Extended abstract

MapModels: a new approach for spatial decision support in silvicultural decision making

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In forest management planning emphasis is being placed not only on timber production but also on values such as recreation, amenities, wildlife and the role of forests in securing sustained water resources. In the mountainous terrain of Austria, forests additionally provide protection against soil erosion and natural hazards such as avalanches and rockfall. Forest managers are challenged by the task to transform these forest management objectives into silvicultural prescriptions for a particular stand, when considering appropriate future species mixtures or silviculture measurements.

Identification of management objectives at the stand level and evaluation of management practices which best meet these forest level goals require the development and application of models. Spatial decision support systems (SDSS) can be a valuable tool for analysis of such complex spatial decision problems in multiple purpose forest resource planning (e.g. Rauscher, 1999). In general terms, SDSS are computer-based systems for integrating data base management systems with analytical and operational research models, graphic display, tabular reporting capabilities and the expert knowledge of decision makers to assist in solving specific problems (Fischer et al., 1996). They include techniques for input, storage and processing of spatial information and provide output in spatial forms. Through a user-interface that is both powerful and easy-to-use data and models are combined in a flexible manner to allow for an operational evaluation and selection of decision alternatives.

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(Densham, 1991). As expert knowledge of forest decision makers and scientists can be formalized, the application of SDSS facilitates decisions that are reproducible and as rational as possible.

However, developing SDSS requires the cooperation of decision analysts and computer programmers. Quite often the lack of mutual understanding of other's tools and methods, create communication problems that result in time-delays and errors. To overcome such limitations MapModels was developed (Riedl and Kalasek, 1998). MapModels is a new and flexible tool for explorative data analysis and modeling of spatial decision problems.

A graphical interface programmed in Avenue™ based on ArcView® 3.0 supports easy development of analysis procedures by means of flowchart representations. Flowcharts proved to be a valuable instrument for illustration of models and the flow of data with their mutual temporal and spatial dependencies (e.g. Kirby and Pazner, 1990; Albrecht et al., 1996). Flowcharts in Mapmodels provide a visual encapsulation of analysis procedures and data objects within the model. Input data and mathematical operations are represented by labeled icons connected by edges which characterize the flow of data along the analysis procedure (Fig. 1). Since the flowcharts in MapModels contain executable program code the user specifies and implements his model in only one operation, thereby avoiding the communication problems stated above. The basic parts of MapModels are (a) MapModel-functions and (b) the MapModel-designer and interpreter.

MapModel-functions are the basic elements from which analytical MapModels are composed. They represent the nodes in the flowchart and transfer a vector of input data into a vector of output data. A rule base guarantees consistency among the elements of the model in terms of compatible data types. In raster-based GIS-technology, concepts such as MapAlgebra are well established and widespread.

![Flowchart example](image-url)  

Fig. 1. A flowchart in MapModels — the example demonstrates the determination of all areas of more than 15% slope and more than 750 m a.s.l.
Table 1
Functional order of map algebra a

<table>
<thead>
<tr>
<th>Function</th>
<th>Data-layers</th>
<th>Area of analysis</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>≥ 1</td>
<td>One gridcell</td>
<td>Multithematic overlays and queries</td>
</tr>
<tr>
<td>Focal</td>
<td>1</td>
<td>For each gridcell a specific area of surrounding gridcells</td>
<td>Neighbourhood-analysis, density functions interpolation, analysis of digital elevation models</td>
</tr>
<tr>
<td>Zonal</td>
<td>2</td>
<td>A zone of a discrete grid</td>
<td>Value aggregation for discrete spatial reference areas</td>
</tr>
<tr>
<td>Global</td>
<td>1</td>
<td>For each gridcell potentially all gridcells in a grid</td>
<td>Distance-mapping, interpolation, hydrologic modeling functions</td>
</tr>
</tbody>
</table>

a Tomlin, 1990, own adaption.

(Tomlin, 1990; Burrough and McDonnel, 1998). The functional order of MapAlgebra is used to organize the available base functions in MapModels (Table 1). Currently, the core functions of MapAlgebra are implemented, but the stock of functions can be easily extended by users with knowledge of Avenue™ programming. Furthermore, the programming language Avenue™ enables the user to modify the standard tools and the graphical user interface of ArcView® 3.0. This extensibility adds flexibility to MapModels for use as a spatial decision support system.

Essentially, MapModel-designer is the tool box to specify the model structure and execute the algorithms. The flowcharts are constructed easily by means of mouse clicks and drags. Model elements selected by the user are simultaneously checked in accordance with the rule base. If necessary, converters between different data formats are applied automatically. The user can define and change model parameters via mouse-click and dialog boxes. The administration of models and model compartment states are handled by the MapModel-interpreter. Visualization of the analysis procedures is managed by means of automatic reset and recalculation, the state of analysis is visualized by appropriate color coding.

The montane and subalpine protection forests of the City of Vienna were chosen as an example of multiple-objective management of forests, where objectives other than timber production are of primary concern. According to the management guidelines the general objectives for the forests are to ensure a sustained yield of quality drinking water, timber production, protection against rock fall, as well as recreation and conservation of biodiversity. For the whole forest area, it is not very realistic to assume that all stands share the same combination of objectives and that all objectives are equally important.

The use of MapModels is demonstrated by determining management objectives for a particular stand. As the management objectives ‘water production’ and ‘conservation of biodiversity’ are considered to be important for the whole forest area, the relative importance of the objectives ‘timber production’, ‘recreation’ and ‘protection against rockfall’ have to be determined for each stand. Using a rule based system, a model was constructed to assign each stand to one of eight different
goal types. Within MapModels, premises for these rule assignments were derived from a digital elevation model (slope, altitude), and include proximity to forest roads/settlements/viewpoints and site/stand characteristics (soil type and site index class). For instance, forest areas containing a steep slope close to rocks, settlements and forest roads have to be considered important for the management objective ‘protection against rockfall’ (MP). The relevance of these factors is determined by the structure of the decision model (Fig. 2). The importance of the factors ‘distance to roads’, ‘distance to settlements’, ‘steepness of slope’ and ‘forest areas close to rocks’ is determined by the eigenvalue method as applied in the analytic hierarchy process (Saaty, 1977). Pairwise comparisons are made on a scale of relative importance where the decision maker or analyst has the option to express their preferences between two factors on a ratio scale from equally important (equivalent to a numeric value of 1) to absolute priority (equivalent to a numeric value of 9) of one factor over another. A consistency ratio (CR) indicates the consistency of the ratings.

With regard to concepts of MapAlgebra, the evaluation of the decision model was accomplished at the pixel-level. Then, a particular objective was assigned to a forest stand if more than 50% of the pixels in the stand were classified for that objective. As a result, a set of different objectives was assigned to each stand. The frequency of the eight goal types with more than one stand level objective shows the complexity of silvicultural planning and decision making when considering suitable future species mixtures or silviculture measurements (Fig. 3).

Complex spatial decision problems are difficult to solve in a satisfying manner when entirely based on the analytical capabilities of the human mind. The use of MapModels for spatial decision support in silvicultural planning enables the user to

Fig. 2. Flowchart for deriving the management objective ‘protection against rockfall’ for a particular stand — input data are forest roads, settlements, elevation and rocky areas.
structure and analyze a decision problem. In the example, different scenario outcomes can be evaluated by changing value judgements with regard to the importance of management objectives. The use of flowcharts documents decisions, which improves transparency and duplication of the decision making process. The user does not have to worry about software-specific structures and can easily build flowcharts in a flexible way through an easy-to-use interface based on pictorial syntax (nodes, edges). The efficiency of spatial decision support systems is determined by the ability to flexibly handle sets of different input parameters and varying decision problems. MapModels enables the user to adapt analysis methods, decision rules and models to a particular problem without relying on specialized computer programming. The forest resource manager can then concentrate on the models and rules, without spending too much time on finding ways to implement them (Burrough and McDonnel, 1998). The application also tries to fulfill the
demands of user-oriented, analytical GIS operations typical for future GIS generations (e.g. Albrecht et al. 1996). There are similarities with other commercial software products, e.g. the Direct Object Manipulation Interface (GRASSLAND, 1998), the Spatial Modeler (ERDAS, 1994), STELLA®, a software designed specifically to facilitate creation-based learning (STELLA, 1996) or Powersim®, a Windows™-based software package for creating dynamic models and custom-designed business simulators (Powersim corp., 1996). For evaluation purposes a free demo-version of MapModels is available via http://esrnt1.tuwien.ac.at/MapModels/Map-Models.htm

References


