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Procedia Engineering 69 (2014) 1054 – 1063

Procedia Engineering

www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

GIS Based Multi-Criteria Analysis for Industrial Site Selection

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Abstract

Site selection is one of the basic vital decisions in the start-up process, expansion or relocation of businesses of all kinds. Construction of a new industrial system is a major long-term investment, and in this sense determining the location is critical point on the road to success or failure of industrial system. One of the main objectives in industrial site selection is finding the most appropriate site with desired conditions defined by the selection criteria. Most of the data used by managers and decision makers in industrial site selection are geographical which means that industrial site selection process is spatial decision problem. Such studies are becoming more and more common, due to the availability of the Geographic Information Systems (GIS) with user-friendly interfaces. Geographic information systems (GIS) are powerful tool for spatial analysis which provides functionality to capture, store, query, analyze, display and output geographic information. Geographic Information Systems are used in conjunction with other systems and methods such as systems for decision making (DSS) and the method for multi-criteria decision making (MCDM). Synergistic effect is generated by combining these tools contribute to the efficiency and quality of spatial analysis for industrial site selection. This paper presents a successful solution for spatial decision support in the case of spatial analysis of Vojvodina as a region of interest for industrial site selection.

Selection and peer-review under responsibility of DAAAM International Vienna

Keywords: industrial site selection; geographic information systems; GIS; multi-criteria decision analysis; MCDA, Decision support system; DSS; ArcGIS; IDRISI

1. Introduction,

Industrial site selection is critical point in the process of starting, expanding or changing the location of industrial systems of all kinds. One of the main objectives in industrial site selection is finding the most appropriate site with desired conditions defined by the selection criteria.

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1877-7058
Selection and peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2014.03.090

In a site selection process, the analyst strives to determine the optimum location that would satisfy the selection criteria. The selection process attempts to optimize a number of objectives desired for a specific facility. Such optimization often involves numerous decision factors, which are frequently contradicting, and the process often involves a number of possible sites each has advantages and limitations. Decision making is based on numerous data concerning the problem of selection appropriate site. Decisions about industrial location typically involve the evaluation of multiple criteria according to several, often conflicting, objectives. While many decisions we make are prompted by a single objective, it also happens that we need to make decisions that satisfy several objectives. These objectives may be complementary or conflicting [1,2,3].

Decision making is based on numerous data concerning the problem. It has been estimated that 80% of data used by managers and decision makers are geographical (spatial) in nature [4]. Decision problems that involve geographical data are referred to as geographical or spatial decision problems [5].

Decision making and problem solving relies on the information and communication technologies and exchange of ideas and information, necessary to tackle a particular decision problem. Spatial decision problems often require that a large number of alternatives be evaluated on the basis of multiple criteria. Spatial decisions are multi-criteria in nature [6].

Geographic information systems (GIS) are powerful tool designed for spatial analysis which provides functionality to capture, store, query, analyze, display and output geographic information. As such they have big influence in spatial decision making process. Recent development in field of decision making leads to dramatic improvements in the capabilities of GIS in location analysis. These development are reviewed through analysis of attribute data especially procedures for Multi-Criteria and Multi-Objective location analysis in GIS. Special emphasis is given to the problems of incorporating subjective influence in the context of decision making; the expression of uncertainty in establishing the relationship between evidence and the decision to be made; procedures for the aggregation of evidence in the presence of varying degrees of trade-off between criteria; and procedures for conflict resolution and conflict avoidance in cases of multiple objective decision problems [7].

Geographic information systems are used in conjunction with other systems and methods such as systems for decision making (DSS) and the method for multi-criteria decision making (MCDM). Synergistic effect, generated by combining these tools contribute to the efficiency and quality of spatial analysis for industrial site selection [8,9,10].

One of the main problem of industrial site selection is that requires a lot of time for decision making, because of a large number of data, required for quality analysis. To speed up decision process is necessary to develop a model for decision making that is optimized and adapted for industrial site selection. In this paper research was done on the defined number of possible industrial locations (alternatives) in the region of interest obtained in the screening phase. Spatial analysis was made with quantifiable data in terms of single-objective decision making with optimized number of criteria, without subjective and conflict criteria, using MCDM in GIS environment. Focus of our research was whether the MCDM methods can be efficiently used in GIS environment as decision support tool for industrial site selection in terms of proposed model.

2. Site selection process

In the past, site selection was based almost purely on economical and technical criteria. Today, a higher degree of sophistication is expected. Selection criteria must also satisfy a number of social and environmental requirements, which are enforced by legislations and government regulations. The proces selection of industrial site means complex multi-criteria analysis wich includes a complex array of factors involving economic, social, technical, environmenta and political issues that may result in conflicting objectives[11,12,13].

Nowadays, in the post-industrial society and knowledge-based society, people become the most important resource [14]. Proximity to universities and scientific institutions, number of innovation per citizen can be one of the key factors for decision makers. All so risk management is an indispensable analysis in site selection process. Managing the risks involved in selecting a new industrial location is one of the most critical factors in determining the ultimate success or failure of a business. To keep risks at a minimum, investors should first be familiar with the stages of the site selection process and what are the key risks that need to be considered and managed during each of these stages.

The time factor is all but negligible in the analysis of the suitability of specific locations. Average time from considering to the realization of investment in Serbia is 13,1 months and time for realization is 7,9 months. Most

important factors for choosing municipality according to a study in Serbia from investor perspective are present in Fig. 1[15]. In the results of study we can clearly see that workforce is the most important factor.

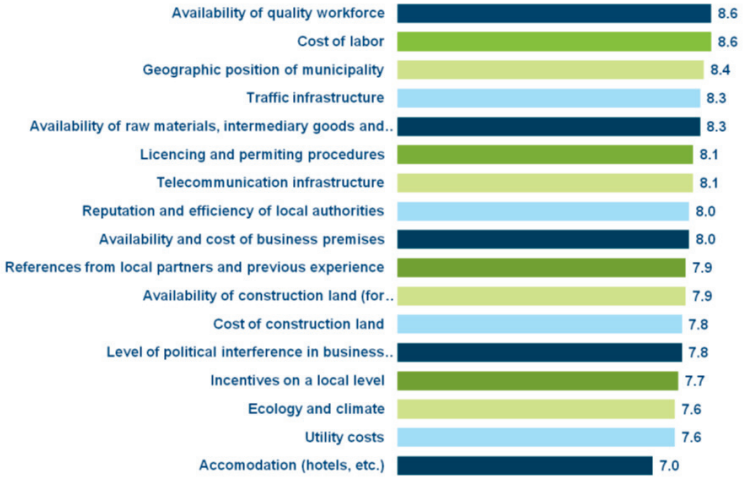

Fig. 1. Factors of importance for choosing the municipality in which to invest, Serbia (graded 1-10, where 1 is the least important).

One of the most important and far reaching decisions faced by operations managers is deciding where to locate new industrial facilities. This is a strategic decision involving irreversible allocation of the firm's capital, and often has a crucial impact on key measures of the firm's supply chain performance such as lead time, inventory, responsiveness to demand variability, flexibility, and quality [16].

Collection of information allows the generation of a potencial industrial sites that can be grouped, while the use of certerm criteria, through several iterations, gradually narrowing to a choice (Fig. 2). In such way, the total number of available sites, the customer is aware of a certain number of them. Of these, only a certain number of location meets the selection criteria of the decison meker, so that makes group of sites for consideration. By collecting information on these sites, it remains just making a group of sites that are included in the shortlist. Out of this group, based on the criteria used by the decison meker (investor) chooses one location [17].

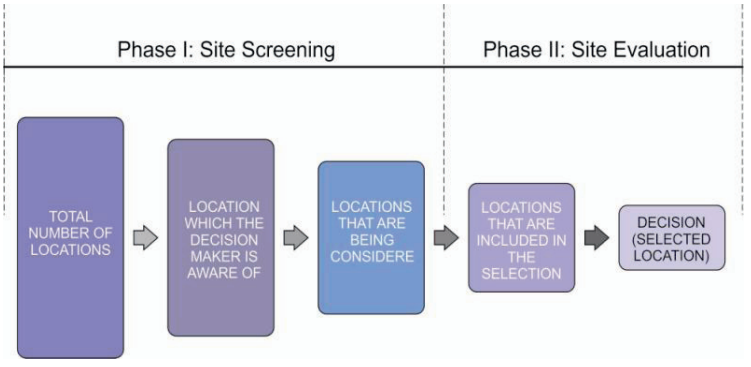

Fig. 2. Potential industrial sites.

The process of site selection includes [18]:

- Establishing a set of influential factors relevant to site selection
- Predicting and evaluating the intensity and direction of their effects in time and given conditions
- Evaluation of possible variants of solutions and selection of optimal variant.

The basic steps in the process of site selection at international and national field are given by Fig. 3:

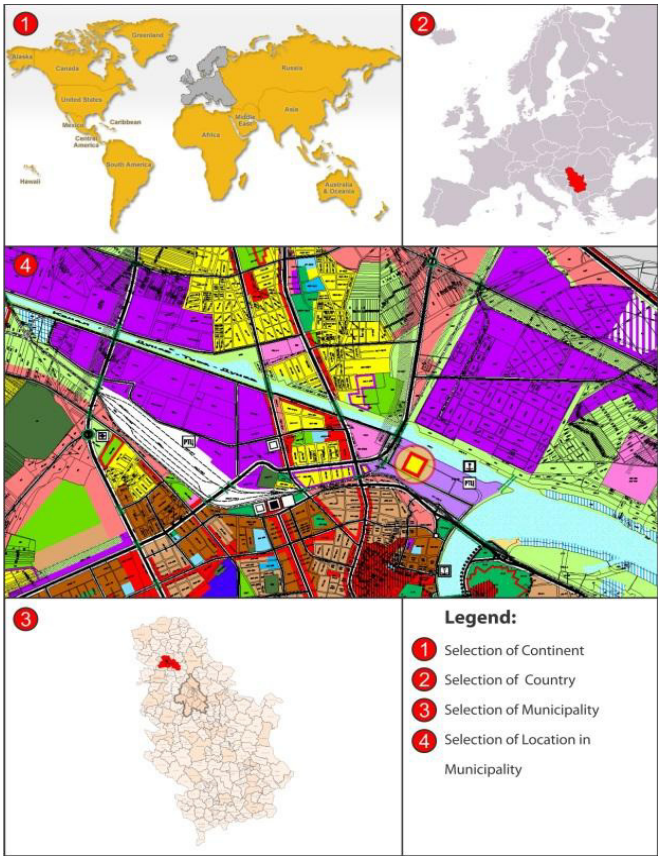

Fig. 3. Basic steps in site selection process.

3. GIS and multi-criteria analysis for Industrial site selection

3.1. Geographic information systems

It is obvious that many factors must be involved in the decision-making process, which makes the problem challenging choice in the selection of appropriate tools to enable concentration data, information and knowledge. New trends in information technologies put Geo-information sistems (GIS) in the center of events in industrial locations science. The siting and placement of a major facility means to satisfy a number of competing objectives and criteria. To accomplish task such as industrial site selection, we need to prepar number of maps, each with a diferent theme.

Geographic information system (GIS) is a group of procedures that provide data input, storage and retrieval, mapping and spatial analysis for both spatial and attribute data to support the decision-making activities of the organization [19]. Since, geographical information systems provide the capability to enter, edit, retrieve, analyze,

map, and visualize spatial data, it is not surprising to see that spatial data is marketed primarily in a GIS format. Looking towards the future, one can project an ever-increasing role for GIS to help support location studies[20].

There are a number of different methods used to analyse geographic data in Geographic information systems (GIS). There are methods of analysis of geographic data and methods of analysis of attribute data. When we are speaking about geographic data there are analysis performed over the vector data and raster data.

The most commonly used spatial analysis in GIS are:

- Analysis of attributive (tabular) data,
- Overlapping layers (i.e. query of spatial data)
- Analysis of the distance,
- Network analysis and
- Nonparametric techniques.

Analysis of attribute data of one thematic layer can be performed: as SQL query against a table with attribute data; using different arithmetic operations(addition, subtraction, multiplication, division), logarithmic functions, trigonometric functions, and so on; application of some nonparametric techniques like Multicriteria methods and methods based on artificial intelligence, and one of them is method that uses artificial neural network[21].

Geographical information can be defined as georeferenced data that has been processed into a form that is meaningful to the recipient decision-maker and which is of real or perceived value in the decision-making process. In general, the MCDA in GIS should be viewed as a process of conversion of data to information that adds extra value to the original data [22].

GIS techniques & procedures have an important role to play in analyzing decision problems recognized as a decision support system for industrial site selection especially in site screening phase. In industrial site screening phase role of GIS is to geo-referenced and analyzes feasible alternatives that will be later consider in evaluation phase. In evaluation phace roll of GIS is to produce criteria, constraints and suitability maps according to the results from Multi-criteria decision analysis and vaule judgments of decision makers.

3.2. Multi-criteria decision analysis

Multi-criteria decision-making problems can be classified on the basis of the major components of multi-criteria decision analysis: multi-objective decision analysis (MODA) versus multi-attribute decision making (MADA), individual versus group decision-maker problems, and decision under certainty versus decision under uncertainty. The distinction between MODA and MADA is based on the classification of evaluation criteria into attributes and objectives [23].

Decision is a choice between alternatives. **Criterion** is some basis for a decision that can be measured and evaluated. It is the evidence upon which a decision is based. Criteria can be of two kinds: factors and constraints.

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore measured on a continuous scale.

A constraint serves to limit the alternatives under consideration. In many cases constraints will be expressed in the form of a Boolean (logical) map: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1 [24].

Multi-attribute decision making methods are data-oriented. An attribute is a concrete descriptive value, a measurable characteristic of an entity, including inter-entity relationships. Multi-attribute techniques are referred to as discrete methods because they assume that the number of alternatives is explicit. Multi-attribute decision problems require that choices be made among alternatives described by their attributes. This implies that attribute-objective relationships are specified in such a form that attributes can be regarded as both objectives and decision variables. Attributes are used as both decision variables and decision criteria [25].

The most significant factors that describe decision problems or affect the choice and implementation of MCDA methods the most significant: Number of decision makers, Number of objectives, Number of alternatives, Existence of constraints and Risk tolerance [26-30].

There are a large number of multi-criteria decision methods that are nowadays in use in GIS environment. The most commonly used analysis are: Analytic hierarchy process (AHP), Weighted linear combination (WLC), Ordered weighted averaging (OWA), ELECTRE, PROMETHEE, VIKOR and Multiple-objective land allocation (MOLA) [31-38].

3.3. GIS-MCDA solution for industrial site selection

Spatial multi-criteria decision analysis can be thought of as a process that combines and transforms geographical data (input) into a resultant decision (output). Geographical information can be defined as geo-referenced data that has been processed into a form meaningful to the recipient. The data in geographical information systems are most commonly organized by separate thematic maps or sets of data, referred to as a map layer. The alternative to the layer approach is object-oriented GIS, where the objects are intended to closely represent real world elements. Irrespective of spatial data organization, the ultimate aim of GIS is to provide support for spatial decisions. The multi-criteria decision-making procedures define a relationship between "input maps" and "output maps" [39].

One of the most important rules governing the use of GIS for spatial decision support systems that GIS themselves do not make decisions – people do.

On the Fig. 4 we are proposing Architecture of the GIS based MCDA approach for Industrial site selection. The model has two major phases: site screening and site evaluation.

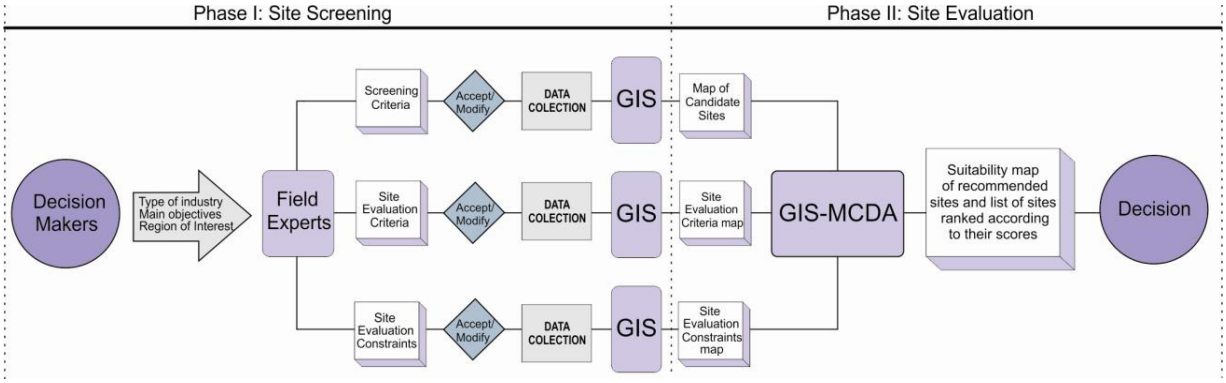

Fig. 4. Architecture of the GIS based MCDA approach for Industrial site selection.

Starting from the definition of main objectives, the type of industry and the region of interest together with field experts, in site screening phase we begin with defining criteria for selecting optimal industrial location. This is important consideration as it eliminates all sites outside the selected region from the list of possible sites. When we speak about feasible sites, after defining the screening criteria begins spatial data collection and analysis for micro and macro location in GIS, what resulting with the map of solutions arias (Fig. 5) and candidate sites (Fig. 6). This stage is very important because now we have clearly defined number of possible sites (alternatives), This is accomplished through levels of satisfaction to divide the candidate sites into those who are acceptable and those who are not. According to the type of industry, the experts of the field and/or the decision makers would define the suitability criteria (physical, environmental, geographical, technical criteria and political) for the sites of interest. The suitability criteria would define the required level of satisfaction that each eligible site must achieve. On the similar way are made input maps for constraints by collecting spatial data and produces standardized maps for GIS-MCDA analysis.

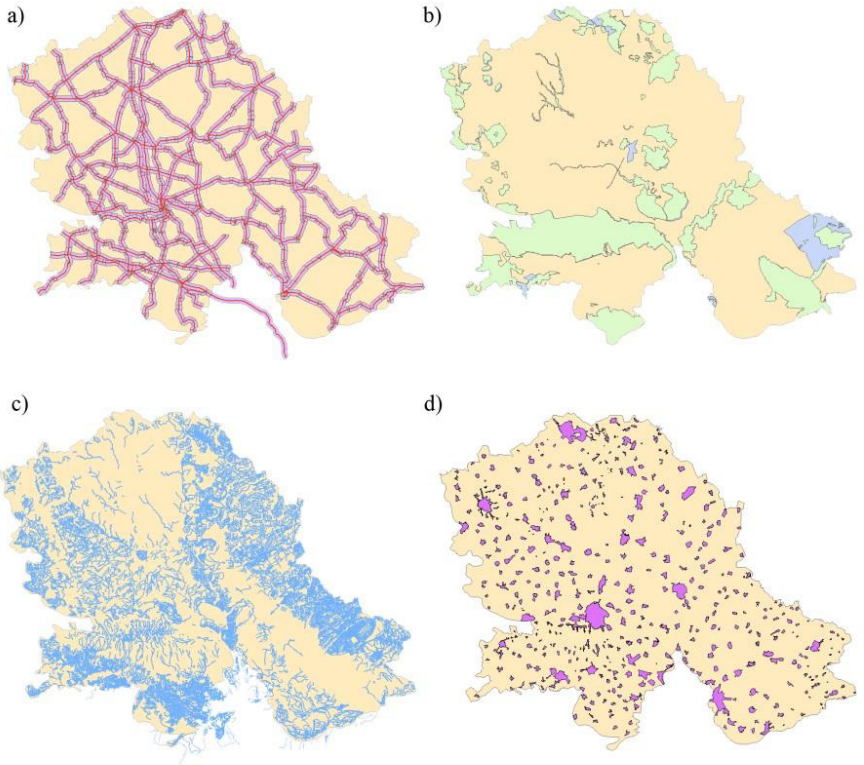

Fig. 5. Screening phase(a)road distance criterion < 1km from road; (b) Protected areas; (c) Water distance criterion >500m from water; (d) Solutions arias.

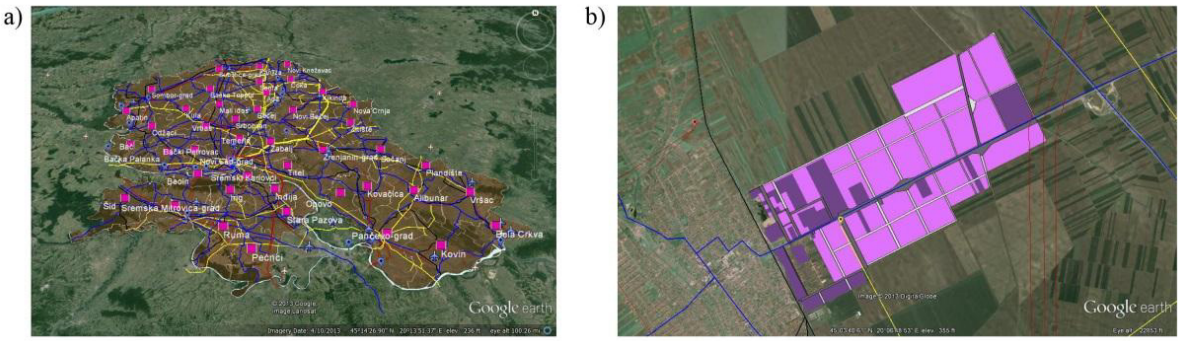

Fig. 6. Screening phase; (a) candidate sites - macro location; (b) candidate sites micro – location.

For better understanding GIS approach in spatial decision making for industrial site selection (Fig. 7) universal model is presented in the form of aof GIS based multi-crtiteria analysis for selection of a optimal industrial site in 10 (ten steps).

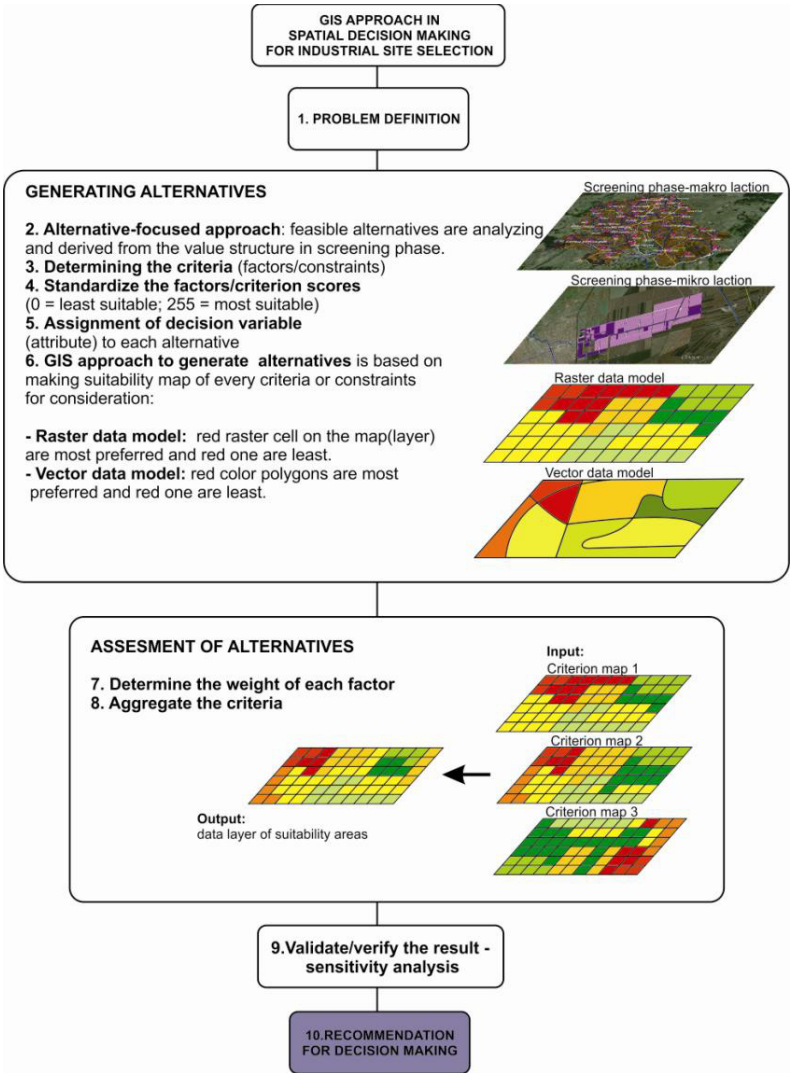

Fig. 7. GIS approach in spatial decision making for industrial site selection.

An important factor in the accessibility of research and methods is the availability of tools that implement them. For instance, ESRI's ArcGIS suite of products (http://www.esri.com) provides the building blocks needed to implement AHP, WLC, OWA including weighting overlay and map algebra. There are numerous free and commercial ArcGIS add-ons implementing other GIS-based MADM techniques [40] (http://arcscripts.esri.com). The most used packages, IDRISI and Common GIS, provide full integration of MCDA [41].

IDRISI (http://www.clarklabs.org) is a commercial GIS that includes decision-support modules based on WLC, AHP, OWA, MOLA and CA, among others, plus a wizard to assist in selection of appropriate decision techniques. Common GIS (http://www.commongis.com), is a Java-based program that runs in a web browser or as a desktop application, and provides a number of multi-criteria decision capabilities including Ideal Point, WLC, OWA and Pareto Sets [42].The final results of Multi-criteria decision analysis in GIS is a recommendation for future action for decision maker presented in the form of suitability map. In the figure 8 are presented raster and vector output suitability maps for industrial site selection in region of Vojvodina generated in ArcGIS using AHP and WLC plugins (Fig. 8). Green color representing the most appropriate locations, while red represents the most unfavorable

location. This suitability map represents macro-ranked sites based on the criteria for selection. The criteria used in the survey are in the domain of technical, social, economical and environmental.

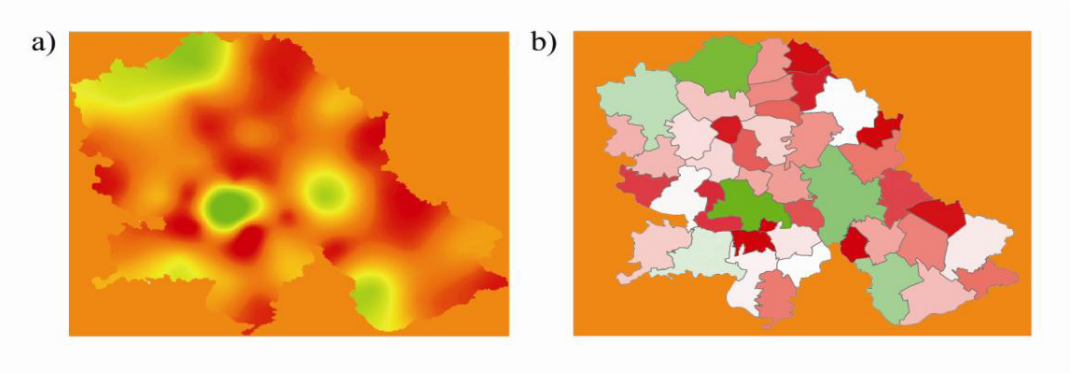

Fig. 8. Output suitability map; (a) raster suitability map; (b) vector suitability map.

4. Conclusion

Industrial site selection is spatial problem. Spatial decision problem typically involve a large set of feasible alternatives. In this paper problem of a large number of possible sites (alternatives) was resolved in screening phase, such as the choice came only sites that meet the basic criteria for industrial site selection (industrial parks, with the necessary infrastructure). In this way, we reduced time required for decision making, increased efficiency and quality in the decision making process by optimizing number of potential sites.

The developed model allows us to make a decision in 10 (ten) steps, with generating alternatives and assessment of alternatives using GIS and MCDM methods for industrial site selection. A clear need for such a model as a decision support system, allows efficient resolution of complex problem such is industrial site selection. Optimizing the number of criteria and alternatives, standardization of criterion scores and making suitability map for each criterion gives us the opportunity to perceive each criterion separately and together through final suitability map. Suitability maps as methods for visualization problem providing by GIS and MCDA are adapted to brain, that processes images much faster than the infinite tables.

Future research will focus on further exploration of appropriate multi-crtiteria decison methodes for industrial site selection and spreding spatial databese of important factors, significant for the right choice of industrial site. Developing of web softvere solutions according to the the developed model as a web decison support system that would allow decision makers to make such important decisions better and more efficient.

Acknowledgements

We use this opportunity to express our deep gratitude to Urbanism of Vojvodina who helped us in our research studies and allowed us access to the spatial data of Vojvodina. We would also like to thank Jasni Lovric and her team for their generous advice and assistance during the study.

References

[1] Eldin, N., & Sui, D. A COM-based Spatial Decision Support System for Industrial Site Selection, Journal of Geographic Information and Decision Analysis, Vol. 7, No. 2, 2003, pp.72 -92.
[2] J. Ronald Eastman, Hong Jiang, James Toledano, Multi-criteria and multi-objective decision making for land allocation using GIS, Multicriteria Analysis for Land-Use Management Environment & Management Volume 9, 1995, pp. 227-251.
[3] Carver, S.J., Integrating Multi-Criteria Evaluation with Geo-graphical Information Systems, International journal of Geographic al Informati on Systems, 5 (3), 1991, 321-339.
[4] Worral L., Spatial Analysis and Spatial Policy using Geographic Information Systems, Belhaven Press, London ,1991.
[5] Malczewski J., GIS-based land-use suitability analysis: a critical overview. Progress in Planning, 62(1), 2004, pp. 3–65.

[6] Chakhar S. and V. Mousseau, Spatial multicriteria decision making. In: Shehkar S. and H. Xiong (Eds.), Encyclopedia of GIS, Springer-Verlag, New York, 2008, pp. 747–753.
[7] J. Ronald Eastman, Hong Jiang, James Toledano, Multi-criteria and multi-objective decision making for land allocation using GIS, Multicriteria Analysis for Land-Use Management Environment & Management Volume 9, 1998, pp. 227-251 .
[8] Jankowski P., Integrating geographical information systems and multiple criteria decision making methods. International Journal of Geographical Information Systems, 9(3), 1995, pp. 251–273.
[9]Khalid Eldrandaly, Developing a GIS-Based MCE Site Selection Tool in ArcGIS Using COM Technology The International Arab Journal of Information Techn ology, Vol. 10, No. 3, May 2013 .
[10] Malczewski J., Integrating multicriteria analysis and geographic information systems: the ordered weighted averaging (OWA) approach. Int. J. Environmental Technology and Management, 2006.
[11]Keeney, R.L., Siting Energy Facilities. New York: Academic Press, 1980.
[12] Williams, E.A. and Massa, A.K., Siting of Major Facilities: A Practical Approach . New York: McGraw- Hill Inc., 1983.
[13] Masood A. Badri, Dimensions of Industrial Location Factors: Review and Exploration, Jornal of Business and public affairs Volume 1, Issue 2, 2007.
[14] Florida, R.. The Rise of the Creative Class. The Washington Monthly, 2002, pp. 15-25.
[15]Strategic Marketing Reasrch &USAID, Investment climate in Serbia- Investors' Perspective, 2008.
[16]Bhatnagar, R., & Sohal, A. S., Supply chain competitiveness: measuring the impact of location factors, uncertainty and manufacturing practices. Technovation, 25(5), 20005, pp. 443–456.
[17]Kotler, P.J., Haider, D.H., Rein, I., Marketing places: Attracting investment, industry and tourism to cities, states and nations, New York, itd: Free Press, 1993.
[18]D. Zelenović, The design of production systems: Book, Faculty of Technical, 2003, Novi Sad.
[19]Grimshaw D J, Bringing Geographical Information Systems into Business (2nd edition). Cambridge, GeoInformation International, 1996.
[20]Church, R. L., Geographical information systems and location science. Computers & Operations Research, 29(6), 2002, pp. 541–562.
[21] Aleksandar Rikalović, Đorđe Ćosić, Srđan Popov, Đorđe Lazarević, SPATIAL MULTI-CRITERIA DECISION ANALYSIS FOR INDUSTRIAL SITE SELECTION: The state of the art, XI Balkan Conference on Operational Research-Balcor, 2013, Belgrade.
[22]Malczewski J. GIS-based land-use suitability analysis: a critical overview. Progress inPlanning, 62(1), 2004, pp. 3–65.
[23]Drobne, Samo, Lisec, Anka, Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging, Informatica 33, 2009, pp. 459–474.
[24Eastman, J.R., P.A.K. Kyem., J. Toledano, and W. Iin,,. GIS and D^ecision Making,Yol. 4, Explorations in Geographic Information System Technology, UNITAR, Geneva, 1993.
[25]Malczewski J., GIS and Multicriteria Decision Analysis, John Wiley and Sons, Toronto, 1999.
[26]Balram, S. and Dragic´evic´, S. (eds), Collaborative geographic information systems. Hershey, PA: Idea Group Publishing, 2006.
[27]Jankowski, P. Integrating geographical information systems and multiple criteria decision-making methods. International Journal of Geographical Information Systems 9 (3), 1995 pp. 251–273.
[28] Chakhar, S. and Mousseau, V., An algebra for multicriteria spatial modeling. Computers, Environment andUrban Systems 31 (5), 2007, pp. 572–596.
[29]Chakhar, S. and Mousseau, V., GIS-based multicriteria spatial modeling generic framework. International Journal of Geographical Information Science 22 (11), 2008, pp. 1159–1196.
[30]Chen, K., Blong, R. and Jacobson, C., MCE-RISK: integrating multicriteria evaluation and CIS for risk decision-making in natural hazards. Environmental Modelling and Software 16 (4), 2001, pp. 387–397.
[31]Eastman, J. R., Multi-criteria evaluation and GIS. In: Longley, P., Goodchild, M. F., Maguire, D J. and Rhind, D. W. (eds) Geographical information systems. 2nd ed. New York / Toronto: Wiley, 2005, pp. 493–502.
[32]Jankowski, P. and Nyerges, T. L. Geographic information systems for group decision making: towards a participatory, geographic information science. London / New York: Taylor & Francis, 2001.
[33]Rinner, C. and Malczewski, J., Web-enabled spatial decision analysis using ordered weighted averaging (OWA). Journal of Geographical Systems 4 (4), 2002, pp. 385–403.
[34]Belton, V. and Stewart, T., Multiple criteria decision analysis: an integrated approach. Boston, MA: Kluwer Academic Publishers, 2002.
[35]Brans, J. P. and Mareschal, B., PROMETHEE methods. In: Figueira, J., Greco, S. and Ehrgott, M. (eds) Multiple criteria decision analysis: state of the art surveys. New York: Springer, 2005, pp. 163–196.
[36]Eastman, J. R. IDRISI Taiga: guide to GIS and image processing. Worcester, MA: Clark Labs, 2009.
[37]Kostanjevec, T.: Development of New Product in the Fuzzy Front End Stage with Multi-Criteria Approachc, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, Volume 22, Published by DAAAM International, Vienna, Austria, EU, 2011.
[38]Karic, E.; Vucijak, B.; Pasic, M. & Bijelonja, I.: Multicriteria Evaluation of Supervisory Boards Effectiveness, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, Volume 22, Published by DAAAM International, Vienna, Austria, EU, 2011.
[39] Malczewski J. GIS-based multi-criteria decision analysis: a survey of the literature. International Journal of Geographical Information Science, 20(7), 2006, pp. 703–726.
[40] Boroushaki, S. and Malczewski, J., Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. Computers and Geosciences 34 (4), 2008, pp.399–410
[41] Nyerges, T. L. and Jankowski, P., Regional and urban GIS: a decision support approach. New York: Guilford Press. 2010.
[42] Randal Greene1*, Rodolphe Devillers1, Joan E. Luther2 and Brian G. Eddy2, GIS-Based Multiple-Criteria Decision Analysis, Geography Compass 5/6, 2011, pp. 412–432.