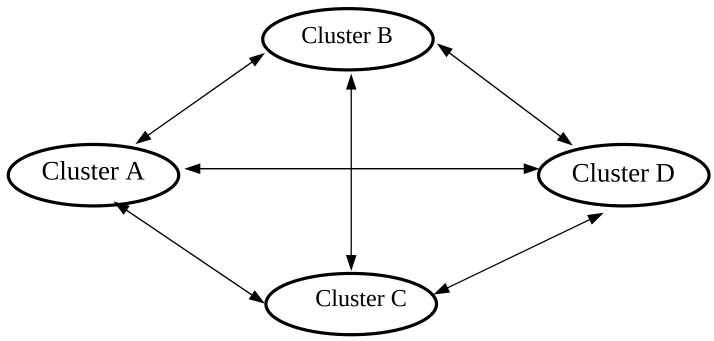

Figure 4. Flows of influence between the elements

Pairwise comparisons are needed for all the connections in the performance model - they are considered as inputs for the computation of the global performance of network production systems. A supermatrix is a matrix of all elements by all elements. The weights from the pairwise comparisons are placed in the appropriate column of the supermatrix. The sum of each column corresponds to the number of comparison sets. The weights in the column corresponding to the cluster are multiplied by the weight of the cluster. Each column of the weighted supermatrix sums to one and the matrix is column stochastic. Its powers can stabilize after several iterations to a limited supermatrix. The columns of each block of the matrix are identical and we can read off the global priority of business units.

In the generalized model we take into account countries, branches, firms and criteria as clusters and different types of connections in the system. There are dependencies and feedback among elements and clusters. The whole system is more properly represented as a network system. We state some examples of dependencies in the system. There are dependencies among countries resulting from foreign trade. The branches are interconnected and the flows can be modeled by input-output models. The questionnaire contains questions about networking activities of firms as rates of co-operation with customers and suppliers. The dependencies and feedback should be expressed by appropriate measures.

We used the alpha version of the ANP software package Super Decisions developed by Creative Decisions Foundation (CDF) for experiments in testing the possibilities of the expression and performance evaluation of the network system (Figure 5). Figure 5 contains an example of 4 clusters of our performance evaluation model and basic dependencies among them. It presents only an introductory idea for the ANP performance evaluation model. The model of the real situation is too complex and it is supposed that it will be elaborated as part of future research.

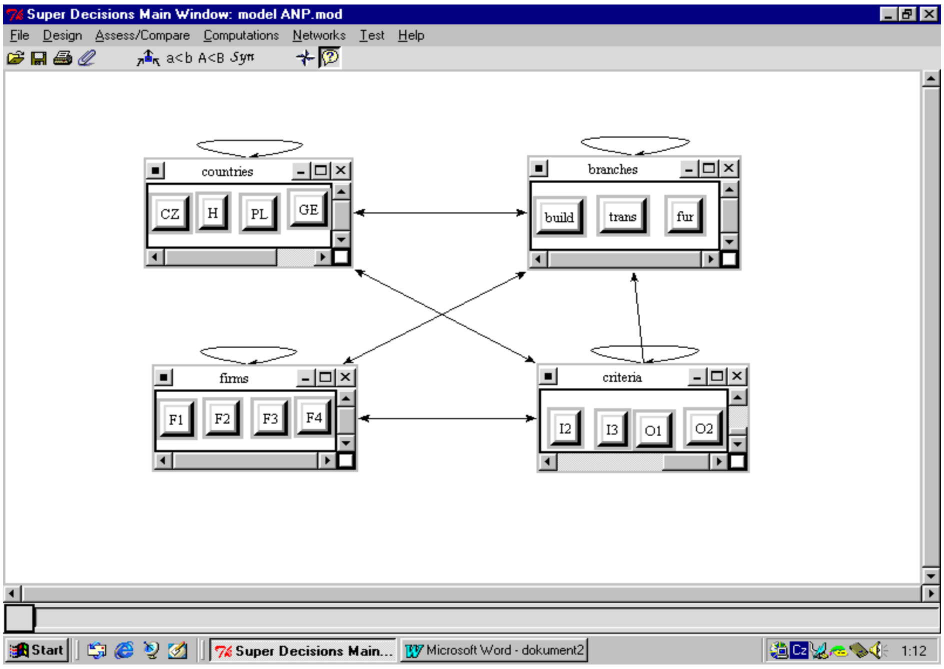

Figure 5. Generalized ANP model

The ANP approach seems better for applications in performance analysis than standard AHP models because it allows to model dependencies among basic elements of the model influencing the performance. In our model there are strong linkages and feedbacks among countries, branches and performance criteria. These relations are important between pairs of clusters on the one hand and among elements of clusters on the other hand.

Conclusions

The analysis and design of production systems has been an active area of research. Performance models help to understand the behaviour of business systems and to provide guidelines to improve their performance.

The AHP model presented in Section 3 offers a simple approach to the estimation of the performance scores of the countries. The possibility to use qualitative and hardly measurable characteristics is its advantage in comparison with other techniques. Small-scale example shows the basic principle of the approach but its results cannot be generalized. A large study taking into account a huge number of firms from much more branches is being prepared and it will be the aim of our future research.

Individual units are interconnected into a network system by material, financial and information flows. The network system is responsible for global performance whereas each unit is responsible for local performance. The ANP approach seems an appropriate method for performance measuring of network production systems. Future research will be oriented towards more detailed and sophisticated network models and methodology of performance measuring of network systems.

Acknowledgements

The research is supported by the Czech-Polish project no. MEB050834 (Czech Republic), 2008/CZ-19 (Poland).

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