ФОРМУВАННЯ МЕХАНІЗМУ ЗМІЦНЕННЯ КОНКУРЕНТНИХ ПОЗИЦІЙ НАЦІОНАЛЬНИХ ЕКОНОМІЧНИХ СИСТЕМ У ГЛОБАЛЬНОМУ, РЕГІОНАЛЬНОМУ ТА ЛОКАЛЬНОМУ ВИМІРАХ

Przemysław SEKUŁA, Henryk BRANDENBURG, Marek MAGDOŃ, Katarzyna FICEK-WOJCIUCH

MULTICRITERIA EVALUATION METHODS IN LOCATION OF TOURISTIC INVESTMENTS

Summary. *Multi-criteria evaluation methods is GIS are used to allocation of land to suit a specific objective on the basis of a variety of attributes that the selected areas should possess. MCE is perhaps the most fundamental of decision support operations in geographical information systems. This paper reviews three methods: Boolean Intersection, Weight Linear Combination (WLC) and Ordered Weighted Average (OWA). These methods were employed in field of tourism, in order to support the decision-making process during the location of hotel in Zabrze – city in Poland.*

Introduction. Geographical Information Systems (GIS) are used for many diversified purposes. The basic and the most obvious way of employing these systems is creating and keeping a record of grounds, buildings, the linear infrastructure, areas and each item of data which can be situated in the given space. In that case the GIS systems may be used by very large group of recipients: from town-planners to people who just want to check something on the map. The second option is to use GIS for presenting various data connected to the specified space, like statistics, results of polls, economical information etc. This time GIS is used for auxiliary purposes like helping to understand something or presenting data needed for analyses. However, it is possible to use GIS systems directly for creating analyses. The spatial representation of data, joined with the opportunity of making complicated calculations turned out to be a powerful tool which is widely used by analysts and managers. One of the examples of supporting the decision-making process by using GIS solutions are the MCE methods – a group of the deterministic methods of decision-making.

1. MCE Analyses. The Multi Criteria Evaluation techniques dates back to the early 1970s. According to S.J. Carver «a number of workers, particularly in the regional economic planning and decision-making research fields, have identified certain weaknesses in the neoclassical view of decision-making and site location» [1]. This resulted in creating a number of alternatives and amendments, which finally led to formulating MCE. The MCE methods «serve to investigate a number of choice possibilities in the light of multiple criteria and conflicting priorities» [2]. Depending on the type of given criteria and on the approach to risk the three main MCE techniques can be identified:

- boolean intersection,
- weighted linear combination,
- order weighted average.

Boolean Intersection. All criteria could be divided into two types: constraints and factors. Constraints are always boolean in character (such as the expectation of some particular type of terrain). They serve to exclude certain areas from consideration. Factors, on the other hand are generally continuous (such as proximity to the transportation). Factors indicate the relative suitability of analyzed areas. In the boolean intersection technique all the criteria are constraints. As constraints serve to exclude unwanted areas, the result of boolean intersection is the product (logical AND) of all criteria. The formula for every given location (every pixel) in boolean intersection is:

$$S = \prod_{i=1}^{n} c_j \tag{1}$$

where:
S – suitability;
n – number of constraints;
c_i – constraint;
Π – product (logical AND).

All the maps with constraints are comprised of the 0 and 1 values, so the suitability map consists of zeros and ones too.

Weighted Linear Combination. While Boolean Intersection is dedicated to constraints, Weighted Linear Combination can cope with factors. The input data of WLC method is comprised of the factors and weights. For every pixel (or every location) of every factor particular number is assigned. This number represents the suitability of the territory from the vantage of this factor. In practice, the factors are very often not equally important. Therefore every factor has its own weight – the number which represents the importance of the factor. To ensure the scalability of the final result, it is usual to assume that the sum of weights is 1. The suitability of every location is calculated as a sum of partial suitabilities multiplied by weights, according to the formula:

$$S = \left(\sum_{i=1}^{n} W_i X_i\right) \tag{2}$$

where:
S – suitability;
n – number of factors;
X_i – suitability of factor *i*;
w_i – weight of factor *i*.

In the WLC method it is possible to use constraints as an addition to defined factors. Because the role of constraints is to exclude some areas, the formula with constraints is:

$$S = \left(\sum W_i X_i\right) * \prod_{j=1}^{m} C_j \tag{3}$$

where:
c_j – constraint *j*;
m – number of constraints;
Π – product (logical AND).

As a matter of fact, the most difficult and time-consuming part of WLC method is preparing the factors and weights. First of all, it is easiest to present the factors in a form of maps. So if it is needed to analyze the proximity to the roads we need to prepare the map of distances. If the slope is important it is necessary to prepare the slope map (from the elevation map) etc. These maps are usually incompatible (for instance slope is given in degrees with a range from 0 to 30, and distance in meters from 0 to 10 000), so we need to normalize them. During the normalization the two main operations are as follows:

- rescaling of values – all values on the maps are rescaled to be in the same range (usually from 0 to 255 or from 0 to 1). The rescaling is not necessarily supposed to be linear. It is possible to use many different functions. The most frequently used one is a sigmoidal (so called s-shaped) function which is presented in figure 1;
- inversion (if necessary) – in every maps the best areas should be represented by the highest values and the worst by the lowest. If the criterion is «as far as possible» the distance map should be simply rescaled. But if it is «as close as possible» it should also be inverted (the highest values for the closest distance).

The next step is to determine weights for every factor. It is simple to do, if there are only two factors. But if there are more, it may be difficult to sort them out in the correct order and assign numerical values. This problem can be solved by using the Analytic Hierarchy Process method which is briefly described in the next subchapter. It is noteworthy, that although the AHP method may be very beneficial, it is not necessary to apply it for fixing the weights. If it is possible, weights can be fixed directly or by using some other solutions. After the normalization and assigning the weights the WLC method may be finally used.

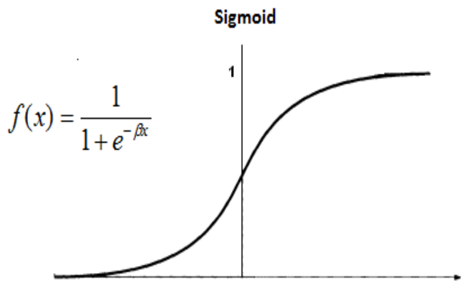


Figure 1. Sigmoidal function

Analytic Hierarchy Process method. The Analytic Hierarchy Process method was proposed in 1977 by Thomas L. Saaty [3]. Instead of defining the entire vector of weights, AHP method requires paired comparisons of every factor. These comparisons are represented by numbers from 1/9 to 9, where the common understanding of these values is presented in table 1.

Table 1

Intensity of importance in AHP method

Value	Importance
1/9	Extremely less important
1/7	Very strongly less important
1/5	Strongly less important
1/3	Moderately less important
1	Equal
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important

It is possible to use values out of the scale (1/9 – 9) but it is not recommended. All the comparisons are presented in the matrix. For instance, if we have 3 factors (A, B and C), and factor A is moderately more important (3) than factor B and strongly more important (5) than factor C, while we consider factor B and C as equal, the matrix will be as presented in table 2.

Table 2

AHP method. Matrix of comparisons

	Factor A	**Factor B**	**Factor C**
Factor A	1	3	5
Factor B	1/3	1	1
Factor C	1/5	1	1

Of course the matrix is «symmetrical» – if A is moderately more important than B (3), B must be moderately less important than A (1/3). Therefore, while using computer programs one has to fill in only half of the matrix. The essence of AHP method is to use the comparison matrix to calculate a priorities ranking of given criteria. T Saaty proved that the best approach to do this is based on the eigenvector solution. The detailed description of this method is too vast to be presented in this paper. For details see the T. Saaty[1] or M. Rao [4] where case studies using this approach to the development of weights in GIS are presented. In practice it is often very difficult to determine an eigenvector using the analytical methods, especially for large matrixes. Due to this, the eigenvector is usually estimated using the approximate methods. In the next part of this chapter one of the simplified algorithms of calculating the eigenvectors and the weights is presented.

The first step of the algorithm is to calculate the natural logarithm of every number in the matrix (table 3, columns (1) – (3)). Then the average of all numbers in the corresponding row is calculated (column (4)). In the next step as presented in column (5), the ***e*** number is risen to the power of the results of the previous step. Finally the results are normalized in order to ensure the correct vector of weights (weights must add up to 1).

Table 3

AHP method calculations

ln(Col 1)	**ln(Col 2)**	**ln(Col 3)**	**Average ((1), (2), (3))**	**Exp((4))**	(5)/ **Σ**(5)
(1)	(2)	(3)	(4)	(5)	(6)
0.000	1.099	1.609	0.903	2.466	**0.659**
-1.099	0.000	0.000	-0.366	0.693	**0.185**
-1.609	0.000	0.000	-0.536	0.585	**0.156**
			Σ	3.744	

Because the comparisons of pairs of factors are being done arbitrarily it is possible to create the inconsistent matrix of comparisons. In this example, A is moderately more important than B and strongly more important than C. So it is reasonable to expect B is more important than C, while B and C were assessed as equally important. To measure the level of this inconsistency T. Saaty suggested calculating so called «consistency ratio».

[1] Ibid.

$$CR = (((\lambda_{max} - n))/((n-1)) \quad (4)$$

where:
CR – consistency ratio;
λ_{max} – maximum eigenvalue;
n – number of factors.

According to T. Saaty, if the CR is not greater than 0.1 the set of factors could be considered as «consistent». If CR is greater than 0.1 the set of factors is inconsistent and the comparisons should be changed.

Ordered Weighted Average. In the WLC method each factor has equal impact on the final result. The result is perfectly balanced among the weakest and the strongest factors. The WLC method could be considered as perfectly balanced from the vantage of risk. However, it is possible to create analyses with a higher or lower risk level. A low risk analysis is one where the area considered most suitable in the final result is minimized as it must be highly suitable in all factors. A high risk analysis is one where the area considered most suitable in the final result will be maximized as any area that is highly suitable for any factor will be considered highly suitable in the result. The method which allows choosing of the expected level of risk is called the Ordered Weighted Average (OWA) method. In OWA, apart from the factor weights, so-called «order weights» are available. Order weights are assigned not to factors themselves but to the rank order position of factor values for a given pixel (location). After factor weights are applied, the factor with the lowest suitability score is given the first order weight, the factor with the next lowest suitability score is given the second order weight, and so on. The best way to present the OWA method is by example.

Let us assume that we have four factors, four corresponding factor weights – presented in column (2) of Table 4, and four order weights – presented in column (3). The first step in the OWA method is to create the maps of factors and normalize them, like in the WLC method. The normalized values (factors) for the considered pixel are presented in column (1). The second step is to multiply these values by the corresponding factor weights. The results are presented in column (4). The next step is different than in the WLC method. The results from column (4) should be sorted out in ascending order. This operation is presented in column (5). After sorting out, the values should be multiplied by corresponding order weights. This is presented in column (6). The final result is a sum of this column.

Table 4

The OWA method calculations

Factors	**Factor weights**	**Order weights**	**(1) * (2)**	**Sorted out (4)**	**(3) * (5)**
(1)	(2)	(3)	(4)	(5)	(6)
58	0.5	0.4	29	13	11.6
95	0.2	0.3	19	17	5.7
130	0.1	0.2	13	19	2.6
85	0.2	0.1	17	29	1.7
				Σ	**21.6**

In this example, the factor with the lowest suitability score (after factor weights were applied) has the highest impact on the final score. This approach shows a low level of expected risk. The lowest level of expected risk will be if we take the order weights vector [1, 0, 0, 0]. For the highest level of risk, the order weight vector will be [0, 0, 0, 1]. The order weights vector with equal values [0.25, 0.25, 0.25, 0.25] represents a moderate level of risk. In that case the results of OWA method are similar to the results of WLC.

2. Case study. The goal of the presented case is to find the best terrains for the location of a hotel in Zabrze – a city in Poland. The hotel is dedicated chiefly to the guests of both the football stadium and the disused coalmine Guido, which is the main tourist attraction of Zabrze. The analysis was prepared in three variations – using WLC method and using OWA method with two different sets of order weights (for high and low risk level).

There were strict criteria (constraints) to fulfill in order to localize the hotel in Zabrze.

– It must be at least 15 meters away from the roads (requirement of Polish the legal system in the area of spatial planning)

– It must be at least 50 meters away from water reservoirs (security requirement in case of inundations or floods)

– It may be localized only in some particular types of terrain, such as discontinuous urban fabric, isolated structures, agricultural areas and lands without current use (investor requirement)

The map which includes all the constraints is presented in figure 2.

Apart from the constraints the factors were defined as well.

– (F1 – Guido) – It must be as close to the historical coal mine Guido as possible. Distances were measured by the average time necessary to travel to the coalmine.

– (F2 – Stadium) – It must be as close to the Górnik Zabrze Stadium as possible. Distances were measured as in previous point.

– (F3 – Motorways) – It must be as close to the motorways as possible.

Figure 2. Zabrze, map of constraints

– (F4 – Terrains) – The location depends on the terrain type. The usefulness of different terrains was determined as follows:

Table 5

Usefulness of terrain types

Terrain type	**Usefulness**
Discontinuous Dense Urban Fabric (S.L.: 50% – 80%)	10
Discontinuous Medium Density Urban Fabric (S.L.: 30% – 50%)	20
Isolated Structures	40
Land without current use	50
Agricultural + Semi-natural areas + Wetlands	35
Other terrains	–

For every factor a corresponding map was created. Then the maps were rescaled to the scale 0 – 1 using the sigmoidal function. The factor maps are presented in figures 3 – 6.

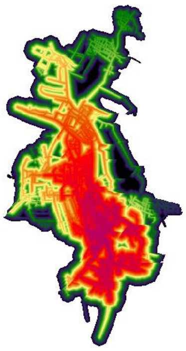


Figure 3. Factor 1 – Distance to the Guido Coalmine

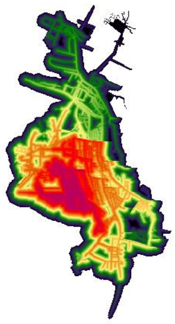


Figure 4. Factor 2 – Distance to the Stadium

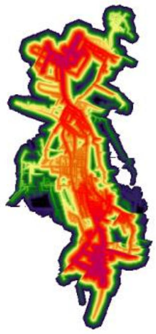


Figure 5. Factor 3 – Distance to Motorways

Figure 6. Factor 4 – Terrain types

The relations among factors were settled as follows:

– F1 (Guido) is moderately less important (1/3) than F2 (Stadium);
– F1 (Guido) is strongly more important than F3 (Motorways);
– F1 (Guido) is very strongly more important than F4 (Terrains);
– F2 (Stadium) is strongly more important than F3 (Motorways);
– F2 (Stadium) is very strongly more important than F4 (Terrains);
– F3 (Motorways) is slightly more important (2) than F4 (Terrains).

These relations were used to create a matrix of comparisons and to calculate the weight vector and consistency ratio.

Table 6

Comparison matrix and AHP results

	F1 - Guido	**F2 - Stadium**	**F3 - Motorways**	**F4 - Terrains**	**Weights**
F1 - Guido	1	1/3	5	7	**0.313**
F2 - Stadium	3	1	5	7	**0.543**
F3 - Motorways	1/5	1/5	1	2	**0.090**
F4 - Terrains	1/7	1/7	1/2	1	**0.054**

CR = 0.06

Having the factors with corresponding weights it was possible to find the best areas using both the WLC and OWA methods. While using the OWA two strategies were employed. The first strategy was pessimistic, the order weights vector was [0.4, 0.3, 0.2, 0.1]. The second strategy had optimistic character with the order weights vector [0.1, 0.2, 0.3, 0.4]. The final results are presented in figures 7 – 9. In the figures only the territories which have suitability over 0.7 are included.

In both, the WLC methods and the pessimistic strategy of OWA the terrains between the stadium and coalmine were selected. There are a few slight differences between the results but in general they are very alike. The optimistic strategy of the OWA method returned different results. In this approach the terrains close to the coalmine Guido were indicated. There are two main factors which had the crucial impact on this result: the proximity to coalmine Guido and the proximity to the motorways. Due to the chosen strategy these two factors turned out to be decisive while the two other (proximity to the stadium and the terrain types) were multiplied by lower order weights and proved to be less important.

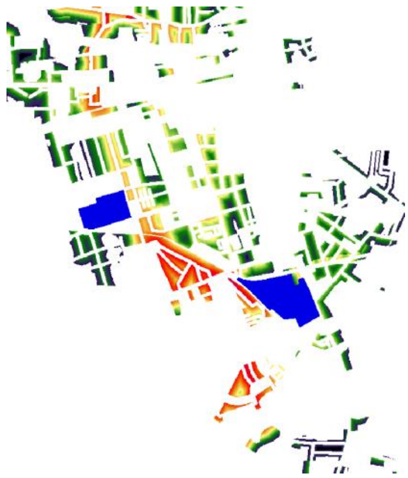


Figure 7. Best territories according to WLC method

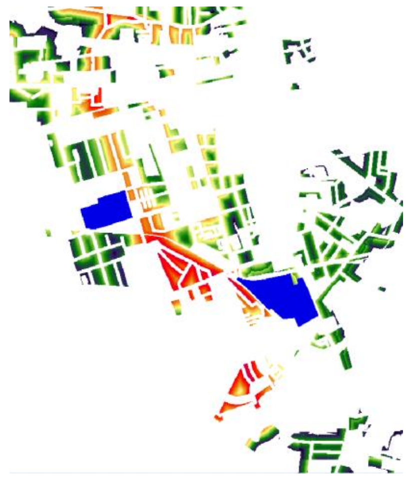


Figure 8. Best territories according to OWA method. Pessimistic strategy

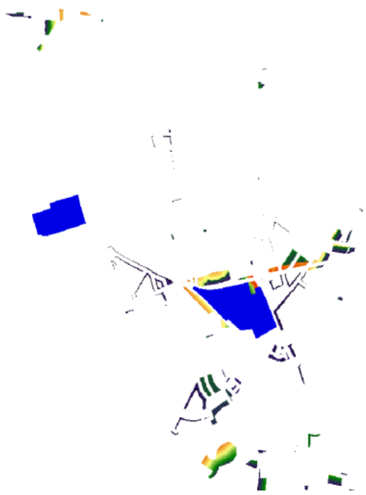
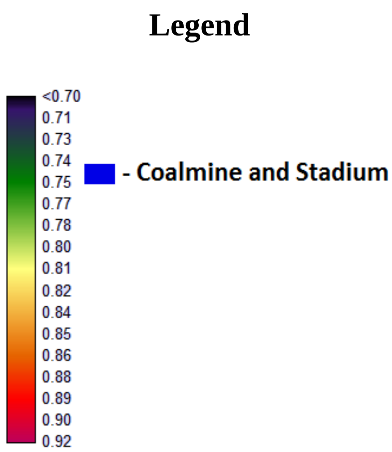


Figure 9. Best territories according to OWA method. Optimistic strategy



Conclusions. The multi-criteria evaluation methods in GIS are very useful tools which can be easily and efficiently employed to support the decision-making process in the field of tourism investments. The local vision confirmed the coincidence of the results with the choices based on common sense. Moreover, using the different set of order weights in OWA method it is possible to take into account an appetite for risk during the process of decision support. The methods by themselves are fairly simple, although the numerous minor difficulties during their application may occur. These difficulties concern rather the preliminary preparations of data than the methods themselves. The stages of the entire process and the typical problems occurring during these stages are as follows:

– Obtaining the information about investor expectations. This is essential in order to start the entire process and it is not always simple to do. Usually in the beginning only general (and sometimes vague) expectations are defined. The clarification of expectations takes place during the next stages.

– Obtaining the maps. The most often used information are landuse, transportation, elevation maps and information typical for a specific problem (such as location of coalmine Guido in presented example).

– Clarification of expectations and setting the relations among them. During this stage it is essential to establish the close cooperation with investor. If many factors are taken into account it might be difficult to fix the relations among criteria directly. In this case AHP method turns out to be very useful and powerful tool.

– Creating the maps and calculate the results. This is the essence of MCE methods. Thanks to varied IT tools it is relatively simple and may be done in numerous variations (for instance taking into account varied levels of risk appetite).

The results of MCE methods can be employed directly in the decision-making process. However, it is also possible to use them in order to carry out further analyses, such as solving the problems of conflicts in space or modeling the changes of the space.

Literature

1. Carver, S.J. Integrating multi-criteria evaluation with geographical information systems, s, International Journal of Geographical Information Systems, 5:3, DOI: 10.1080/02693799108927858, 1991.
2. Voogd. H. Multicriteria Evaluation for Urban and Regional Planning [Text] / H. Voogd. – London, Pion, 1983.
3. Saaty, T.A. Scaling. Method for Priorities in Hierarchical Structures [Text] / T. Saaty, J. Math. – Psychology, 15.
4. Rao, M. A Weighted Index Model for Urban Suitability Assessment [Text] / M. Rao, S.V.C. Sastry et. al. – A GIS Approach. Bombay, India: Bombay Metropolitan Regional Development Authority, 1991.

Received 04.02.2016