

# Implementation of decision support tools in ArcGIS and IDRISI and their environmental applications

**Abstract**— In recent years, the GIS is increasingly understood as a means used to support decision-making and recognizes as the basis for the SDSS. Paper in first part describes an analysis of spatial decision support systems based on GIS and the decision-making processes and tools available in two key products, ArcGIS and IDRISI. Second part of paper, in the five small studies, deals with practical testing of the declared methods' implementation. It tests the quality of implementation of identical tasks in the Litovelské Pomoraví Protected Landscape Area in two environments using equally well-established methods. It provides a commentary on differences identified and gives recommendations as to what is to be taken into account to obtain correct results.

**Keywords**— boolean methods, comparison, decision-making strategies, weighted average.

## I. INTRODUCTION

THE theory on Decision deals with the problem of the manner of arriving at an optimized decision based on existing alternatives [26]. Usually, there is no simple guide to deriving a solution, and every decision entails a certain amount of risk. In the present-day situation of increasing anthropogenic pressure on the environment, one of the important themes is the problem of resource allocation. However, a qualified decision concerning resources requires seeking, assembling and verifying reliable information. At many decision-making levels, such information is hardly obtainable as it is difficult to combine often conflicting opinions [24]. Today, the land represents as a very limited resource; it is, therefore, important to recognize its potential and optimize its usage [15]. Due to the complexity of the requirements and the large number of criteria (environmental, economic, sociological, and natural), it is necessary to use multi-object planning techniques and multi-criteria analysis [9], [10], [30]. The rapid process of urbanization brings along the need for effective spatial planning with emphasis on the construction of urban infrastructure for housing, work and various supportive activities of the population [12]. Pursuant to the high number of specific criteria (geotechnical, environmental, constructional, municipal, etc.) [16] that must be

concentrated into this planning, the application of multi-criteria analysis method may have significant impacts on the planning quality, speed and cost [27]. An effective approach using the instruments of geospatial analysis methods (GIS) and multi-criteria system analyses will allow spatial planning to solve the problems associated with landscape planning in somewhat easier and faster ways [19]. Related topics – where the instruments of decision-making systems are also applied – include the identification of plots with natural and technological prerequisites for development [15]. Creating an optimal model for land assessment, which indicates the cost operation of investments and compliance with the provisions and objectives of urban development in accordance with international conventions is further demanded [21]. Decision-making strategies may also become useful in evaluating other natural phenomena, such as floods, landslides, hurricanes, volcanic activity, etc [22].

Multi-object decision making increases the need for participatory techniques; this is primarily based on the recognition that the decision applies to a wide range of management levels, often requiring inputs from groups of stakeholders. A considerable proportion of the tasks relates to resource allocation. In connection with the multi-object decision making, the object is perceived as a perspective or a philosophy that governs the structuring of the decision rules [8].

## II. KNOWLEDGE AND INFORMATION SYSTEMS

### A. Decision Support Systems

Decision Support Systems (DSS) enable application of analytical and scientific methods in decision-making process. After [27] DSS is defined as a group of programmes that support decision-making. Originally, these systems were intended for financial planning where they were to become means for making estimates and evaluation of hypothetical development scenarios. These systems are to be used for complicated spatial problems difficult, or only partially possible, to structure and when the decision-maker cannot fully define the problem or set up objectives [7], [21].

After [27] Densham proposes to identify DSS using six attributes:

- o DSS are directly designed to solve problems difficult to structure;
- o they represent an efficient and user-friendly environment;
- o they are able to examine accessible solutions by creating alternatives;
- o they enable interactive and recursive solution;
- o they are able to flexibly combine analytical models and data;

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- o the system uses more decision-making methods.

### B. Spatial Decision Support Systems

Spatial Decision Support Systems (SDSS) are a special type of information system. There is no unambiguous and generally accepted definition because forms of technology have not been profiled yet. However, the majority of authors agree that it is a spatial expansion of DSS, or rather an integration of GIS and DSS. Computer information systems that provide support for problems difficult to formulate and structure and cases when it is impossible to use a fully automated system are usually considered SDSS. SDSS are closely related to knowledge-based and expert systems whose creation was possible due to artificial intelligence.

SDSS as a spatial expansion of DSS have four further attributes:

- o they provide a mechanism for entry of spatial data;
- o they enable representation of spatial relations and structures;
- o they include analytical means for spatial and geographical analysis;
- o they enable creation of spatial outputs, as well as maps.

### C. Expert systems

Expert systems are computer programmes able to simulate actions of an expert in a particular field when solving complicated tasks. They are considered a sub-category of knowledge-bases systems. They are based on symbolic representation of knowledge and its implementation in an inference mechanism. Experts in the given field present the source of knowledge and procedures. These systems are able to justify solution procedures. They are used primarily for tasks difficult to structure and algorithmize, e.g. problems with recognition of situations, diagnosis of status, construction, planning, monitoring of status, corrections, management and decision-making. However, experience and intuition have to be part of the solution.

## III. GEOINFORMATICS AS A TOOL OF DECISION-MAKING PROCESSES

The geographic information system represents an organized system of computer hardware, software and geographic information designed to capture, store, manage, analyze and present all forms of geographical data. GIS also ranks among technology allowing solutions of spatially-oriented problems [19] and is acknowledged as a basis of SDSS. The major advantages of GIS application as a decision support tool encompass its processing simplicity, easy definition, selection and change in the evaluation criteria, user-friendly representation of possible options, etc.

The integration of GIS with multi-criteria decision analyses has become popular in the past twenty years [27]. The spatial aspect of decision-making encompasses a vast set of real alternatives and multiples of conflicting and incommensurable evaluating criteria [24]. To identify individual factors and their consequent evaluation, it is effective to use tools from a spatial decision support expert system. This consists of two key components: decision-making systems and GIS, whose key feature is the capacity to represent information in map form. Thus accessible information is easier to process and analyze [27]. The

process of selecting the best option (or optimization) out of a number of possible phenomena in the environmental sphere encompasses landscape analysis, interpretation of results and formulation of recommendations, which may frequently be presented in the form of a map.

At present, GIS are applied in many fields of human activities associated with the use of natural resources. There are a number of applications of GIS as a tool for analysis and consequent optimized decision. GIS in its simplest form is used for direct localization of natural resources. The resulting product, in most cases, is a more or less simple map showing the distribution of studied resources. Decision-making strategies may find application in evaluations of other natural disasters, such as floods, landslides or hurricanes [7].

GIS is a tool which has its place in decision-making processes. According to [21],[27],[28], there are two basic categories in understanding and using GIS as a tool for decision support. i) GIS is used as decision support because it helps collect, organize, analyze and visualize data utilized by a user when solving a problem. When deciding about a suitable solution, alternative scenarios may be modeled and their decisive parameters then compared. ii) GIS finds a relatively wide use in solving specific SDSS tasks focusing on location and allocation issues and is also heavily applied in network analysis.

GIS application in SDSS is characterized by the fact that apart from building data structure, which tends to constitute the primary reason for application, specific decision-making methods are also used [24]. Other authors view the relation between GIS and SDSS similarly [27]. [28] observes that every GIS enables its users to give better explanation or justification of their decision. At the same time, however, he sees a deficiency in missing interconnection between GIS and decision-making methods in a closer sense of the word. After [16] perceive GIS as a tool linking databases with management processes and state that the spatial character of GIS makes them into systems suitable for the identification of various phenomena conditioned by the geographical space. Application of the system in spatial decision-making finds its use in many scientific disciplines [22], particularly in applied biological sciences [11], [13], [22], [24].

At a general level, GIS meets the criteria for decision support tools. However, this statement needs clarification with respect to the given decision support level, specifying whether it is decision support in a narrower or wider sense of the word.

Decision support in the wider sense of the word represents efficient processing of large volumes of diverse data which must be analyzed and presented very quickly and efficiently to enable quick decisions [18]. GIS offers broad application in this type of decision support, providing tools for mutual combinations of different data types related to a certain geographical space as well as analysis of such data [1], [10]. At the same time it provides wide-ranging tools for presentation of individual data, proposals and scenarios, usually in the form of a map or 3D animations. Visual interpretation of information facilitates orientation in large volumes of data and offers the possibility to express the monitored aspects in a structured manner. In this respect, the

cartographic options of the thematic mapping programme and the possibility of programme customization are highly important. Users tend to favour powerful tools with intuitive interfaces, such as the program tools provided by Esri Inc. and their third-party extensions. These tools and principles are increasingly finding their way into all levels of decision-making processes and into many spheres of human activities (ranging from nature conservation to optimization of rescue team routing and business analysis). However, easy interface unaccompanied by a deeper understanding of the processes and algorithms involved may result in a completely wrong interpretation of results obtained and in bad decisions informed by such interpretations [27].

The situation changes upon full integration of DSS tools in GIS environment. There is a limited number of GIS programme packages with implemented DSS tools. In fact, only the IDRISI system meets such specifications [21]. The basic software package contains a complete set of decision-support tools, including tools (modules in IDRISI terminology) for adding weight factors, tools for data axis transformations or tools of multi-criteria and multi-destinal analysis.

However, these tools require a deeper understanding of the issue and their interface is less user-friendly. Conducting of analysis represents a time-consuming operation which is beyond the usual scope of everyday practice, and for this reason the analysis find more application in expert studies and research papers [15], [24]. Their often austere interface and difficult integration with commonly used software further adds to the limited application of these tools [27]. A positive feature which may accelerate the integration of DSS tools is their ability to automate processes, store and share decision-making schemes and the need to modify only input parameters.

The example of GIS MCDA (*GIS-based Multicriteria Decision Analysis*) outlines the possible development of GIS decision support applications. At its most basic level, GIS-MCDA may be understood as a thought process which transforms and combines geographic data with evaluating criteria to obtain information for decision-making. This is within the scope of synergistic abilities of both GIS and MCDA and benefits the ongoing theoretical and applied research in the field of GIS-MCDA. Efforts to integrate MCDA into GIS represent the basic tool for developing paradigms of spatial decision support [15].

Generally used GIS combinatorial operators, such as logical (Boolean) intersection and weighted linear combination, may be generalized in the field of ordered weighted average operators. This method of multi-criteria decision-making allows decision makers to define a decision strategy on the continuum between optimistic and pessimistic strategies. According [15], it was proposed to extend older implementations of the ordered weighted average using linguistic quantifiers to simplify the definition of decision strategies and thus make GIS multi-criteria analyses more user-friendly. Spatial decision-making tends to encompass a vast set of real alternatives and a number of often conflicting and incommensurable evaluating criteria. These alternatives are often evaluated by groups of individuals (officials, managers, investors, inhabitants,

stakeholders, etc.) influenced by their subjective perspectives of the relative importance of the criteria based on which the alternatives are evaluated. This fact prompted GIS application in spatial decision-making based on multi-criteria decision analysis [15]. GIS and MCDA have already seen their beneficial application in the field of spatial decision-making [9], [10], [12], [28].

GIS technology and procedures play an important role in decision analysis and GIS is often referred to as a decision support system integrating spatially oriented data in the solution of environmental problems [26]. MCDA provide a wide scope of techniques and procedures allowing the structuring of decision problems as well as planning, evaluating and giving preference to alternative actions.

Using GIS and SDSS has a characteristic feature: except for creating data structure, which tends to be the primary reason for deployment, specific decision-making methods are applied. There are two basic categories of perceiving and using GIS as a tool for decision support [7]:

- o GIS is used for better decision support because it helps assemble, organise, analyse and appropriately visualize data used for problem solving by the user. When making a decision on the suitability of solution it is possible to make use of alternative scenarios and then compare their decisive parameters.

- o GIS is relatively amply used in solving specific SDSS tasks oriented at location and allocation problems, as well as in network analyses.

Other authors also mention a similar view of GIS and SDSS. For example [12], [15], [19] state that each GIS helps the user to perform better explanation or justification of his decision. However, at the same time, he sees a problem in lack of interconnection between GIS and decision-making methods in narrower sense. He perceives GIS as a means for interconnection of data bases with management processes and says that the spatial character of GIS makes it a system suitable for identification of various phenomena dependent on geographical space. O'Looney mentions three ways in which GIS can be used in a decision-making process:

- o GIS enables representation of problem in graphical/spatial form, thus leading to a more elegant solution of the given problem.

- o Using GIS changes our perception of the world and makes us realise the spatial context.

- o GIS as a strong tool of information processing can also be deceptive (intentionally, or not) by representing things that do not exist [21].

Systems for spatial decisions are applied in a number of different fields, especially in applied biological sciences. GIS application during decision support in relation to natural resources management:

- o identification of areas meeting certain conditions - e.g. areas with dead trees;

- o identification of various phenomena dependent on space, e.g. impact of spatial margins on the inner space area, possibilities of origin of buffer zones around polygons;

- o prediction models – e.g. species composition;
- o models of fire probability, probability of undesirable impact of climate, etc.;
- o spatial process analyses - e.g. characterisation of spatial variability of ecological phenomena;
- o a number of interesting studies using GIS as the basic component of SDSS appear in hydrological applications. The extent of involvement of GIS is variable, from external environment for occasional analyses, through thematic application expansion to independent complicated hydrological, or hydrometeorological simulation models.

#### IV. TWO LEVELS OF SDSS

On a general level GIS sufficiently fulfils requirements for decision support tools. However, this allegation has to be specified; do we speak about decision support in broader or narrower sense?

Decision support in broader sense stands for a tool for efficient work with a high amount of miscellaneous data that has to be analysed and represented quickly and efficiently in order to be able to make quick decisions. For this type of support the current GIS offers extensive possibilities and tools for mutual combinations of data of different nature with relation to a certain geographical space, and their analyses. At the same time GIS provides wide-ranging tools for presentation of data, suggestions, scenarios and results, most often in the form of a map or 3D animation. Visual interpretation of information significantly facilitates orientation in a high number of data and provides the possibility of structured expression of the monitored aspects. The most significant here are the programme's cartographic possibilities to create thematic maps and the possibilities of user adaptation of the programme. Therefore, users appreciate a strong tool with intuitive handling like ArcGIS and its supplements by third parties. Nevertheless, we must emphasize here that the possibility of easy handling without deeper knowledge of processes and algorithms may lead to a completely incorrect interpretation of results, and thus, erroneous decisions.

In case of decision support in narrower sense, i.e. real DSS tools, the situation is different. There are few GIS programmes with implemented DSS tools, or rather only the IDRISI system can be included in this group. Another programme with suitably implemented DSS tools is the EMDS system stipulated as an optional supplement (extension) of ESRI products. These tools require deep knowledge of the issue and their handling is not so user-friendly. Performing analyses is more time-consuming and often there is not much time for such an operation. Therefore, these analyses are used rather in expert studies and scientific work. Low diffusion of these tools is also caused by plain interface of programmes and complicated integration with common programme packages. A positive element leading to quicker integration of DSS tools is the ability to automate processes, retain and share decision-making patterns and modify only input parameters.

#### V. DECISION-MAKING STRATEGIES

##### A. Multi-Criteria Evaluation – Boolean Intersection

This is the simplest variant of criteria processing. It is often referred to as constraint mapping. First of all, prior to the combination of criteria and their comparison, this method (as well as others) requires the standardization of factors according to a certain scale of suitability. This relates to reducing all the factors to Boolean images of suitable and unsuitable areas. It is done through reclassification into two classes, converting the desired content into classes with value of 0 for unsuitable areas and value of 1 for suitable areas of the given task; in this way, the factors are transformed to constraints. If all the criteria are presented as Boolean images of ones and zeros, they can be aggregated into a final solution using the Boolean algebra. In this combination, AND operation (minimum) is used most frequently. The advantage of this MCE method consists in the possibility of entering any number of constraints that are subsequently multiplied by each other and provide the resulting image of suitability. If all the criteria equal 1, the resulting value will again be 1. The resulting value of 0 appears whenever at least one of the criteria acquires the value of 0. In other words, the suitability of one criterion cannot replace the lack of suitability regarding any other criterion – they cannot be used interchangeably [8]. Examples of use are [1], [7], [11], [21], [22], [27], [28], [30].

##### B. Multi-Criteria Evaluation – Weighted Linear Combination

When using this method, the factors are not reduced to simple Boolean constraints as in the previous method; instead, they are standardized into a continuous scale of suitability within the interval from 0 (least suitable) to 255 (most suitable). The transformation of factors into such continuous scale allows mutual comparisons and combinations, analogous to the Boolean case. Unlike the previous one, however, this method allows avoiding an unambiguous Boolean decision that defines each criterion as entirely suitable or entirely unsuitable. In order to characterize the suitability of areas, the WLC method uses a “soft” or fuzzy concept. It is used for factors where suitable-unsuitable boundaries are defined [20]. Constraints will retain their “hard” Boolean character.

This method preserves the variability of continuous data and, at the same time, enables the interchanging of individual factors, i.e. any criterion with a low level of suitability can be compensated by a high level of suitability appertaining to another factor. In the group of weights indicating the relative importance of each factor, the manner of interchanging the factors is determined. In addition, this aggregation procedure shifts the analysis away from the AND operation extreme risk rejection. WLC is an averaging technique that places the analysis accurately between AND (minimum) and OR (maximum) operations, which means that neither extreme risk rejection nor extreme risk assumption occurs [8]. Examples of use are [2], [7], [17].

### C. Multi-Criteria Evaluation – Ordinal Weighted Average

This approach is akin to the WLC method because the criteria are again standardized and weighted in the same way. Regarding the OWA method, factors are subject to a second set of weights, the so-called ordinal weights. Ordinal weights enable a higher degree of control over the entire level of interchangeability (trade-off) between the factors as well as over the level of decision-making risk assumed when determining suitability. The decision-making risk can be defined as a probability that the decision taken is wrong.

The possibility of controlling the level of risk and the level of interchangeability is given by specifying the set of desired weights for various rank order positions at each position (pixel). Initially, the ordinal weights govern the degree to which the factorial weights can affect the aggregation procedure. After assigning the factorial weights (to some degree) to the original factors, the results rank for each position from the low up to the high level of suitability. A factor with the lowest level of suitability then obtains the first ordinal weight; a factor with subsequent low suitability obtains the second ordinal weight, etc. This leads to weighting of factors based on their ordinal value from the minimum to the maximum for each position. A relative skew (asymmetry) towards the minimum or the maximum of ordinal weights controls the level of risk, while the degree to which the ordinal weights are evenly distributed across all positions (locations) controls the level of total interchangeability, i.e. the degree to which factorial weights exercise influence [8]. Examples of use are [5], [7], [18].

### D. Multi-Destinal Decision-Making

The multi-destinal decision-making process is a process that must accommodate complementary and/or conflicting requirements. Complementary targets do not pose any major problem because the areas can be identified as highly suitable for any number of targets. However, the case of conflicting targets is much more complex because it results in identifying such territories that utmost maximize the results of the decision rules that are part of the decision-making strategy for one target. When solving a multi-destinal problem, the first step is to create suitability maps for each of the given targets. The next step is to identify areas that are most suitable for each of these targets and also those areas that maximize the suitability for each target using a compromise solution [8]. Therefore, simple allocation maps with one target are usually created in order to solve a problem that includes two targets. After overlapping the results, it is possible to identify the areas that come into conflict. Generally, results represent four different classes [7]:

1. areas selected by target 1 and not by target 2,
2. areas selected by target 2 and not by target 1,
3. areas not selected by any target,
4. areas selected by both targets (and thus in conflict).

It is clear that there is a need to resolve the area in conflict. This can also be perceived through a decision-making space determined pursuant to the suitability scale for each target, as a separate axis in multi-dimensional space.

Each cell in the region may be located in the space based on the suitability for each target [7]. This area of conflict is repeatedly divided among the targets using the logic of minimum distance from an ideal point. This logic divides the decision-making space by a line, the angle of which is determined by the relative weight assigned to the targets. Examples of use are [23], [29].

### E. Analytic Hierarchy Process

The AHP method provides the framework for preparing effective decisions in complex decision-making situations, and helps to simplify and accelerate the natural process of decision making. It allows decomposing a complex unstructured situation into simpler components; in other words, it creates a hierarchical system of the problem. This hierarchical system represents the generalization and the extension of capabilities of the multi-criteria decision-making system. At each level of the hierarchical structure, the Saaty's method of quantitative pairwise comparison is used. Through subjective evaluations of pairwise comparisons, this method assigns quantitative characteristics to individual components, expressing their importance [10]. A synthesis of these assessments then results in determining the component with the highest priority at which the decision-maker focuses in order to obtain the solution of the decision-making problem. The Saaty's method serves for determining the weights of criteria if these are evaluated only by one expert; when more experts participate in the evaluation, it is appropriate to use AHP procedures. It is a method for quantitative comparison of criteria [4]. For the purpose of evaluating the pairwise criteria comparisons, a nine-point scale is used whereas intergrades can be used as well:

- 1 – equivalent criteria i and j,
- 3 – i criterion slightly preferred to j criterion,
- 5 – i criterion strongly preferred to j criterion,
- 7 – i criterion very strongly preferred to j criterion,
- 9 – i criterion absolutely preferred to j criterion [25].

### F. Simple Multi-Attribute Rating Technique

Simple Multi-Attribute Rating Technique (SMART) is a powerful and flexible tool for decision making [6]. This technique is widely used because of the simplicity it puts on the decision maker and the manner of analysing simple responses. This method selects from a large number of alternatives with reference to various attributes that they contain [3]. Main stages of the SMART analysis are as follows:

- Identification of theme(s),
- Determination of alternatives to evaluate ,
- Identification of the relevant dimensions of values for the evaluation of alternatives (the attribute weights) – only as much as one can watch at once,
- Dimension order by importance,
- Appraisal of dimensions in importance while maintaining proportions,
- Sum of the significance weights and division by the whole,
- Measuring how well each alternative fits on each dimension,
  - Value calculation.

## VI. METHODS

### A. Study Area

The Protected Landscape Area of Litovelské Pomoraví (PLA) was established in 1990. It is located in a 3 – 8 km wide strip of land along the Morava River between the cities of Olomouc and Mohelnice and is composed mainly of floodplain forests and wet meadows habitats. The ancient city of Litovel lies in the heart of the region and gave the area its name. The entire area belongs to the Olomouc County and former districts of Olomouc and Šumperk. The mission of the PLA is to ensure appropriate protection and environmental-friendly uses of the alluvial landscape with exceptional natural values. The core of the PLA and the main natural phenomenon of the area is the “inland river delta” – the naturally meandering course of the Morava River with its branches and tributaries – followed by complexes of floodplain forests, wet alluvial meadows and wetlands. Třesín, a karst area with famous publicly accessible caves, and Doubrava, an area of upland deciduous forests, represent the other two parts of the PLA. Marginal pieces of agricultural land and built up areas are as well included in the PLA in order to even out its border [13].

The PLA mission can be seen above all in (1) nature conservation and landscape protection in an extraordinarily valuable area; (2) securing ecologically optimal land use and exploration of natural resources while restoring landscape values and the typical character of the region. The PLA thus has an important task to create and preserve ecologically optimal functions of the landscape together with nature conservation itself. Methods of active ecosystem management and landscape stewardship are preferably applied in the PLA. Litovelské Pomoraví is an area that has always been influenced by human activities. Thanks to the wisdom of our ancestors and their sensitive approach to the landscape, a large amount of rare natural values has been preserved in a fairly small area [14]. The aim of the PLA is to maintain this balanced character of cultural landscape in alluvial planes with natural streams, forests and meadows, and to continually improve its ecological functions. Litovelské Pomoraví has a special position among other protected landscape areas in the Czech Republic. It was one of the last founded PLA and due to its area of belongs to the smallest ones in the country. However, establishing the Litovelské Pomoraví PLA represented one of the first important steps towards systematic protection of nature in alluvial planes of large rivers. So far, most of the large-scale protected areas included mountain landscape only [13].

### B. Data and software

We used the following data. Linear data - line transport networks, land use boundaries, networks of pipelines from ZABAGED (Czech national topographic dataset) in scale 1:10 000. Hiking and nature trails and cycle paths in the scale 1:10 000 was obtained from our data warehouse. Polygon layer biotop of Natura2000 at the scale of 1:10 000, source Agency for Nature Conservation and Landscape. The extent of study area was border of Litovelské Pomoraví PLA extended by 50 meters. Analysis were carried out in a raster environment with pixel size of 10 m.

Implementation of the decision-making strategies was tested on the following GIS programs: ArcGIS for Desktop Advanced version 10.1 with extension ArcGIS Spatial Analyst and Analytical Hierarchy Process. Version 1.1. IDRISI Taiga version 16.02 and Criterium DecisionPlus (CDP) version 3.0.

### C. Boolean Method in ArcGIS and IDRISI

The task was to identify risk areas in the PLA of Litovelské Pomoraví that could be endangered by human presence with regard to landscape valuables. Areas surrounding the trails – hiking, nature and bicycle trails with the zone of influence up to 350 meters – were considered as risk factors. With regard to the Boolean logic, these highest risk areas assumed the value of 1. All other areas assumed the value of 0. The type of habitat was a factor reflecting the landscape richness. AA, AB, AC and BA habitats were selected as the most valuable areas. These areas were represented by the value of 1; all other areas were represented by the value of 0.

### D. WLC Method in ArcGIS and IDRISI

Again, the goal was to determine risk areas in the PLA of Litovelské Pomoraví that could be endangered by human presence with regard to landscape valuables. The distance from hiking, nature and bicycle trails was chosen as a risk factor. The most vulnerable areas were zones within 100 meters from these trails; they assumed the value of 255. Subsequently, the whole territory was converted into a continuous surface showing the degree of threat with a 100-meters interval. After standardization, these areas took on values from 0 to 255. Landscape richness was represented by habitat type. The most valuable areas were AA type habitats (these areas were represented by the value of 255), followed by zones with AB type habitats (they took on the value of 170) and AC, BA type habitats (with the value of 85). All other areas assumed the value of 0. Another chosen factor included paved roads and field paths. The most vulnerable zones were areas within 100 meters of these elements, assuming the value of 255. Using the interval of 100 meters, the remaining area was uniformly converted into a surface expressing the degree of threat. The range of values assumed was 0 – 255. To specify the relative importance of various factors in determining the aggregate output value, the following factorial weights were used 0.4 for habitat factor and 0.3 for factors of trails and roads.

### E. WLC and OWA Methods in IDRISI

WLC and OWA methods were used to determine risk areas in the PLA of Litovelské Pomoraví that could be endangered by human presence with regard to landscape valuables. This study was conducted in the IDRISI environment. The types of factors and their degree of threat were consistent with the values in the preceding study. The solution to the analysis using the WLC method was, therefore, the same as in the previous task. As for the OWA method, the combination of individual factors was based on the same factorial weights as in the WLC method, 0.4 for habitat factor and 0.3 for factors of trails and roads; considering the risk and interchange of factors, we chose three different adjustments of ordinal weights that were used in the process of aggregating data layers.

In the first case, the solution represented an average risk and full interchangeability that implied that all factors were given the same value when entering ordinal weights and, as we worked with three factors, this value was 0.3333 for each factor. The result was identical to that of WLC analysis because each layer was of the same importance in the process of aggregation as it is when using the WLC method calculation.

The second option was the solution with minimal risk and no interchangeability. Ordinal weights were adjusted as follows: the first factor was given the highest weight 1 and other factors obtained the value of 0. In this way, the entire weight was attributed to the first order, the factor nearest to the minimum value the value with the minimum suitability level in the given location. Since other factors did not obtain any ordinal weight, no interchange between the factors was possible.

The third solution brought results with maximum risk and no interchangeability. Ordinal weights were set as follows: the last factor was given the highest weight 1 and other factors obtained the value of 0. In the area of interest, at least one of the factors, therefore, poses a high level of suitability for each pixel meaning that the identified area is quite extensive and, in addition, takes values indicating high risk.

#### F. AHP and SMART Methods in CDP

In the CDP environment, we assessed five selected sites in the PLA with regard to the representativeness of PLA valuables and taking into account the aspect of accessibility to these sites. The study was carried out in the area of this PLA with boundaries extended by 50 meters, five towns – Horka nad Moravou, Litovel, Mladeč, Stavenice and Sřeň – were chosen in this area, representing the compared locations referred to as alternatives in the given model. The criteria used for selecting the most suitable locations were as follows: the distance from roads, the distance from field paths, the distance from hiking trails, the distance from nature trails, the distance from cycling trails and the habitat type (table I.).

Table I. Values of factors in relation to the target using SMART in CDP.

Factor	Weight
Distance from roads	25
Distance from field paths	50
Distance from hiking trails	50
Distance from nature trails	50
Distance from cycle trails	50
Habitat type	75

own source

In the model, these criteria were applied to create the respective hierarchical links to the target. Within the next step, SMART and AHP computing techniques were used to evaluate the criteria in relation to the target. The values were chosen so that both techniques followed the same target and their weights mutually and meaningwise corresponded in order to obtain comparable results. Subsequently, the alternatives in relation to the criteria were evaluated, reflecting real conditions in the territory.

#### G. Selection of Optimal Sites for Bio-Houses in the PLA of Litovelské Pomoraví

The final study was conducted as a selection of the optimal locations for building the information bio-house in the PLA of Litovelské Pomoraví. The study was conducted in the area of this PLA with boundaries extended by 50 meters in order to include any possible effects of the surroundings. The results were then adjusted only for the real PLA area. In reference to the underlying data, we chose the pixel size of 10 meters. This study was carried out in ArcGIS and IDRISI environments.

We selected the following factors affecting the localization of these information sites: the distance from hiking and nature trails, the distance from roads and field paths (regarding the site accessibility); the distance from electrical network/grid (regarding power availability); and the distance from the forest-meadow interface. These factors were processed by the WLC method. The Boolean method was applied to the following factors: the distance from watercourses including distributaries (regarding the representativeness of the potential site surroundings); the type of land use (pits, opencast mining areas, quarry, dumping ground, parking places, graveyard, purpose areas, urban areas, water bodies and forest land with trees were considered as unsuitable areas; other limitations were represented by the presence of small protected areas (SPA) and selected habitat types); and the access road routing (the road to the potential bio-house may not lead through any SPA). The data was standardized using linear standardization for all factors. As regards site accessibility, we chose intervals of 50, 100, 150 meters; the corresponding values after standardization are presented in table II. The electrical network availability was established at distances of 100, 200, 300 meters. With regard to the factor of forest-meadow interface distance, it was necessary to identify these interfaces within the area of interest. Appropriate distances from these elements were at intervals of 100, 200, 300 meters; the corresponding values after standardization are given in table II

Table II. Values of factors after standardization used within the WLC method

Factor	Value
Roads with the zone of influence up to 50 m	255
Roads with the zone of influence up to 100 m	170
Roads with the zone of influence up to 150 m	85
Others	0
Hiking trails with the zone of influence up to 50 m	255
Hiking trails in the zone of influence up to 100 m	170
Hiking trails in the zone of influence up to 150 m	85
Others	0
Nature trails with the zone of influence up to 50 m	255
Nature trails in the zone of influence up to 100 m	170
Nature trails in the zone of influence up to 150 m	85
Others	0
Field paths with the zone of influence up to 50 m	255
Field paths in the zone of influence up to 100 m	170
Field paths in the zone of influence up to 150 m	85
Others	0
Electrical networks with the zone of influence up to 100m	255

Electrical networks with the zone of influence up to 200m	170
Electrical networks with the zone of influence up to 300m	85
Others	0
Forest-meadow interface with the zone of influence up to 100m	255
Forest-meadow interface with the zone of influence up to 200m	170
Forest-meadow interface with the zone of influence up to 300m	85
Others	0

own source

These factors were processed by the WLC method; when combining individual factors, factorial weights were applied (see table III).

Table III. Factorial weights used in the WLC method

Factor	Factorial weight
Availability of roads	0.4
Availability of electrical networks	0.3
Availability of forest-meadow interfaces	0.3

own source

Eligible sites had to be located within 300 meters from a water flow and, at the same time, within 500 meters from a water arm. To meet the last factor, it was necessary to identify all roads, field paths, nature and hiking trails leading through SPAs, with an envelope zone of 50 meters. The values of factors after standardization and used in the Boolean method are provided in table IV. Finally, we selected areas fulfilling the above-mentioned conditions. For areas with the highest degree of suitability (assuming the values of 255 in this case), we identified plots with a minimum surface of 200 x 200 metres.

Table IV. Values of factors after standardization used in the Boolean method

Factor	Value
Water flow including a water arm with zone of influence up to 300 m or 500 m, respectively	1
Others	0
Selected types of land use	0
Others	1
Small protected areas	0
Others	1
AA, AB, AC, BA habitat types	0
Others	1
Roads, field paths, nature and hiking trails with zone of influence up to 50 m in SPAs	0
Others	1

own source

## VII. RESULTS

As for the first case study that compared the Boolean method in ArcGIS and IDRISI environments in identifying risk areas within the PLA of Litovelské Pomoraví, it was found that the results obtained in each of these environments

are identical. When including data layers such as hiking trails, nature trails and cycling paths with the zone of influence up to 350 meters and AA, AB, AC, BA habitat types, the same endangered areas were identified in both cases after appropriate standardization, whereas the total endangered area was 12636800 m<sup>2</sup>. The same results were obtained after extending this study by factors of roads with the zone of influence up to 100 meters and field paths with the zone of influence up to 350 meters; in this case, the total endangered area was 12633500 m<sup>2</sup>. It was found, in both environments, that the order of single data layers entered does not make any difference.

The second case study had the same target to identify vulnerable areas in the PLA of Litovelské Pomoraví using the weighted linear combination in ArcGIS and IDRISI environments. Data layers entering the analysis were trails with the zone of influence up to 100 meters, habitat type, roads and field paths with the zone of influence up to 100 meters. These layers are adequately standardized and then combined with the respective factorial weights. The results from both programs were slightly different. First differences already emerged in comparing the results during the standardization of trail data layers trails. Nevertheless, the results provided by IDRISI and ArcGIS environments were the same regarding the extreme minimum and maximum values. The maximum value represents the areas with the highest risk in the PLA, according to the two results, this relates to an area of 2740100 m<sup>2</sup>.

The third case study compared the methods of weighted linear combination and ordinal weighted average using the IDRISI environment in identifying areas endangered by human presence with regard to landscape valuables. The analysis worked with data layers of trails with the zone of influence up to 100 meters, habitat types, roads and field paths with the zone of influence up to 100 meters. When addressing this situation by the WLC method, appropriate factorial weights were applied after the respective standardization of data layers. The result was thus the same as in the previous study. In the case of OWA method, we used three different adjustments for solutions with average risk and full interchangeability, with minimal risk and no interchangeability, and with maximum risk and no interchangeability. Incoming layers were adequately standardized and combined with the appropriate factorial weights; ordinal weights necessary for the aggregation procedure were then applied to each data layer. As for the solution with average risk and full interchangeability, the OWA method produced expectantly the same results as the WLC method. Areas with the highest risk with the maximum values assumed in the PLA, represented an area of 2740100 m<sup>2</sup>. The results of the OWA study with minimal risk and no interchangeability brought, especially, a large area of surfaces with minimum values, the area posing no risk for the PLA of Litovelské Pomoraví. The highest risk area amounted to 2740100 m<sup>2</sup>. In contrast, the OWA solution with maximum risk and no interchangeability represented a large area of maximum values, the most vulnerable areas in the PLA with an acreage of 76008200 m<sup>2</sup>.

The fourth case study compared AHP and SMART techniques in the CDP. These two techniques were used to

compare five sites in the PLA with regard to the representativeness of PLA valuables and taking into account accessibility to these sites. The criteria affecting the selection were as follows: the distance from roads, the distance from field paths, the distance from hiking trails, the distance from nature trails, the distance from cycling trails, and the habitat type. After assessing the criteria in relation to the target and the alternatives in relation to the criteria with regard to both techniques, the single weights for relevant criteria and alternatives were calculated. The results calculated by both techniques identified the same sites as the most suitable locations (sites with the highest weights). In this case, the SMART and AHP methods are implemented at the level of evaluating the relationship of criteria toward the target, which means that either the direct method (SMART) or the pairwise comparison method (AHP) was used. Evaluation of individual sites in relation to the criteria is only solved by the direct method and corresponds to the actual environmental conditions. Of course, weights calculated in both methods differ. When using the AHP method (table V.), the calculated weights place much greater emphasis on the habitat type, compared to the SMART method (table VI.) weights that are more spread among all of the factors.

Table V. Weights for criteria and variations according to the AHP method in CDP

	Horka nad Moravou	Litovel	Mladec	Slatinice	Střen	Weights of model
Distance from roads	1	0.75	1	1	1	0.03
Distance from field paths	1	1	1	1	1	0.09
Distance from hiking trails	0	0	0	0	0	0.61
Distance from nature trails	1	1	1	0.25	1	0.09
Distance from cycle trails	1	1	1	1	1	0.09
Distance from field paths	1	1	1	0.5	1	0.09
Results	0.39	0.38	0.39	0.28	0.39	0

own source

Table VI. Weights for criteria and variations according to the SMART method in CDP

	Horka nad Moravou	Litovel	Mladec	Slatinice	Střen	Weights of modell
Distance from roads	1	0.75	1	1	1	0.08
Distance from field paths	1	1	1	1	1	0.17
Distance from hiking trails	0	0	0	0	0	0.25
Distance from nature trails	1	1	1	0.25	1	0.17
Distance from cycle trails	1	1	1	1	1	0.17
Distance from field paths	1	1	1	0.5	1	0.17
Results	0.75	0.73	0.75	0.54	0.75	0

own source

The final study used the Boolean and WLC methods to identify the most suitable locations for building bio-houses. The result was an area duly meeting the specified conditions with different levels of suitability (see table VII).

Table VII. Result of the analysis focused on selecting optimal areas for the bio-house construction with different levels of suitability

Value	Number of pixels
0	4 452 108
85	7 241
170	7 089
255	9 882

own source

The most suitable area achieved the suitability level of 255 and assumed an acreage of 988.200 m<sup>2</sup>. A contiguous plot with minimum acreage of 200 x 200 meters was identified in this area as necessary for the bio-house construction. In this way, an area of 100500 m<sup>2</sup> for potential development was determined within the territory of interest, consisting of two locations in the southern part of the PLA of Litovelské Pomoraví. These sites had acreages of 58600 m<sup>2</sup> and 41 900 m<sup>2</sup> respectively.

### VIII. DISCUSSION AND CONCLUSION

The aim of this study was to analyse and evaluate the currently implemented / available decision strategies in GIS. Based on the processed theoretical findings, we created utilization case studies. We analyzed multi-destinal decision-making strategies such as the Analytic Hierarchy Process and the Simple Multi-Attribute Rating Technique. Each of these strategies was evaluated with regard to the decision-making principle, the used algorithms and efficient deployment. Furthermore, our attention was focused on the degree of implementation of relevant strategies in GIS. Strategies evaluated in ArcGIS were the Boolean method, WLC and AHP. The implementation rate of the Boolean method, WLC, OWA and MOLA is presented in the IDRISI software; implemented AHP and SMART strategies were evaluated in the Criterium DecisionPlus software.

The first two studies compared the Boolean and WLC methods in ArcGIS and IDRISI environments using the example of potential threat to the PLA of Litovelské Pomoraví. Both of these methods can be used in either of the environments; the Boolean methods produced the same results in both cases. Regarding the WLC method, the results obtained in these software were slightly different but showed the same values in extremes. In this case, these differences were due to the fact that values cannot be rounded off normally in the ArcGIS environment. The third study compared the WLC and OWA methods in the IDRISI environment. We introduced the basic differences between these methods and compared the solutions with different levels of risk and interchangeabilities of factors. The fourth study compared the AHP and SMART methods in the Criterium DecisionPlus. This study resulted in identifying the same comparison sites as suitable for the given assignment and in calculating weights by both techniques,

applicable to further processing in GIS. In the final study, all previous knowledge of the individual methods was applied and used to identify the optimal locations for building the bio-houses. Their spatial distribution was shown in the final map. In such way, the result was characteristic of the selected decision-making strategies from different perspectives. Based on the knowledge acquired, we conducted case studies that demonstrated these individual decision-making mechanisms in various software and the differences between them.

The current development in application of geo-information decision support tools (SDSS) is driven by the increased computing capacity of available computers, as well as by boom in environmental information science. This has been increasingly becoming important with respect to decision support following the increasing volume of data obtained through monitoring and statistical summaries. Mathematical models and other mathematical decision support tools enable the processing of a vast volume of data and its conversion to information and knowledge. The importance of models in strategic planning, evaluating the economic tool efficiency in meeting strategic and operation goals, identification of different options and their cost assessment – all this is subject to mathematical modelling [6].

GIS application represents a current development trend in environmental information science. Most monitoring systems, including satellite observation, generate large volumes of spatially structured information. GIS serve as efficient tools for storing, visualizing and analyzing this data in relation to efficient database management systems. The current trend is to develop integrated modelling systems that serve as decision support tools in the search for optimum processes of environmental management [10]. There is a number of practically tested models of various scales (local, regional, global) and various complexity, whose integration would make utilization of data streams from various sources (stationary on-line monitoring, satellite observation or digital image analysis) more effective. It may be assumed that future development will focus on expert SDSS which will not only utilize databases and data streams but also expert knowledge and estimates. Not all parameters are available, the results of practical SDSS application are to be validated and mathematical models are to be further developed and improved. Mere isolated modelling outputs which do not take into consideration the wider context and therefore also data uncertainty or the stochastic nature of the modelled processes are not adequate from the perspective of decision-making processes [26].

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