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ID 1666 | OPERATIONAL RESEARCH IN SPATIAL PLANNING

Magdalena Wagner[1]
[1]Wroclaw University of Technology
magdalena.wagner@pwr.edu.pl

1 INTRODUCTION

The need to develop new methods supporting spatial planning is nowadays one of major challenges of modern urban planning. Discourse on new ways of urban management gains new meaning and is in fact a discussion about the contemporary urban planners skills and tools. The paper presents new solutions which could provide a support for coordinated, rational, and transparent decision making under conditions of risk and uncertainty. MCDA is a is a sub-discipline of operational research and was developed in 1960s in the business sector. MCDA is used in the situation of having multiple, usually conflicting, criteria and therefore has a potential for implementation in spatial planning. Some examples of using the MCDA methods for the purpose of urban management are offered. General evaluation of the proposed approach is conducted in order to identify strengths and weaknesses that could be addressed in further research. So far, it seems that bringing together economics, operational research, ICT, and applying them in the field of urban studies, could improve city policy making and urban management. It seems fair to say that urban planners might have no other choice but to look far outside their own academic discipline in search of new tools; therefore, the paper encourages a discussion on whether methods derived from operational research could be incorporated into spatial decision making process.

2 DECISION MAKING AND PLANNING PROCEDURE

In the process of urban policy making several steps can be distinguished: complex analyses are followed by formulation of a vision, mission, and main objectives, then operational tasks are identified, and finally projects/activities pursuing these goals are recognized. This procedure is connected with making up the balance of resources and time schedule of urban projects (Ossowicz 2003). Between these elements several complex interrelationships, feedbacks, and correlations could be identified. An attention should be paid to a relatively large number of bodies, institutions, and groups involved in the decision making process and the fact that the interests of these parties may sometimes be in conflict. Therefore, following issues should be taken into consideration:

- the essence of city governance: definitions (city management, city governance, spatial policy, urban policy, etc.), features of governing, city governance in the light of organization and management theory, uncertainty and risk in spatial planning;
- local government: its role and tasks, structure, features, and management instruments;

- urban planning: actors, features and attributes of the local level spatial planning, models of integrated planning in cities, models of strategic planning (including models taking into account the specificities of public organizations management);
- city finances;
- controlling and monitoring.

The decision making process both within regional and municipal planning addresses a broad spectrum of issues such as, among others: transportation, environmental protection, research and development, competitiveness and innovativeness, economic activity, or social inclusion. The interrelations between these fields are described to some extent, however, no numerical (quantitative) analysis has been conducted.

3 METHODS

Literature review and own observations of planning practices indicate lack of comprehensive and advanced tools which could support decision making at local or regional level. The procedure of prioritizing spatial projects in a big city was described by Ossowicz (2003) who also paid attention to the use of mathematical analysis in the urban policy making. However, it seems fair to say that this matter has not been thoroughly investigated and resolved yet. The need to develop new solutions providing support for coordinated, rational, and transparent decision making is an important prerequisite to undertake a research on the topic of spatial decision making. In the next chapters of this paper, numerical solutions derived from operational research are offered and discussed. MCDA (multi-criteria decision analysis) is a sub-discipline of operational research and was developed in 1960s in the business sector and is helpful in the situation of having multiple, usually conflicting, criteria. In general, it is used to improve a decision making process by making it more rational and transparent (Figueira, Ehrgott, Greco 2005). There are several methods which help with: choosing the best option, building a ranking, or sorting alternatives – in general, these methods advocate rational choices. There is also a group of methods which do not support the decision making process directly, however, they are useful for problem structuring. Two of multi-criteria decision making methods, namely DEMATEL and PROMETHEE, are the focus of this paper.

3.1 DEMATEL

Decision Making Trial and Evaluation Laboratory (DEMATEL) is a robust analysis tool used for identification of cause-effect relationships (Fontela, Gabus 1974). It can be used for both tangible and intangible factors. The method has been applied to illustrate the interrelations among criteria and to find the central criteria to represent the effectiveness of factors/aspects. It has also been applied in many situations, such as marketing strategies, control systems, safety problems, development of the competencies of global managers, and group decision making (Lee et al. 2013). The end product of the DEMATEL process, namely the impact-relations map, is a visual representation of importance and causative nature of each analysed factor. To evaluate the relations, a pairwise comparison is conducted. The measurement criteria of 0, 1, 2, 3, and 4 are used to illustrate no influence, low influence, medium influence, high influence, and extremely high influence, respectively. Despite the interesting features, no application of DEMATEL method in spatial planning (neither regional nor urban) has been identified. The steps of the DEMATEL method (Lee et al. 2011) are described as follows:

Step 1: Find the average matrix

Step 2: Calculate the normalized initial direct-relation matrix.

We then create a matrix D by using a simple matrix operation on A. Suppose we create matrix D and D = s · A where

$$s = Min\left[\frac{1}{\max_{1\leqslant i\leqslant n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_{1\leqslant j\leqslant n}\sum_{i=1}^{n}|a_{ij}|}\right].$$

Matrix D is called the normalized initial direct-relation matrix. The (i, j) element dij denotes the direct-influence from factor xi to factor xj. Matrix D shows the initial influence which a factor exerts and receives from another. Each element of matrix D portrays a contextual relationship among the elements of the system and can be converted into a visible structural model—an impact-relations map—of the system with respect to that relationship.

Step 3: Derive the total-influence matrix T

A continuous decrease of the indirect effects of problems along the powers of matrix D, e.g. D2, D3, … , D∞, guarantees convergent solutions to the matrix inversion, similar to an absorbing Markov chain matrix. The total relation matrix T is an n × n matrix and is defined as follows:

$$\begin{aligned}\sum_{m=1}^{\infty} D^i &= D + D^2 + D^3 + \cdots + D^m \\ &= D(\mathbf{I} + D + D^2 + D^3 + \cdots + D^{m-1}) \\ &= D(\mathbf{I} - D)^{-1}(I \\ &\quad - D)(\mathbf{I} + D + D^2 + D^3 + \cdots + D^{m-1}) \\ &= D(\mathbf{I} - D)^{-1}(\mathbf{I} - D^m) \\ &= D(\mathbf{I} - D)^{-1},\end{aligned}$$

where I is the identity matrix and T is called the total relation matrix. The (i, j) element of the matrix T, tij, denotes the full direct- and indirect-influence exerted from factor xi to factor xj.

Step 4: Obtain the prominence and relation.

Once T = [tij]n×n is obtained, we can define r and c as n × 1 vectors representing the sum of rows and the sum of columns of the total relation matrix T as follows:

$$r = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1},$$

$$c = [c_j]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)'_{1\times n},$$

where the superscript ′ denotes transpose.

Let ri be the sum of the i-th row of the matrix T. Then ri shows the total effect, both direct and indirect, given by the factor i to other factors. Let cj denotes the sum of the j-th column of the matrix T. Then cj shows the total effect, both direct and indirect, received by the factor j from other factors. Thus when j = i, the sum (ri + ci) gives us an index representing the total effect both given and received by the factor i. In other words, (ri + ci) shows the degree of the importance (total sum of the effects given and received) that the factor i plays in the system. In addition, the difference (ri − ci) shows the net effect that the factor i contributes to the system. When (ri − ci) is positive, the factor i is a net causer, and when (ri − ci) is negative, the factor i is a net receiver (Tzeng at al. 2007).

Step 5: Set a threshold value and obtain the network relationship map

In order to explain the structural relationship among the factors while keeping the complexity of the system to a manageable level, it is necessary to set a threshold value p to filter out the negligible effects in matrix T.

3.2 PROMETHEE

Another promising method is PROMETHEE (and its descriptive complement geometrical analysis for interactive aid which is better known as GAIA). The main advantage of the PROMETHEE method is the clear reasoning which helps decision makers build well-structured framework for the decision problem. It is useful for solving complex problems with several criteria that need to be evaluated. The method could be applied to: choosing the best location for an investment, ranking action projects or investment plans, allocating resources. The information requested by PROMETHEE and GAIA is particularly clear and easy to define for both decision makers and analysts. It is based on a preference function associated to each criterion as well as weights describing their relative importance. Usually there is no alternative optimising all the criteria at the same time, therefore a compromise solution should be selected. (Brans, Mareschal, 2005). The algorithm of the method is as follows:

Step 1: Using the data contained in the evaluation matrix, the alternatives are compared pairwise with respect to every single criterion. The results are then calculated and expressed by the preference functions, which are calculated for each pair of options and can range from 0 to 1, where 0 means that there is no difference between the pair of options (indifference), 1 indicates a strong preference, and value between 0 and 1 indicates weak preference:

Pj(a, b) = Fj [dj(a, b)] ∀a, b ∈ A
where:
dj(a, b) = gj(a) − gj(b)
For criteria to be minimised, the preference function should be reversed or alternatively given by:
Pj(a, b) = Fj [−dj(a, b)]

In order to facilitate the identification of preferences six types of particular preference functions have been proposed (Brans and Mareschal, 2005). Additionally, such parameters as threshold of indifference or threshold of strict preference can be used.

Step 2: Aggregated (global) preference degree for each pair of alternatives on each criteria is calculated:

$$\pi(a,b) = \sum_{k=1}^{q} P_k(a,b) \cdot w_k$$

Step 3: Positive and negative flow scores are calculated:

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x)$$
$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a)$$

Step 4: Net flow score is calculated in order to obtain a complete ranking of alternatives:

$$\phi(a) = \phi^+(a) - \phi^-(a)$$

4 RESULTS

In this chapter two example uses of the aforementioned methods are presented. The research is checking whether selected method, namely DEMATEL, derived from operational research could be incorporated into decision making process at regional level. The focus is on the 2020 Development Strategy for Lower Silesia Voivodeship which is one of the most important development documents prepared in and for the region. However, the methodology presented in this paper could be adapted and used while creating development strategies for modern and smart cities (Lorens, Martyniuk-Pęczek 2010). The method can be used for analysing linkages between urban policy goals or for evaluating planning process at local level (Ogrodnik 2015). The Development Strategy for a Voivodeship is the most important document drawn up by the self-governments of the Voivodeships (which are equal to NUTS-2). The document identifies strengths and weaknesses of the region and indicates objectives and priorities of the regional development. The strategy is a tool to design and stimulate the development: it serves as a guideline for the authorities and indicates fields requiring regulations and financing. The purpose of this document is to indicate the directions for economic and infrastructural development. It also serves as a tool for improving the life conditions of the inhabitants of Lower Silesia. The structure of the strategy is rather typical (compare: Dymon 2013, Kożuch 2011): initial analyses and diagnosis are followed by identification of development goals; then, territorial dimension of the policy is described; next, financial aspects and implementation system are discussed; in the next step, the so-called development macro-spheres are identified; the document's last part is the monitoring section where development indicators are described. The most novel feature of the document is identification of macro-spheres which are groups of projects pursuing eight development goals. These goals cover eight key groups, so-called macro-spheres. Each macro-sphere is related to at least one strategy goal and they are aimed at strengthening the economic development of the Lower Silesia region. The relations between abovementioned macro-spheres and strategy development objectives are presented in the Table 1 below.

	Development of a knowledge-based economy	Development of sustainable transport and improvement of accessibility	Strengthening the competitiveness, especially of small and middle enterprises	Environmental protection, efficient use of resources, adaptation to climate change	Increasing the accessibility of information and communications technologies	Increase in employment and labour mobility	Social inclusion and improvement of life quality	Increasing the level of education and lifelong learning
Infrastructure		X		X		X		
Development of urban and rural areas	X	X	X	X	X	X	X	X
Resources				X				
Tourism		X	X	X		X	X	
Health and safety		X		X	X		X	X
Education, science, culture, sport and information	X				X	X		X
Society and partnership	X		X		X	X	X	X
Entrepreneurship and innovation	X		X		X	X	X	X

Table 1. Relations between adopted strategy goals and macro-spheres.
Source: own compilation; based on: The 2020 Development Strategy…, 2013.

The strategy offers also proposal of financial distribution of assets, however it is "an initial, qualitative", not quantitative, division (Strategia… 2013). This share was determined in an experts panel discussion, but no numerical methods have been used to support the process. This research offers an analysis of cause-effect relationship between the macro-spheres which could be useful for better structuring the problem. For the purpose if this study, the relations between macro-spheres have been analysed and named by the (former) Director of the Department of Regional Development in the Marshal's Office, who was co-responsible for preparing and issuing the 2020 Development Strategy for the Lower Silesia Voivodeship. The relations provided by the specialist are presented in the table below (Table 2), which is a direct-relation matrix

	Infrastructure	Development of urban and rural areas	Resources	Tourism	Health and safety	Education, science, culture, sport and information	Society and partnership	Entrepreneurship and innovation
Infrastructure	0	4	1	3	4	2	2	3
Development of urban and rural areas	3	0	1	3	4	4	4	3
Resources	1	3	0	3	3	1	1	2
Tourism	2	4	1	0	3	2	3	1
Health and safety	1	3	1	3	0	2	4	2
Education, science, culture, sport and information	2	3	3	2	2	0	4	4
Society and partnership	2	2	2	3	3	3	0	4
Entrepreneurship and innovation	3	4	3	1	2	3	3	0
Scale	0 – no direct impact (one medium to another); 1 – low impact; 2 – average impact; 3 – high impact; 4 – very high impact							
Example	Macro-sphere "Education, science, culture, sport and information" has a very high impact (4) on the sphere "Entrepreneurship and innovation", while "Entrepreneurship and innovation" has a high impact (3) on "Education, science, culture, sport and information".							

Table 2. Direct relations between macro-sphere. Expert's evaluation.

The findings indicate that "Development of urban and rural areas" is the most important macro-sphere with the value 11.98, while "Resources" is the least important component with the value 7.25. The ranking of macro-spheres based on their prominence is as follows: "Development of urban and rural areas", "Society and partnership", "Entrepreneurship and innovation", "Education, science, culture, sport and information", "Health and safety", "Tourism", "Infrastructure", "Resources". "Infrastructure", "Resources", "Education, science, culture, sport and information", and "Entrepreneurship and innovation" are net causes, whereas "Development of urban and rural areas", "Tourism", "Health and safety", and "Society and partnership" are net receivers (based on r-c values). The cause and effect diagram is shown in Figure 1. The most "causative" (i.e. the most influential) macro-sphere is "Infrastructure", followed by "Education, science, culture, sport and information" and "Resources". Two macro-spheres: "Entrepreneurship and innovation" and "Development of urban and rural areas" are very close to the cause-effect borderline. The most "effectual" macro-sphere is "Health and safety", then "Society and partnership", then "Tourism".

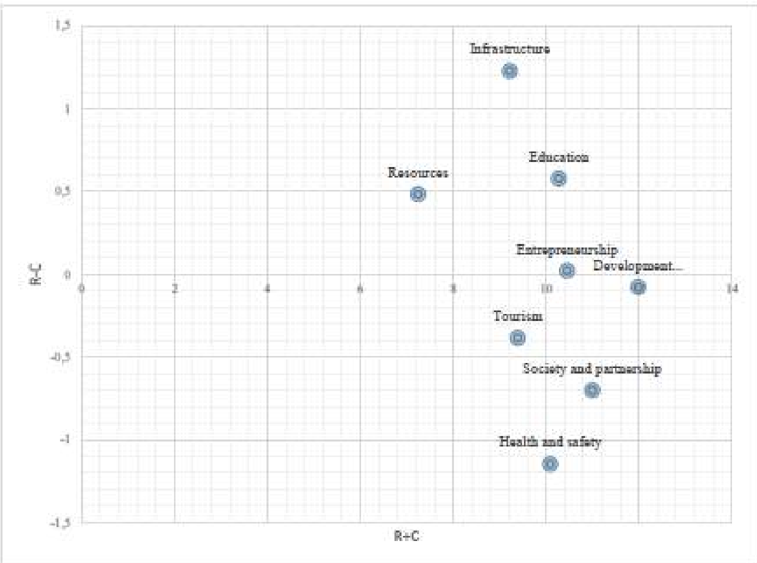

Figure 1. The relationship map.

Another method that seems to be promising for use by urban planners is PROMETHEE, which (as all outranking methods) can simultaneously deal with qualitative and quantitative criteria. Criteria scores can be expressed in their own units. The method can be used for example for solving a locational problem. If we consider buying a building plot, we take into account several attributes. For instance, we may consider following criteria:

- f1 – utilities/services (water, electricity, etc.) – if yes, then value 1; if not, then value 0;
- f2 – price of a plot (thousands, PLN – Polish Zloty)
- f3 – ground surface (square metres)
- f4 – number of shops within d = 300 metres
- f5 – distance from city centre (kilometres)

We assume that price of a plot and distance from city centre should be minimized and ground surface and number shops should be maximized. In this example we consider four alternatives ai, i={1,2,3,4}. The starting point is an evaluation matrix, which presents the performance of each alternative in relation to each criterion. Weights giving the relative importance of the criteria are given in the last row of the table (Table 3). Decision makers are required to weigh criteria and to choose a preference function. PROMETHEE does not provide specific guidelines for determining weights to criteria, but assumes that the decision maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large (Macharis et al. 2004).

Alternatives	Criteria				
	f_1	f_2	f_3	f_4	f_5
a^1	0	249	850	1	21,5
a^2	1	386	923	8	7,25
a^3	1	366	873	11	12
a^4	0	324	640	4	8
w_k	0,2	0,3	0,25	0,1	0,15

Table 3. Evaluation table

Next steps of PROMETHEE method, i.e. calculating global preference degree for every pair of alternatives and calculating net outranking flows are presented in the tables below (Table 4 and Table 5).

$\pi(a^i, a^j)$	a^1	a^2	a^3	a^4
a^1	0	0,300	0,300	0,55
a^2	0,625	0	0,261111	0,525
a^3	0,486111	0,125	0	0,55
a^4	0,175	0,300	0,397	0

Table 4. Global preference degree for every pair of alternatives

	$\varphi+$	$\varphi-$	φ
a^1	0,383	0,429	-0,045
a^2	0,470	0,242	0,229
a^3	0,387	0,319	0,068
a^4	0,291	0,542	-0,251

Table 5. Net outranking flows

In the example discussed above, the best solution, according to the given criteria and their weights, is alternative a2, followed by a3, then a1, and last one is a4. In other words, plot number 2 seems to be the best choice for the decision maker – according to the criteria and weights he provided.

5 CONCLUSIONS

The paper presents possible application of two methods derived from operational research. Selected application case of the DEMATEL technique in spatial planning deals with the development strategy for a Voivodeship (region equivalent to NUTS-2). The calculations presented in this paper allow to determine the prominence and cause-effect relationships between important regional development strategy components. The analysis of the macro-spheres, which are directly linked with strategy goals, help with better structuring and understanding the problem. The reflections presented in the paper may serve as guidelines for division of financial assets between macro-spheres, i.e. between groups of projects pursuing strategy objectives. The DEMATEL technique was exercised on a regional level; however, merits of the method make it suitable for solving other decision making problems, for instance in urban planning while preparing a city policy or city development strategy. It seems fair to say that such methods may be a promising tool while designing a “smart” development strategy.

The PROMETHEE methods (or outranking methods in general) could be used in various multi-criteria problems, such as ranking of investment plots (for various activities) or ranking of city development objectives/goals in the process of strategy making. By providing a ranking of alternatives, the PROMETHEE method allows for evaluation of alternatives and therefore for supporting the decision making process. Thanks to this, the process of choosing the optimal solution gains transparency and objectivity. Methods presented in this paper may be useful for solving locational problems or for formulating development policy at local or regional level.

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