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SPATIAL DECISION MAKING FOR LOGISTICS CENTRE ALLOCATION

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ABSTRACT:
We can state, that transportation market goes through its own blossom not only in the Czech Republic, but worldwide. Enterprises are still often forced to act quickly and deliver their goods as soon as possible, because the market itself is changeable and get back lost position is very difficult. To ensure enough of goods sophisticated hubs are established and several private logistics centres have been build. The situation concerning public logistics centres is little bit worse. Thus a big challenge has arisen. According to Transportation policy another means of transport then road transport is supported, but actually we must realize that existing roads network is still very important and cannot be forgotten. Regional authority of the Region Vysočina has decided to build a public logistics centre. With respect to given limits and requirements three basic models (Boolean, WLC and OWA model) based on spatial decision making methods were developed. Subsequently each model was tested and examined from usefulness, factors trade-off and area capacity and availability point of view. For data processing Idrisi and ArcGIS for Desktop software were used.

***Key-words**: Spatial decision making, Fuzzy standardization, Logistics centres, OWA, WLC.*

1. INTRODUCTION

The rise of new technologies has enabled the rapid development of the transportation market in the Czech Republic. Most used, but least-friendly component of the transportation market is road transport. After the Czech Republic joined the European Union goods mobility demands has increased. For this reason there are requirements for establishment of logistics services. They are concentrated mainly in logistics centres, which are characterized by two means of transport. Logistic centres (LC) integrate businesses also integrating customs or postal services. In the Czech Republic there are both logistics centres private and public logistics centre (PLC). Logistics centres provide transport of shipments, logistics outsourcing services, warehousing services, value added services, customs services, distribution services, government services, financial and insurance services, consulting services and other (Cempírek & Kampfl, 2002). Until 2005, the development of logistics services was realized outside the public administration, hence the logistics services, including logistics centres are included in the Transportation Policy of the Czech Republic for the years 2014 - 2020 period. The establishment of LC is specifically addressed in the Logistics support from public finance document. LC has become a part of all distribution services. The Vysočina Region has a few LC, which are privately owned but there is no PLC. The effort and also the obligation to build PLC in the Vysočina Region stems from an approved Spatial Development Policy of the Czech Republic in 2008. Network of public logistics centres should primarily serve to a division of logistics services with regard to protection of the environment, cheaper, friendlier and more efficient technologies. The concept of public logistics centres in the Czech Republic in the context of reinforcing the importance of multimodal freight transport stated that the system of public logistics, based on the regional principle, should have, if built on the basis

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of a clear concept, the impact on regional development. Hýblová, Lejsková and Jiráková (2007) divides logistics centres by the purpose and size. In relation to the purpose, they further distinguish company logistic centres, serving to a large firm or a business chain, logistics centres of logistics companies operating by logistics providers, logistics centres of courier, express and parcel network services and online stores logistics centres. Given the size of the logistics centres local, regional and international logistics centres are distinguished. Sector operational program named the Transport defines PLC as a destination for offers of wide range of logistics services concentration, including intermodal transport, which can provide services at least of two means of transport. The establishment and the development of PLC is only possible with a unique concept at all levels (supranational, national, regional) with possible support from public funding eventually with the help of EU funds. The PLC issue is being solved at both, the national and the European level. The first European public logistics centres were built up in Germany and Italy. Here, however, the public sector is involved only marginally. In some EU countries the situation is different, but concerning existing public logistics centres the Czech Republic can follow existing ones. Regarding the connection to international supply chains following suitable sites were delineated: Prague, Brno, Ostrava considering international importance and Pardubice, Přerov (or Olomouc), Liberec, Ústí nad Labem, České Budějovice and Plzeň considering regional importance. With regard to a number of variables, it is necessary to delineate a suitable area using one of spatial decision making methods.

2. PUBLIC LOGISTICS CENTRE ALLOCATION

A network of logistics centres shall ensure efficient and environmentally friendly use of built-up areas and roads. Needs of individual manufacturing sectors as users of logistics and transport services, restrictions and limits (nature and landscape protection), present and future state of the transport network and the possibility of its development, and distance from other logistics centres are considered for suitable areas delineation. The case study was carried out on the example of the Vysočina Region. Officers of the regional authority preselected the key area involving administrative districts of municipality with extended power (AD MEP) Jihlava, Havlíčkův Brod a Humpolec (Matějková, 2013). The updated Principles of Territorial Development of the Vysočina Region closely specified the study area as the preselected area involving AD MEP Jihlava without municipalities in the southwestern part, AD MEP Humpolec without municipalities in the western part an AD MEP Havlíčkův Brod with municipalities only in the southern part. The study area includes 53 municipalities (**Fig. 1**). The main reason for the choice was that specified territory belongs to the region of influence of the county town of Jihlava. This is an area with a relatively high concentration of population and economic activities with a good location in relation to the highway D1 access junction. The criteria for delineating the most suitable areas were divided into constraints and factors. Constraints identifying areas, which must be with respect to their value excluded from suitable alternatives, were set by the regional authority and can be defined as follows:

1) geological point of view
    a) mineral deposits
    b) undermined areas

2) nature preservation point of view
   a) protected mineral deposits
   b) forest with 50 m protected zone
   c) 1st and 2nd class of soil quality
   d) small especially protected areas
   e) NATURA 2000 areas
   f) territorial system of ecological stability
   g) location of specially protected plants and animals

3) historical point of view
   a) areas with archaeological foundations
   b) war graves

4) hydrological point of view
   a) water bodies
   b) flooded areas
   c) location of surface water accumulation

5) significant infrastructure point of view
   a) important objects for national security
   b) 50 m protected zone along telecommunication lines
   c) 300 m protected zone along pipelines
   d) built up areas

Key factors identifying the area with the highest suitability were gathered into two groups: transport and infrastructure. The transport factor took into account road transport network of the first class roads and high speed roads and the distance to highway junctions and railways. Within the infrastructure factors distance from power lines (wiring), pipelines, water conduits and sewerage networks were considered. Each factor was based on the set distance. Bigger the distance is higher costs are expected. That is why closer areas are favoured.

1) Transport factor
   a) 1st class roads and high speed roads – up to the distance of 1 km
   b) highway junction – up to the distance of 3 km
   c) railway – up to the distance of 1,5 km

2) Infrastructure factor
   a) wiring – up to the distance of 1,5 km
   b) pipeline – up to the distance of 1 km
   c) water conduit – up to the distance of 1 km
   d) sewerage – up to the distance of 1 km

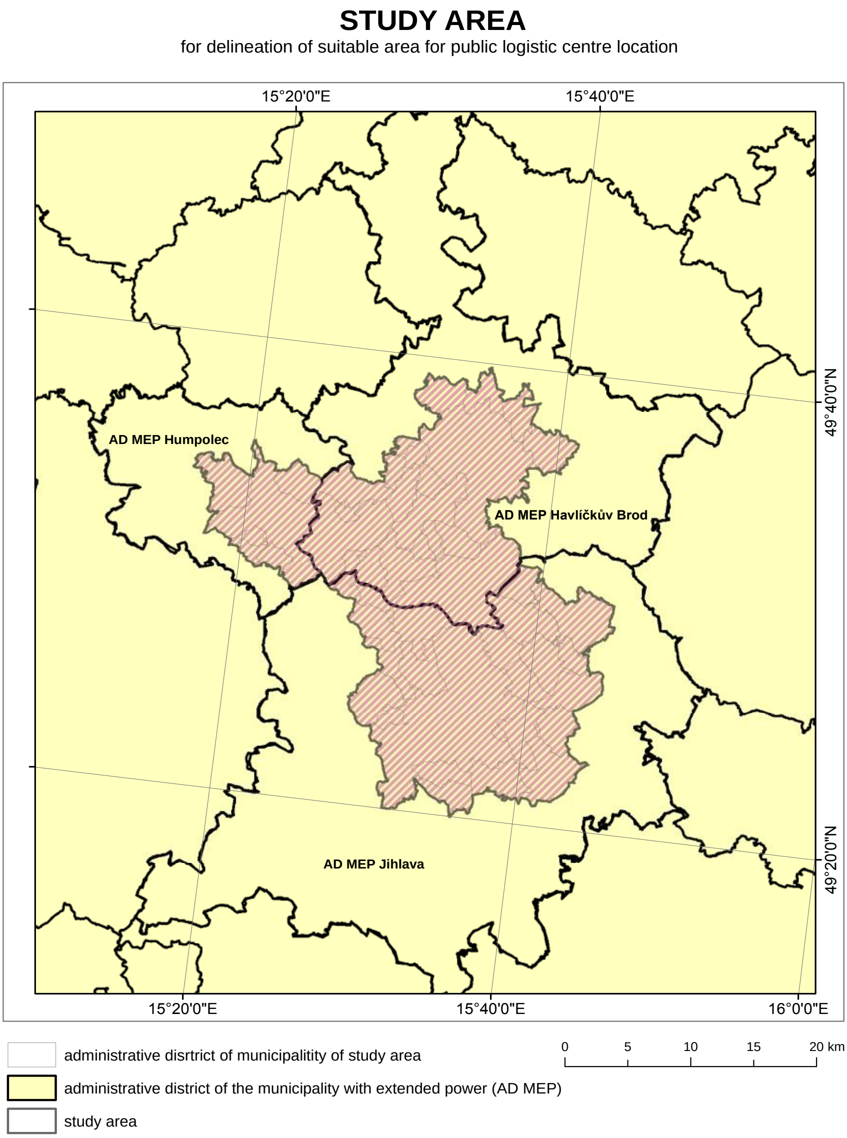

Fig. 1 Study area. (Source: own processing in ArcGIS 10.1).

3. METHODOLOGY BACKGROUND

Due to the presence of a number of criteria (factors and constraints) it is suitable to use appropriate multi-criteria evaluation approaches enabling the selection. Effat and Hegazy (2009) states, that Multi-Criteria Decision Making (MCDM) includes both Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). In the case of MCDM applications the term Multi-Criteria Analysis (MCA) or Multi-Criteria Evaluation (MCE) is often used. The principle of data overlaying representing more criteria for the evaluation of given problem in order to resolve it already appeared in the works of McHarg (1969), who used a variety of criteria to solve the socio-economic dimensions.

In contrast to conventional approaches of MCDM spatially oriented MCDM includes individual criteria as well as their location in space. In essence, the spatial multi-criteria decision making takes into account both the geographic data (data with spatial localization) with decision-making preferences and their final summarization according to specified decision rules (Malczewski, 1999; Malczewski, 2006a; Malczewski, 2006b; Voogd, 1983). In general, MCDM decision-making process can be divided into four basic steps (Yager & Kelman, 1999):

a) criteria and alternatives selection,
b) data normalization and weights setting,
c) specific decision making method implementation,
d) result aggregation and interpretation.

The preferred beneficial of multi-criteria decision-making methods is the opportunity to work with many alternatives, which can be judged by the pros and cons of each option alternative properties Pechanec (2013). In this case the pros and cons can be scored and then it is possible to eliminate the alternative with the lowest ratio of pros to cons. The combination of the worst and the best properties allows maximizing the most important criterion, even if it is not enough considering positive ratings of less important properties it may be selected as a significant one. The difference between the most positive and most negative properties is used to exclude those alternatives whose differences are largest and therefore difficult to achieve in practice. A number of multi-criteria evaluation methods both for raster and vector data have been implemented in GIS software (Malczewski, 2006a, Malczewski, 2006c, Malczewski, 2006d).

The choice of criteria and each alternative is determined by the purpose and character of the solved task and varies according to the appropriate circumstances. One problem with multi-criteria decision making may be different scale in data layers origin, hence the standardization of input data is needed. The most commonly used standardization approach includes linear transformation (Chakhar & Mousseau, 2008), whose goal is to adjust input values appropriately. To be accurate the easy way to standardize the input values is based on the maximum value (1) and (2) and the variation range of data set (3) and (4).

$$x_{ij}^{'} = \frac{x_{ij}}{x_j^{\max}}, (1) \qquad x_{ij}^{'} = 1 - \frac{x_{ij}}{x_j^{\max}}, (2)$$

$$x_{ij}^{'} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}}, (3) \qquad x_{ij}^{'} = \frac{x_{ij}^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}}, (4)$$

Where: $x_{ij}^{'}$ is an adjusted value for alternative i of the criterion j a x_{ij} is the input value. Adjusted (standardized) value becomes size 0 – 1. Equations (1) and (3) are used in case of the value criterion maximization, equations (2) and (4) are needed for minimizing the criterion value. Scoring is another possible way when the most important criterion gets the lowest value, the least important criterion gets the highest value. The final result is achieved by summing up and the level of significance decreases with higher value.

Fuzzy standardization represents a compromise solution, when it is not strictly necessary to accept or reject given criterion. The theory, as it is known, allows only to state that the element belongs or does not belong to the group. Fuzzy logic extends this concept considering both full membership and partial membership of the element in the group (Kolísko, 2014). The importance of membership of an element in the fuzzy group is expressed by the level of membership. This can be achieved by using the membership functions (Zadeh, 1965). In this case, it is necessary to define a fuzzy value, acquiring the value range from 0 to 1 or from 0 to 255 in a continuous scale using the relevant function. Among the most commonly used belong sigmoid function, J-shaped function, linear function (**Fig. 2**) and user-defined function. They can be used according to the nature of the data in ascending or descending order.

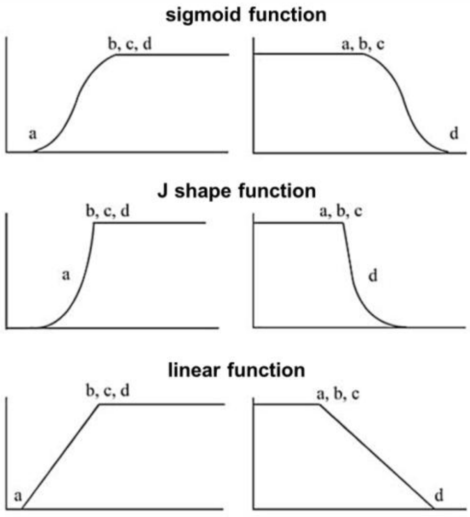

Fig. 2 Fuzzy membership function; increasing (left), descending (right).

Determination of the weights of the criteria is the crucial part of multi-criteria decision making. Their derivation is the key step for the decision-making preferences selection. The higher the weight of the criterion is, the higher importance in decision making the criterion has. The sum of the weights of all criteria is usually equal to 1. There are a number of methods that can determine the weights, the easiest way is to sort the various criteria in order of importance and following calculation of the weights according to the this equation (5) (Malczewski, 1999; Malczewski, 2006a)

$$w_j' = \frac{n - r_j + 1}{\sum (n - r_k + 1)}, (5)$$

Where: w_j is the normalized weight of criterion j, n is the number of specific criterion a r_j is given criterion rank.

Very often when working with spatial data Saaty´s method of pairwise comparison is used. Saaty´s method allows pairwise comparisons using the method of AHP (Analytic Hierarchy Process) to decompose a complex situation to a simpler and thus to create a hierarchy of the problem (Ruda, 2010). Saaty (1980) suggested a point scale assigning nine points considering the relation between each factor pair, comprising basic values (1, 3, 5, 7, 9) and the intermediate values (2, 4, 6, 8) for finer resolution.

With regard to the desired data processing in GIS various methods of spatial decision-making can be applied. Boolean method represents this type of standardization for raster data resulting in simplification of all criteria into Boolean images. Their importance is reduced to a form of suitable or unsuitable areas. This is achieved by reclassification of values into two required classes (0 - inappropriate surfaces, one - suitable surface) using binary logic. This way strictly determine constrains in raster format It should be noted that using only this method wipes out any intermediate steps in the decision-making process and strictly excludes or permits alternatives under specified conditions. Weighted linear combination (WLC) is a well-known method developed by Keeney and Raiff (Ozturk & Batuk, 2011), also titled Simple additive weighting (SAW). WLC Uses continuous criteria (factors) that are standardized in normal numerical range (0-255) and then combined using weighted averages. The weak value of one criterion may be trade off by a number of high-quality criteria. The possibility of factors trade-off, or their replacement by other factors determine the factor weights. The decision rule for each alternative is defined as follows (6):

$$A_{WLC} = \sum_{j=1}^{n} a_{ij} w_j, (6)$$

Where: a_{ij} is the value of alternative i respecting criterion j and w_{ij} is the normalized weight of j criterion (Triantaphyllou, 2000).

According to Žídek (2001) WLC shifts the analysis from extreme risk rejection expressed by AND operation (see Boolean method) exactly between the operations AND and OR, where the extreme risk is not nor rejected neither accepted. Thus WLC allows full trade-off of factors and brings an average level of risk. In connection with Yager´s fuzzy sets theory (1988) a method of Ordered-Weighted Average (OWA) has been developed. Naturally, OWA is similar to WLC. Although criteria are standardized and weighted the same way order weights are applied for factors. They are not directly linked to a specific criterion, but assigned to different criteria values from minimum to maximum, which reduce the risk of trade-off. The factor with the lowest suitability is assigned to the first order weight, the next factor is assigned to another increasing order (Pechanec, 2013). Using this processing OWA allows to control the level of risk and the level of trade-off. The decision rule is given by (7, 8):

$$A_{OWA} = \sum_{j=1}^{n} \left(\frac{w_j ow_{ij}}{\sum_{j=1}^{n} w_j ow_{ij}} \right) a_{ij}, (7) \qquad ow_{ij} = \left(\frac{k}{n}\right)^{\delta} - \left(\frac{k-1}{n}\right)^{\delta}, (8)$$

Where: ow_{ij} is the order of criteria i weights with regard to criterion j and δ represents the degree of the polynomial function (Tesfamariam & Sadiq, 2008).

The possibility to control the level of risk of decision-making process and the level of trade-off, OWA provides results similar to Boolean operations AND, OR and WLC. Other available methods used for multi-criteria decision making are SMART (Simple Multi-Attribute Rating Technique) based on techniques of Multi-Attribute Utility Theory (MAUT), ELECTRE and PROMÉTHE (Lootsma, 1996). Defining the problem is similar to AHP and creates a hierarchical structure. SMART offers the user to evaluate alternatives in terms of the lowest criterion on the basis of the measurement and subsequent standardization of the evaluation (Baron & Barrett as cited by Pechanec, 2013). This is a relatively simple solution, focusing on the structure of multi-criteria respectively multi-attribute alternatives.

4. DATA PROCESSING

In the beginning, it should be emphasized that the case study works with one objective, set of unified constraints and seven key factors divided and defined previously. Three possible approaches including Boolean method, WLC and OWA methods were considered for data processing. Firstly, all constraint layers were unified into one constraint layer. All the data was available in vector format (SHP) using S-JTSK coordinate system. Then data was transformed to raster format with a pixel resolution of 10 m. In case of constrains pixels were assigned with 0 value. Individual factors represent point or line features and affect the output by specified distance from their location. These distances were given by regional authority and were mentioned above. During the processing of distance value assignment Euclidean Allocation tool in ArcGIS was used. As it was underlined the output was in raster format. For the purpose of Boolean method processing buffer zones were defined along individual features and subsequently transformed to raster format.

Boolean model

Boolean method is based on the strict rejection of any risk. Map algebra, especially raster calculator was used to calculate model results. Input raster pixels assigned number 1 confirm the presence of desired factor as well as pixels outside the constraints. Other pixels have No Data value. These setting ensure that when multiplying of individual layers is taken only those pixels that meet the necessary factors and also do not cross any of constraints remain. Regarding risk rejection the result introduced a set of 25 fragmented areas north of Jihlava with not too compact shape and relatively small size (**Fig. 3**). Only three areas are greater than 0.1 square kilometres (0.12 km^2; 0.121 km^2; 0.126 km^2).

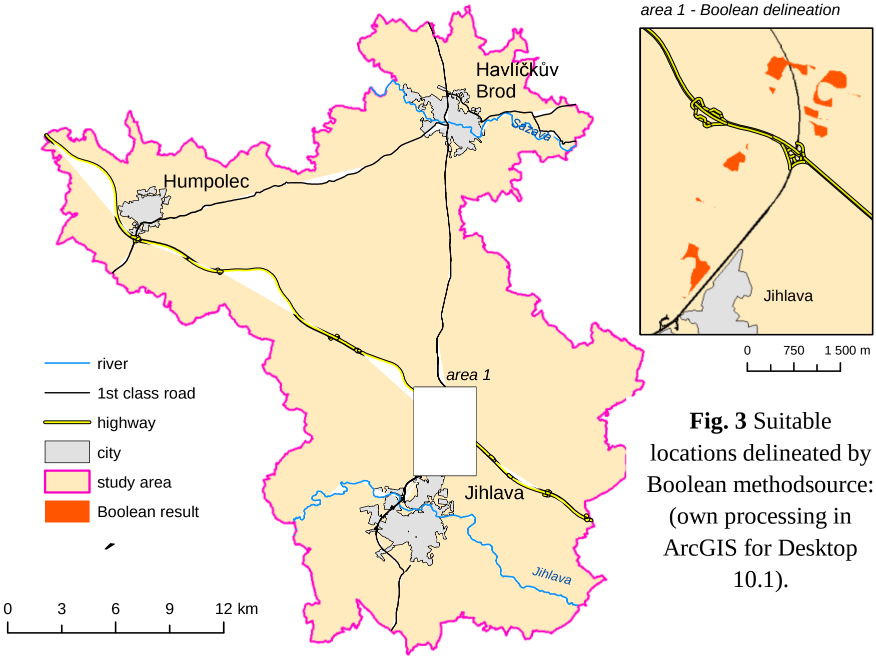

Fig. 3 Suitable locations delineated by Boolean methodsource: (own processing in ArcGIS for Desktop 10.1).

WLC model

Preparation of data for WLC assessment is the same as for OWA method. It included data conversion, correct identification of their potential, data standardization and factor weights setting (**Fig. 4**). In principle, two groups of data, factors and constraints were considered. As it was mentioned Euclidean distance was calculated for each pixel of factor layers. Output raster has 10 m resolution. To determine the Fuzzy membership sigmoid monotonically decreasing function was used for better defining with respect to set suitable distance. All standardized layers were summed up using Weighted Sum tool. Individual factor weights (**Table 1**) were derived based on cost regarding building missing infrastructure.

Table 1. Factor weights calculated according to Saaty´s pairwise method.

factor	roads	railways	highway junction	pipeline	sewerage	water conduit	wiring	**weight**
roads	1	3	3	7	5	5	5	**0,3951**
railways	1/3	1	3	5	1/3	5	1/3	**0,0798**
highway junction	1/3	1/3	1	3	1/5	1/5	1/5	**0,0471**
pipeline	1/7	1/5	1/3	1	1/5	1/3	1/3	**0,0298**
sewerage	1/5	3	5	5	1	1	3	**0,1775**
water conduit	1/5	1/5	5	3	1	1	1/3	**0,1213**
wiring	1/5	3	5	3	1/3	3	1	**0,149**

Source: own processing

Their values were calculated using AHP 1.1 tool, which must have been additionally installed. The result is a weighted linear combination of standardized factors and factor weights generally called suitability map. Individual pixels received the sum of the weighted values. For better interpretation using qualitative statements values were reclassified based on Natural breaks algorithm into five classes symbolizing the least suitable - less suitable - suitable - more suitable - most suitable area.

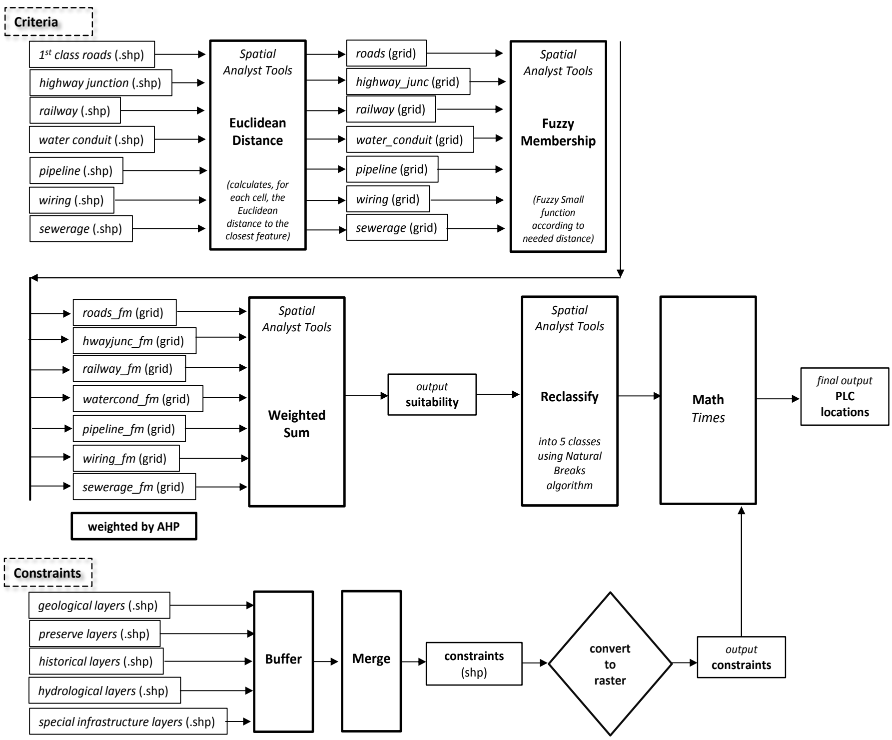

Fig. 4 Carthographic model of WLC data processing.

The input data formats for constraints identification were shapefiles. Around each feature required buffer zone was delineated. These layers were unified into a single file and converted to raster format and pixels identifying constraints were given numerical value 1 to be used as a mask. Constraints layer and map suitability layer were multiplied in and the result includes pixels with values identifying different type of suitability (**Fig. 5).**

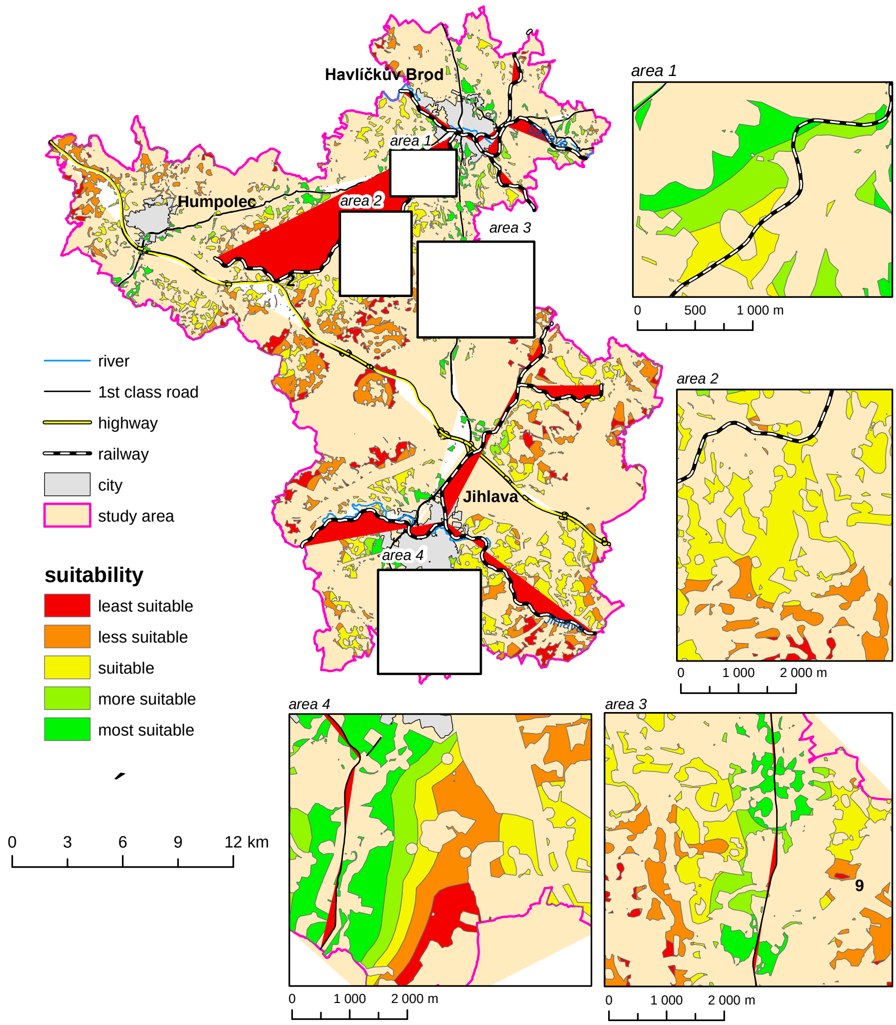

Fig. 5 Suitable locations delineated by WLC method (Source: own processing in ArcGIS for Desktop 10.1).

OWA model

Spatial analysis using Ordered Weighted Average (OWA) method was due to easier facilitating implementation processed in Idrisi 17.0 the Selva Edition (Idrisi). At the beginning conversion to Idrisi raster format of previously distance evaluated rasters used in WLC processing must have been done. For this purpose, all rasters were transformed in

ArcGIS for Desktop 10.1 into an Imagine format, uploaded in Idrisi and stored as a specific Idrisi raster format (.rst). Fuzzy standardization using sigmoid monotonically decreasing function was used for data normalization. The key difference between OWA and WLC is ordinal scales determination during OWA processing. In Idrisi it is possible the use a decision making triangle to set three possible scenarios. If we want to produce a low risk result (scenario 1) then we must give greater order weight to lower rank-orders. In our case of strictly refusing risk we give full weight. The result closely resemble the AND operation as it was mentioned in Boolean method. Medium risk (scenario 2) represents a situation where all factors have the same order weight. The output has the same results as WLC method, because the same order weight does not change the result of WLC. In contrast, the risk taking situation (scenario 3) assigns a weight of 1.0 the factor that has the highest value, which indicates a high trade-off. Even the OWA technique can produce similar results as operation AND, OR and WLC method varying levels of risk and trade-off can be made. With respect to several scenarios the most suitable scenarios giving ordered weights regarding low level of risk and some trade-off (**Table 2**) was subsequently developed into a final model.

Table 2. Ordered weights for scenario with low level of risk and some trade-off.

order weight No.	weight 1	weight 2	weight 3	weight 4	weight 5	weight 6	weight 7
weight value	0.5	0.25	0.125	0.065	0.040	0.020	0

As it is shown these order weights specify an operation right between the extreme of AND operation and the average risk position of WLC. The final output was uploaded in ArcGIS for Desktop 10.1 and modified with respect to previous data processing described during WLC processing. Opposite WLC results, OWA results were filtered according to areas size and their shape. In the final selection we have only continuous areas with the area greater than 1 square kilometre. Additionally analysis assessing the areas distance from railways was also taken because the increasing importance of this mean of transport was announced by the regional authority. The most suitable areas location numbers are 1, 4, 5 and 6 (**Fig. 6**).

5. RESULTS AND CONCLUSION

Comparing these three models it is important to mention that every model has its application according to defined purpose. Boolean method provides results without any risk but does not consider any trade-off. This can be useful in situation when we have strictly defined constraints and it is not possible to reconsider their importance. For our case study it provides unsatisfactory results. WLC method enables certain factors trade-off and extends the number of alternatives just like OWA method. Comparing OWA and WLC results we find out that WLC results provide all five categories of alternatives quality. This is caused by the order weighting reducing the final high value for the majority of alternatives. We can also see that the recommended areas also differ. Concerning WLC results without filter processing the most suitable continuous areas can be found southward from Havlíčkův Brod and Jihlava. Using OWA model we have different locations, but both models evaluated similarly area 1 and area 2 delineated in **Fig. 6**. It is because of the low risk and some trade-off during OWA processing. Finally we can highly recommend location 1 and 4. Location 1 is situated near the railway and the intention to support other than road transportation is highly important. On the other hand location 4 is situated near the Jihlava city next to places of enterprises. There were not any given requirements for further processing then it is up to regional authority to select the most suitable area.

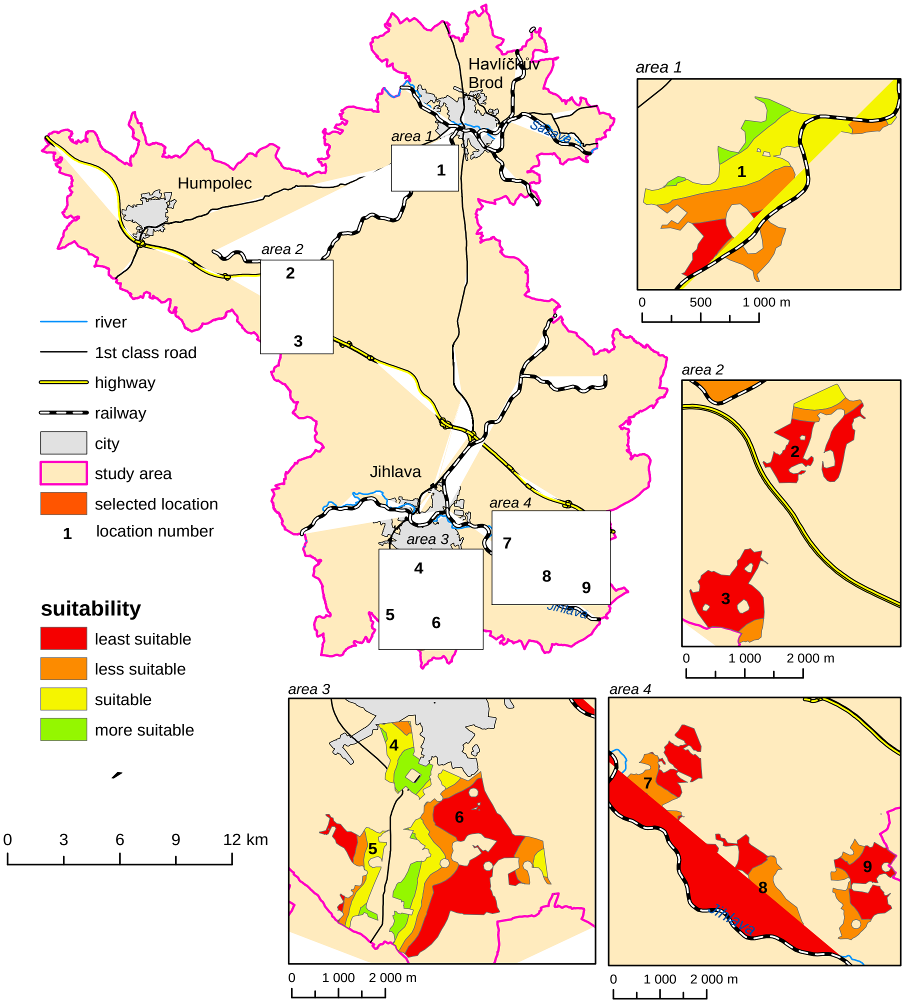

Fig. 6 Suitable locations delineated by OWA method.
(Source: own processing in Idrisi 17.0 The Selva Edition and ArcGIS for Desktop 10.1).

REFERENCES

Cempírek, V., & Kampf, R. (2002) *Logistická centra*. Logistika, roč. VIII, č. 3, s. 27. ISSN 1211-0957.

Chakhar, S., & Mousseau, V. (2008) *Spatial multicriteria decision making, in Encyclopedia of GIS*, eds. S. Shekhar and H. Xiong. New York: Springer. pp. 747–753.

Effat, H., & Hegazy, M.N. (2009) *Cartographic modeling and Multicriteria evaluation for exploring the potentials for tourism development in the Suez governorate, Egypt*. Applied geoinformatics for society and environment.

Hýblová, P., Lejsková, P., & Jiráková A. (2007) *Logistická centra, jejich činnosti a záměry v České republice*. In Outsorcing dopravně-logistických procesů a prostorová lokalizace veřejných logistických center. 1. vyd. Pardubice: Univerzita Pardubice,194 s. ISBN 978-80-7395-022-4.

Kolísko, P. (2014) *Bike Trail Difficulty Rating in the South Moravian Region Modelled Using Fuzzy Sets*. Geoinformatics, Faculty of Civil Engineering, Czech Technical University in Prague, 11, 5-23. ISSN 1802-2669 . [Online] Avaible from http://geoinformatics.fsv.cvut.cz/pdf/geoinformatics-fce-ctu-2013-11.pdf. [cit. 2014-01-07].

Lootsma, F.A. (1993) Scale sensitivity in a multiplicative variant of the AHP and SMART. *Journal of multi-criteria decision analysis*, 2 (2), 87-110. ISSN 1099-1360.

Malczewski, J. (1999) *GIS and Multicriteria Decision Analysis.* New York: John Wiley and Sons. 392 s

Malczewski, J. (2006a) Integrating multicriteria analysis and geographic information systems: The ordered weighted averaging (OWA) approach. *International Journal of Environmental Science and Technology*, 6, 7–19.

Malczewski, J. (2006b) GIS-based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science* 20 (7), 703–726.

Malczewski, J. (2006c) Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. *International Journal of Applied Earth Observation and Geoinformation* 8 (4), 270–277.

Malczewski, J. (2006d). *Multicriteria decision analysis for collaborative GIS*. In: Dragic´evic´, S. and Balram, S. (eds) Collaborative geographic information systems. Hershey, PA: Idea Group, 167–185.

Matějková, L. (2013) *Lokalizace Veřejného logistického centra v Kraji Vysočina*. Diplomová práce. Brno: Mendelova univerzita, 112 s.

McHarg, I.L. (1969) *Design with nature*. London: John Wiley and Sons.

Ozturk, D., &bBatuk, F. (2011) Implementation of GIS-based multicriteria decision analysis with VB in ArcGIS. *International Journal of Information Technology and Decision Making, World Scientific Publishing Company*, 10, (6), 1023 – 1042.

Pechanec, V. (2013) *Analýza krajiny prostřednictvím SDSS*. Habilitační práce, Brno: Mendelova univerzita, 173.

Ruda, A. (2010) Contribution to assessement of the tourism impact on landscape. *Acta Universitatis Carolinae Geographica*, Praha, Karolinum, Vol. XLV (1), 61-74.

Saaty, T. L. (1980) *The Analytic Hierarchy Process: Planning, Priority Setting.* Resource Allocation, New York: McGraw-Hill.

Tesfamariam, S., & Sadiq, R. (2008) Probabilistic risk analysis using ordered weighted averaging (OWA) operators. *Stochastic Environmental Research and Risk Assessment*, 22, 1–15.

Triantaphyllou, E. (2000) *Multicriteria Decision Making Methods: A Comparative Study*. Dordrecht: Kluwer Academic Publishers.

Voogd, H. (1983) *Multicriteria Evaluation for urban and Regional Planning*. London: Pion.

Yager, R. R., & Kelman, A. (1999) An Extension of the Analytical Hierarchy Process Using OWA Operators. *Journal of Intelligent and Fuzzy Systems*, 7 (4), 401-417.

Yager, R. R. (1988) On ordered weighted averaging aggregation operators in multicriteria decisionmaking. *Systems, Man and Cybernetics, IEEE Transactions on*, 18(1), 183–190, DOI:10.1109/21.87068.

Zadeh, L. (1965) Fuzzy Sets. *Information Control*, 8 (93), 338-353. [Online] Avaible from: DOI: 10.1016/S0019-9958(65)90241-X.

Žídek, V. (2001) *Analýza v GIS a zpracování dat DPZ pro pokročilé*. Brno: Mendelova zemědělská a lesnická univerzita v Brně, Lesnická a dřevařská fakulta, 107 s. ISBN80-7157-506-2.