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MULTIPLE SELECTIONS OF ALTERNATIVES UNDER CONSTRAINTS: CASE STUDY OF EUROPEAN COUNTRIES IN AREA OF RESEARCH AND DEVELOPMENT

Andrea Furková

INTRODUCTION

According to the "Lisbon" strategy for growth and jobs the EU member states have expressed their ambition to increase Europe's overall level of investment in research and development (R&D) to 3 % of GDP and to raise the share of R&D funded by business. The policy activities in area of R&D are significant parts of many national reform programs prepared by the member states as a part of Lisbon strategy. There are several reasons for governments to take active role in stimulation investment in R&D. R&D are generally considered to be the main engine of long-run economic growth. The objective of R&D activity is the generation of new knowledge which may be transformed into commercial innovations. Next process of innovation adoption by consumers and firms induces the long term positive effect of R&D activity on economic growth. Public authorities may contribute to enhance a country's R&D system by providing the infrastructure and the institutional framework for supporting innovation activity. Also The European Commission is providing more and more resources to R&D activities through Community Framework Programs while the objective of making R&D activities more efficient is at the core of the European Research Area (ERA) initiative (Conte et al., 2009).

This study provides a multicriteria evaluation approach to the issue of international comparison of R&D indicators. We suggest a methodology for the performance evaluation of EU member states in terms of R&D efficiency. Multi-attribute decision-making methods are used to evaluate R&D indicators of the countries. Moreover, based on the obtained results from the first empirical part, the paper also suggest an optimization model for resources distribution - subsides for R&D encouragement.

1. MULTI-ATTRIBUTE DECISION-MAKING METHODS

Multicriteria decision-making problems can be divided into certain main groups according to the definition of the feasible set of alternatives. The first is the case when we have a finite number of criterions, but the number of feasible alternatives is infinite (the alternatives being determined by the system of the requirements constraints). These problems belong to the field of multiple criteria optimization. On the other hand, the type of problem, when the number of criterions and alternatives is finite, and the alternatives are explicitly given, are called multi-attribute decision-making problems (MDMP). The theory of MDMP is very well-established, and the possibilities of real applications (evaluation of investment alternatives, evaluation of the credibility of bank clients, the rating of companies, consumer goods evaluation and many others) are very large. We know relatively many different methods e.g. PROMETHEE, ELECTRE, WSA, TOPSIS (see e.g. Brezina, Gertler & Pekár, 2006; Fuguera, Greco & Ehrgott, 2005; Jablonský & Dlouhý, 2004).

The multi-attribute decision-making problem is usually defined by a criterion matrix as is shown below:

$$\begin{array}{c} \\ X_1 \\ X_2 \\ \vdots \\ X_n \end{array} \begin{array}{c} \begin{array}{cccc} Y_1 & Y_2 & \cdots & Y_k \end{array} \\ \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1k} \\ y_{21} & y_{22} & \cdots & y_{2k} \\ \vdots & & \ddots & \\ y_{n1} & y_{n2} & \cdots & y_{nk} \end{bmatrix} \end{array} \qquad (1)$$

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where $X_1, X_2,...,X_n$ is the set of n alternatives,

$Y_1, Y_2,..,Y_k$ is the set of k criterions,

y_{ij} is the criterion value of the alternative X_i, i=1,2,...,n, j=1,2,...,k.

In the matrix, each column belongs to a criterion and each row describes the performance of an alternative, i.e. each element of the matrix y_{ij} is a single numerical value representing the performance of alternative i on criterion j. The essential part of the multi-attribute decision-making problem is setting the type of the criteria (minimization or maximization) and assigning weights to the criteria. The weight w_i reflects the relative importance of the criteria and is assumed to be positive. The weights of the criteria are usually determined on a subjective basis. They represent the opinion of a single decision-maker or synthesize the opinions of a group of experts using a group decision technique as well. The main goal of the multi-attribute decision-making techniques can be complete or partial ranking of alternatives.

Multi-attribute decision-making methods are based either on the Multi-attribute Utility Theory or Outranking Methods (Fuguera, Greco & Ehrgott, 2005; Jablonský & Dlouhý, 2004. In this paper, we focus on outranking methods. These methods are based either on pair-wise outranking assessments (e.g. Promethee methods, Electre methods) or the distances to the ideal solution and negative ideal solution (e.g. Topsis). In this paper Topsis method is used in our analysis of R&D of European countries and next obtained results are bases for optimization under constraints. As our main goal was to find an optimal selection of several alternatives given a set of constraints we formulate optimization model inspired by Promethee V method. The Promethee V method extends the PROMETHEE II method (for more detail see e.g. Fuguera, Greco & Ehrgott, 2005) to this selection problem, i.e. optimization under constraints. The objective is to maximize the total net outranking flow value (for more detail see e.g. Fuguera, Greco & Ehrgott, 2005) of the selected alternatives, at the same time being feasible to the constraints. Binary variables are introduced to represent whether an alternative is selected or not, and integer programming techniques are applied to solve the optimization problem (Fuguera, Greco & Ehrgott, 2005). The Topsis method and Promethee V method will be briefly outlined in the following section.

The PROMETHEE V method procedure can be summarized as follows:

Let $\{X_i, i = 1,2,...n\}$ be the set of possible alternatives and let us associate the following variables to them:

$$x_i = \begin{cases} 1 \text{ if } X_i \text{ is selected,} \\ 0 \text{ if not.} \end{cases} \qquad (2)$$

The next two following steps are necessary:

STEP 1: The multicriteria problem is first considered without constraints. The PROMETHEE II ranking is obtained and computed net flows $\phi(X_i)$ are used in the next step of the procedure.

STEP 2: The following model of linear programming is then considered in order to take into account the additional constraints:

$$\max\left\{\sum_{i=1}^{n} \phi(X_i)x_i\right\}$$

$$\sum_{i=1}^{n} \lambda_{p,i}x_i \sim \beta_p \qquad p = 1,2,...,P \quad (3)$$

$$x_i \in \{0,1\} \qquad i = 1,2,...,n$$

where ~ holds for =, ≥ or ≤. The coefficients of the objective function of the model (3) are the net outranking flows. The higher the net flow is the better for the alternative. The constraints of this model can include such constraints as, e.g. budget, return, marketing, etc., and they can be related either to all alternatives or to some clusters [4]. After having solved the formulated binary linear programming model, we obtain an alternative or a subset of alternatives satisfying the constraints and providing as much net flow as possible.

Topsis (Technique for Order Preference by Similarity to Ideal Solution) method is a popular approach of the multi-attribute decision making

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methods and has been widely used in the literature. Topsis simultaneously considers the distances to the ideal solution and negative ideal solution regarding each alternative and selects the most relative closeness to the ideal solution as the best alternative. That is, the best alternative is the nearest one to the ideal solution and the farthest one from the negative ideal solution. The procedure of Topsis can be summarized as follows:

1. Former criteria values y_{ij} are transformed to normalized value r_{ij} :

$$r_{ij} = \frac{y_{ij}}{\left(\sum_{i=1}^{n} y_{ij}^2\right)^{1/2}} \qquad i = 1,2,\ldots,n, \qquad j = 1,2,\ldots,k. \tag{4}$$

2. Calculation of the weighted normalized decision matrix **W**=(w_{ij}) as $w_{ij}=v_j r_j$ for $i = 1,2,...,n,$ $j = 1,2,...,k.$
3. Determination of the positive ideal (H_1, H_2,...,H_k) and negative ideal solution (D_1, D_2,...,D_k), where $H_j = \max(w_{ij}) \quad D_j = \min(w_{ij}), \quad j = 1,2,...,k.$
4. Calculation of the distance of each alternative from the positive ideal (d^+) and negative ideal (d^-) solution measures, using the *n*-dimensional Euclidean distance:

$$d_i^+ = \left[\sum_{j=1}^{k}\left(w_{ij} - H_j\right)^2\right]^{1/2} \qquad i = 1,2,\ldots,n, \tag{5}$$

$$d_i^- = \left[\sum_{j=1}^{k}\left(w_{ij} - D_j\right)^2\right]^{1/2} \qquad i = 1,2,\ldots,n. \tag{6}$$

5. Calculation of the relative closeness c_i to the ideal solution:

$$c_i = \frac{d_i^-}{d_i^- + d_i^+} \qquad i = 1,2,\ldots,n. \tag{7}$$

6. Ranking the preference order: The closer the c_i is to 1 implies the higher priority of the alternative.

2. EMPIRICAL RESULTS

In the first part of our analysis Topsis method is applied in order to evaluate R&D activities of EU member states (we excluded Cyprus due to the missing data and included Norway) through opted indicators. Our data set of 27 European countries and Norway observed in 2012 is based on statistics of Eurostat (2014). As indicators which would significantly influence activities of R&D were chosen:

- Patent applications (PAT) defined as patent applications to the European Patent Office (per million of inhabitants). This indicator was chosen due to the fact that patent applications are considered to be one of the outputs of successful R&D.
- Total intramural R&D expenditure (EXP) (percentage of GDP). There is ambition to increase Europe´s overall level of expenditure to R&D and also to raise the share of R&D funded by business. Therefore we decided to involve to our analysis indicators EXP and also EXP2 (defined below).
- Human resources in science and technology (HRST) (percentage of active population). This indicator can be perceived as human capital that is basic assumption of successful R&D.
- Employment in knowledge-intensive activities (KIA) (percentage of total employment). Nowadays knowledge-intensive industries have significant share in process of innovations.
- Business enterprise R&D expenditure (EXP2) (percentage of GDP).

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Tab. 1: Criterion matrix, Topsis results and optimal solution of optimization model

	MAX	*MAX*	*MAX*	*MAX*	*MAX*	d_i^+	d_i^-	c_i	Optimal solution
	PAT	*EXP*	*HRST*	*KIA*	*EXP2*			(alternative rank)	
Belgium	132,95	2,24	48,5	42,1	1,52	**0,06271**	**0,07423**	**0,54206 (6)**	**0**
Bulgaria	2,53	0,64	31,1	26,9	0,39	**0,12682**	**0,01258**	**0,09022 (27)**	**1**
Czech Republic	17,92	1,88	35,5	30,9	1,01	**0,10360**	**0,04107**	**0,28389 (15)**	**0**
Denmark	220,33	2,98	46,6	39,5	1,96	**0,03415**	**0,10291**	**0,75083 (4)**	**0**
Germany	276,95	2,98	43,5	37,3	2,02	**0,02917**	**0,11465**	**0,79717 (3)**	**0**
Estonia	32,13	2,18	46,4	32,6	1,25	**0,09350**	**0,05377**	**0,36511 (14)**	**0**
Ireland	65,52	1,72	47,6	43,2	1,2	**0,08662**	**0,05499**	**0,38831 (13)**	**0**
Greece	3,53	0,69	33,1	35,1	0,24	**0,12635**	**0,01855**	**0,12804 (23)**	**1**
Spain	33,12	1,3	39,3	32,5	0,69	**0,10768**	**0,03132**	**0,22533 (18)**	**0**
France	125,77	2,29	46,3	39,4	1,48	**0,06549**	**0,07143**	**0,52170 (8)**	**0**
Croatia	6,77	0,75	30,2	29,7	0,34	**0,12522**	**0,01408**	**0,10107 (26)**	**0**
Italy	69,57	1,27	32,9	32,6	0,69	**0,10141**	**0,03410**	**0,25161 (16)**	**0**
Latvia	6,6	0,66	38,9	32,6	0,15	**0,12713**	**0,01945**	**0,13271 (22)**	**1**
Lithuania	6,09	0,9	43,1	31,8	0,24	**0,12345**	**0,02323**	**0,15835 (21)**	**1**
Luxembourg	133,66	1,46	56,7	56,6	1	**0,07594**	**0,07058**	**0,48170 (10)**	**1**
Hungary	19,81	1,3	34,4	34,1	0,85	**0,10875**	**0,03226**	**0,22880 (17)**	**0**
Malta	3,59	0,84	34,7	42,1	0,5	**0,11966**	**0,02813**	**0,19033 (20)**	**0**
Netherlands	163,49	2,16	47,1	36,4	1,22	**0,06369**	**0,07250**	**0,53236 (7)**	**0**
Austria	214,17	2,84	39,4	35,0	1,95	**0,04099**	**0,09825**	**0,70561 (5)**	**0**
Poland	12,09	0,9	36,0	28,9	0,33	**0,12227**	**0,01777**	**0,12687 (24)**	**1**
Portugal	7,01	1,5	27,0	30,1	0,7	**0,11461**	**0,02811**	**0,19698 (19)**	**0**

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Romania	1,78	0,49	23,8	20,0	0,19	**0,13458**	**0,00121**	**0,00891 (28)**	**0**
Slovenia	41,61	2,8	40,6	34,5	2,16	**0,08131**	**0,07972**	**0,49508 (9)**	**0**
Slovakia	9,58	0,82	31,4	29,8	0,34	**0,12381**	**0,01529**	**0,10989 (25)**	**1**
Finland	269,61	3,55	48,7	37,3	2,44	**0,02219**	**0,12566**	**0,84989 (2)**	**0**
Sweden	288,67	3,41	48,2	43,3	2,31	**0,01663**	**0,12708**	**0,88429 (1)**	**0**
United Kingdom	79,59	1,72	49,2	43,0	1,09	**0,08481**	**0,05533**	**0,39484(12)**	**0**
Norway	111,26	1,65	49,8	39,2	0,87	**0,08297**	**0,05529**	**0,39989 (11)**	**1**
Weights	**0,20000**	**0,20000**	**0,20000**	**0,20000**	**0,20000**				
Ideal	**0,08723**	**0,06954**	**0,05208**	**0,05905**	**0,07381**				
Basal	**0,00054**	**0,00960**	**0,02186**	**0,02087**	**0,00454**				

Source: EUROSTAT, 2014 and own calculations

The numerical values of indicators are listed in tab. 1. All these indicators we set as maximization criterions and we assumed unit weights. The goal of the first empirical part was to rank countries via topsis, i.e. to identify the best and worst performers of R&D among of EU member states. The results are provided in tab. 1, the scores of countries were calculated according to equation (7) and the ranks of the countries are listed in the brackets. As the best countries according to our results were assigned Sweden, Finland, Germany, Denmark, etc. and on the other hand as the worst performers are assigned Romania, Bulgaria, Croatia, Slovakia, etc. There is apparent lag of post-communist countries and the "west" countries reached leading positions. Therefore we also decided to formulate an optimization model for resources distribution - subsides for R&D encouragement. Let us suppose situation that The European Commission (EC) is providing through Community Framework Programs subsides to R&D activities in order to encourage R&D activities especially in post-communist countries. The goal is to provide e.g. 8 grants in total but there are following additional requirements:

- It is required that at least four post-communist countries will be granted.
- The total budget is 8 million euro and cannot be exceeded. Financial resources must be used only for R&D institute establishment. Individual countries´ estimated financial requirements for the R&D institute are evident from the third equation of the model (in thousand euros).
- As sufficient skilled labour force is necessary condition to efficient performance of R&D, it is set that overall value of HRST indicator in granted countries must be at least 320.

To make a decision concerning proper countries selection we employ optimization model (for more details see e.g. Brezina, Čičková & Reiff, 2004) inspired by Promethee V which enables us to take into account the results of previous empirical part (preference ranking of countries according to Topis) and, at the same time, to take into account defined constraints. The calculated coefficients ci (from tab. 1) are used as inputs in the objective

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function of the binary linear programming model formulated in (3). This is in contrast to Promethee V method, where the calculated net outranking flows are used in the objective function. Another difference to Promethee V is that our objective function is minimalized because of specified aim to support backward countries in activities of R&D. Four constraints of the model are formulated based on the EC requirements and the binary variables represent countries. The model of binary linear programming can be formulated as follows:

$$\begin{aligned}\min f(\mathbf{x}) = {} & 0{,}54206x_1 + 0{,}09022x_2 + 0{,}28389x_3 + 0{,}75083x_4 + 0{,}79717x_5 + 0{,}36511x_6 + 0{,}38831x_7 + \\ & + 0{,}12804x_8 + 0{,}22533x_9 + 0{,}52170x_{10} + 0{,}10107x_{11} + 0{,}25161x_{12} + 0{,}13271x_{13} + 0{,}15835x_{14} + \\ & + 0{,}48170x_{15} + 0{,}22880x_{16} + 0{,}19033x_{17} + 0{,}53236x_{18} + 0{,}70561x_{19} + 0{,}12687x_{20} + 0{,}19698x_{21} + \\ & + 0{,}00891x_{22} + 0{,}49508x_{23} + 0{,}10989x_{24} + 0{,}84989x_{25} + 0{,}88429x_{26} + 0{,}39484x_{27} + 0{,}39989x_{28}\end{aligned}$$

$$\begin{aligned}& x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} + x_{19} + x_{20} + \\ & + x_{21} + x_{22} + x_{23} + x_{24} + x_{25} + x_{26} + x_{27} + x_{28} = 8\end{aligned}$$

$$x_2 + x_3 + x_6 + x_{11} + x_{13} + x_{14} + x_{16} + x_{20} + x_{22} + x_{23} + x_{24} \geq 4$$

$$\begin{aligned}& 750x_1 + 500x_2 + 560x_3 + 800x_4 + 900x_5 + 630x_6 + 700x_7 + 600x_8 + 720x_9 + 910x_{10} + 660x_{11} + \\ & + 670x_{12} + 590x_{13} + 600x_{14} + 950x_{15} + 530x_{16} + 660x_{17} + 780x_{18} + 800x_{19} + 630x_{20} + \\ & + 600x_{21} + 580x_{22} + 600x_{23} + 580x_{24} + 800x_{25} + 850x_{26} + 910x_{27} + 830x_{28} \leq 8000\end{aligned}$$

$$\begin{aligned}& 48{,}5x_1 + 31{,}1x_2 + 35{,}5x_3 + 46{,}6x_4 + 43{,}5x_5 + 46{,}4x_6 + 47{,}6x_7 + 33{,}1x_8 + 39{,}3x_9 + 46{,}3x_{10} + 30{,}2x_{11} + \\ & + 32{,}9x_{12} + 38{,}9x_{13} + 43{,}1x_{14} + 56{,}7x_{15} + 34{,}4x_{16} + 34{,}7x_{17} + 47{,}1x_{18} + 39{,}4x_{19} + 36x_{20} + 27x_{21} + \\ & + 23{,}8x_{22} + 40{,}6x_{23} + 31{,}4x_{24} + 48{,}7x_{25} + 48{,}2x_{26} + 49{,}2x_{27} + 49{,}8x_{28} \geq 320\end{aligned}$$

$$x_i \in \{0;1\} \quad i = 1,2,\ldots,28$$

Optimal solution of the model is listed in the last column of the tab. 1 and if the EC takes into account the results of the model, it is appropriate to support Bulgaria, Greece, Latvia, Lithuania, Luxembourg, Poland, Slovakia and Norway. Surprisingly Luxembourg and Norway were chosen however, with regard to fulfilment of the third equation of the model this may be caused by their high values of HRST indicator.

CONCLUSION

The purpose of this paper was to exploit a multicriteria evaluation approach to the issue of international comparison of R&D indicators. The application of the Topsis method has provided us complete ranking of the countries and we were able to identify the best and the worst performers in the group. We found out apparent lag of post-communist countries. We also suggested and illustrated an optimization model for resources distribution - subsides for R&D encouragement which was based on results of Topsis method. We presented multi-attribute decision-making method and model for multiple selections of alternatives under constraints as a contribution to the discussion about quantitative measurement evaluation of R&D indicators.

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MULTIPLE SELECTIONS OF ALTERNATIVES UNDER CONSTRAINTS: CASE STUDY OF EUROPEAN COUNTRIES IN AREA OF RESEARCH AND DEVELOPMENT

Andrea Furková

Abstract

This paper is given over to a multicriteria evaluation approach to the issue of international comparison of research and development indicators. The policy activities in R&D (Research & Development) area are significant parts of many national programs of many EU member states. There are several reasons for governments to take active role in stimulation investment in R&D. R&D are generally considered to be the main engine of long-run economic growth. Also The European Commission pays more attention to R&D activities and provides more and more resources to these activities through Community Framework Programs. We decided to exploit multi-attribute decision-making to evaluate R&D indicators of European countries. As multi-attribute decision-making method Topsis method was applied. Topis method has provided us complete ranking of the countries taking into account indicators such as patent applications, total intramural R&D expenditure, human resources in science and technology, employment in knowledge-intensive activities and business enterprise R&D expenditure. Having these results in a hand; we proceed to making multiple selections of countries under constraints. Our main goal was to suggest an optimization model for resources distribution - subsides for R&D encouragement, i.e. to find an optimal selection of several alternatives given a set of constraints. To make a decision concerning proper countries selection we employed optimization model inspired by Promethee V, which enables us to take into account the results of previous empirical part and, at the same time, to take into account defined constraints. Formulated binary linear programming model could be useful support decision making tool in the process of resources distribution - subsides for R&D encouragement.

Keywords: Multi-attribute decision making methods; Topsis; Research and Development; Promethee V

JEL Classification: C6, M2, M3

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