GIS based Planning of Forest Road Networks

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Summary

This paper focuses on an interdisciplinary approach using Geoinformation Science and Technology, Operations Research and Forest Science to overcome the limitations of the traditional forest road planning process. A pilot study shows that combining Geoinformation Science and Technology and Operations Research supports forest road planning. The first research objective solved in the project is the development of a system architecture that combines the strengths of software and tools from Geographical Information Science and Operations Research. This will be the starting point for further research activities towards the development of a Spatial Decision Support System prototype for planning forest road networks.

1 Introduction

The current workflow of forest road planning is based on knowledge and rich experience of a forest engineer. Based on a forester's experience a lot of field trips in the forest area to be accessed are done before a final decision on a new forest road network in this area is made. Thus, a formal description of this workflow proves difficult. For those reasons the evaluation of forest road variants is often cumbersome and subjective (DIETZ *et al.* 1984). Thus, the actual planning of forest road networks in large inaccessible areas is inefficient and error prone. Although there are spatial data available on several topics (Digital Elevation Model, etc.), a *Geographical Information System* (GISystem) is rarely used to support the forest road planning process to achieve objective solutions.

The above mentioned circumstances lead to the idea "GIS based planning of forest road networks". Within the scope of a diploma thesis (SCHOLZ 2004) a pilot study using GIS&T such as digital terrain modeling and raster analysis to successfully support the forest road planning process was done.

The main idea of this work is to combine modern methods of *Forest Science* with *Operations Research* (OR) and *Geoinformation Science and Technology* (GIS&T). OR and GIS&T provide methods and tools to overcome the shortcomings of the traditional forest road planning process. Our hypothesis is that these scientific fields provide the basis for creating a *Spatial Decision Support System* (SDSS) that is capable of supporting the engineer in the forest road planning process. Such an efficient planning process involves data that is voluminous and spatial in nature. This requires the use of a GISystem within a SDSS (MALCZEWSKI 1999). The modeling process of forest road planning leads to graph theoretical and optimization problems. *Graph Theory* offers many algorithms and methods for solving basic graph optimization problems (AHUJA *et al.* 1993; PAPADIMITRIOU & STEIGLITZ 1998; JUNGNICKEL 2002).

2 Pilot Study in Forest Enterprise "Inneres Salzkammergut"

The pilot study mentioned above is carried out in the "Kemetgebirge", which is part of the forest enterprise "Inneres Salzkammergut" of the Österreichische Bundesforste AG (ÖB*f*). The required spatial data were provided by the ÖB*f*. First we analyzed the terrain properties of the area "Kemetgebirge". Our result is, that it is sufficient to concentrate our research activities on two well defined subareas of "Kemetgebirge". The terrain conditions of these subareas represent almost the whole area character. In detail they can be described as follows:

- The first study area (T_1) shows different slope conditions, ranging from very steep to moderate sloped areas. T_1 contains protection forest, which will not be subject to this work here.
- The second study area (T_2) is more flat and shows homogenous, flat or moderate sloped terrain conditions.

2.1 Spatial Data Model

State of the art research shows, that regular tessellation is the common discretization method (BURROUGH & MCDONNELL 1998; TAN 1999; HEINIMANN *et al.* 2003), and therefore raster data are employed here. The chosen resolution is 10 m, due to the fact that the width of forest roads including the embankments is approximately 10 m in moderate sloped areas (TAN 1992; TAN 1999; TUCEK & PACOLA 1999; MALLINGER 2002; HEINIMANN *et al.* 2003). We have to say that our limitation was the resolution of the provided Digital Elevation Model (DEM), which was 50 m. We generated a DEM with 10 m resolution using the interpolation method from MITASOVA and MITAS (1993), which clearly needs deeper investigation.
This way for both study areas T_1 and T_2 the raster data model is developed and shown in Figure 1. It has to be mentioned that attribute data are merged with the polygon data, to give them spatial reference.

2.2 Modeling the Comparison Parameters

For each study area the following parameters with respect to the existing and alternative forest road networks are calculated: road length, construction costs, feasibility and benefit. These parameters may be used for a comparison of existing and alternative forest road networks, which supports the forest engineer in the planning process.
The calculation of the construction costs is based on empirical expert knowledge. This process takes into account several influence parameters: steepness of terrain, if gravel can be produced at construction site, rock formations, unstable soil conditions (e.g. swampy ground), existing haul roads, forest roads or existing fences and watercourses. Therefore the real construction costs, without road maintenance costs, can be approximated using computer techniques. The feasibility of forest roads can be extracted from road inclination. Based on existing literature (DIETZ *et al.* 1984) and empirical expert knowledge we define that 15 % inclination indicates an infeasible road segment, whether an inclination of 3 % to

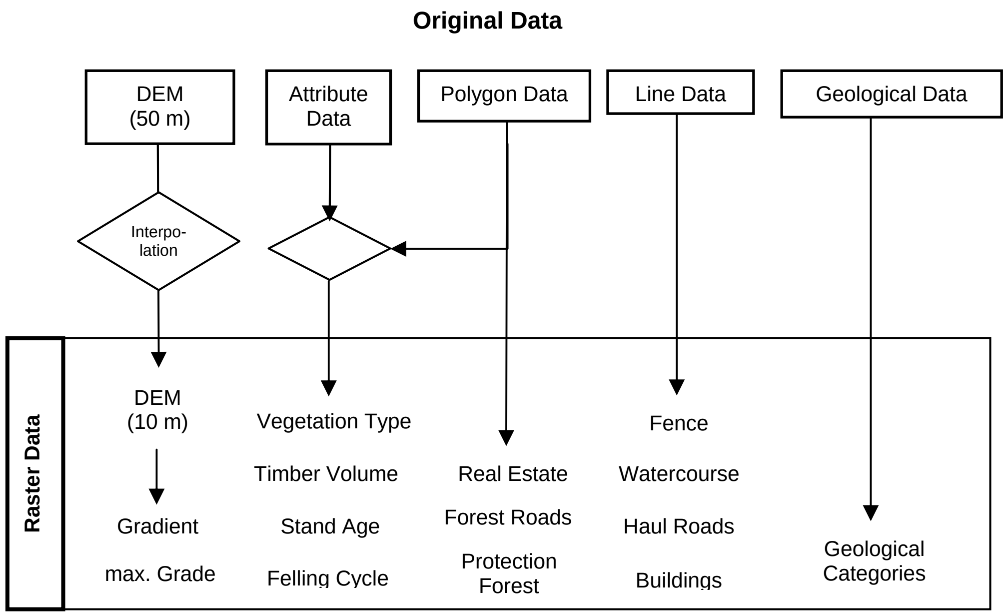

Fig. 1: Raster data model for the forest road planning process.

15 % indicates a feasible road segment and an inclination of less than 3 % shows a feasible but too flat road segment, with respect to drainage issues.

The benefit is the revenue from sustainable forest operations over a defined time period within the accessible areas. This requires a calculation of the accessible areas around a forest road network with respect to the possible harvest and logging system. The determination of possible harvest systems is based on terrain parameters, which can be found in literature (FPP 1996). To estimate the revenue of future forest operations the future standing timber volume has to be calculated, which is done with Marschall's yield tables (MARSCHALL 1975). The definition of sustainable forest operations is based on literature (MAYER 1992; BURSCHEL & HUSS 1997; PRETZSCH 2002) and expert knowledge. Hence, it is assumed to carry out one thinning per 20 years and to remove stands that reach the end of the felling cycle.

2.3 Comparison of Existing and Alternative Forest Road Network

In each study area alternative forest road networks are created using methods of GIS&T and OR. The calculation of alternative forest roads is based on constraints that originate from forest science and forest engineering. Such constraints are: area to be opened up, geological situation, vegetation type, maximum grade and user defined limitations (e.g. protected forest areas).

To compare the existing and alternative forest road networks the parameters road length, construction costs, feasibility and benefit are generated for each road network. In this pilot study the investigation period for the estimation of the benefit is 40 years. Figure 2 shows a comparison of the accessible areas of the existing and an alternative forest road network in

T_2. Our investigations described in section 2.2 lead to the results shown in table 1.The outcomes justify our research activities in this field.

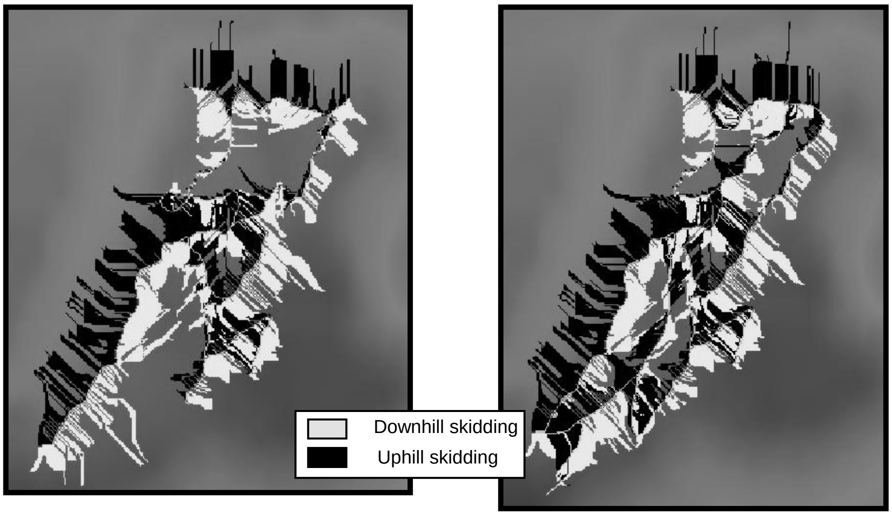

Fig. 2: Comparison of existing (left) and alternative (right) forest road network in T_2. The accessible areas around the road networks are marked with grey and black color. Grey indicates the areas where downhill skidding and black indicates the areas where uphill skidding is assumed.

Tab. 1: Results of existing and alternative forest road networks in T_1 and T_2.

	Road Length [m]		**Construction Costs [EUR]**		**Benefit [EUR]**	
	Existing	**Alternative**	**Existing**	**Alternative**	**Existing**	**Alternative**
T_1	13.234	13.876	422.000	466.000	899.000	1.294.000
T_2	11.559	15.514	359.000	491.000	888.000	1.205.000

3 System Architecture for future SDSS Prototype

In addition to the pilot study mentioned above, a system architecture is established that incorporates an interdisciplinary fusion of software from GIS&T and OR (see figure 3). This system architecture will be the first step towards an SDSS for forest road network planning.

The system architecture consists of a GISystem, that supports gathering, storage, management, analysis and presentation of spatial data and optimization software tools that can handle linear and nonlinear problems. The chosen GISystem is Intergraph's GeoMedia (INTERGRAPH CORPORATION 2004). As a platform for new developments in the interaction of GIS&T and OR we use Matlab (MATHWORKS 2004).

The developed system is able to calculate the construction costs, benefit (over a defined time period) for every raster cell of the area of interest with additional calculation modules.

These data sets and the elevation of every raster cell as well as the junctions with the public road network are the input for the optimization part in this system architecture. In this environment for getting suboptimal solutions the selection of appropriate existing and/or the development of new optimization modules will be the key issue of this research. Several open questions in this field have to be investigated in further research. The calculations in Matlab lead to results that can be incorporated into the GISystem with a special import module. This allows the evaluation of forest roads concerning construction costs, benefit, feasibility and road length.

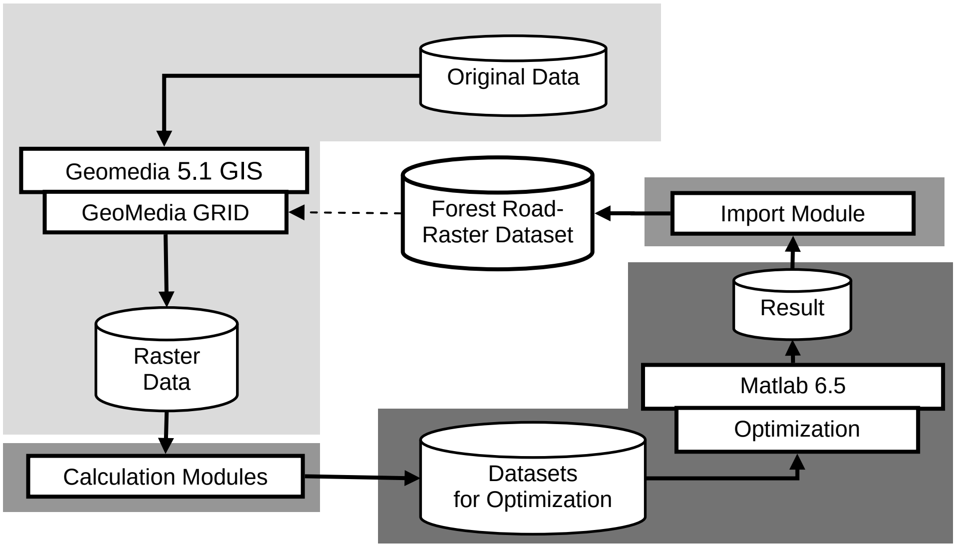

Fig. 3: System architecture for forest road planning.

4 Conclusion and Future Perspectives

The results show that with methods of GIS&T and OR it is possible to successfully support the forest road planning process. Moreover the basis for a future SDSS for forest road planning is described. During the work a number of open theoretical and algorithmic problems arose that require further research. In order to generate DEM's from sparse point data or coarse resolution raster data, the existing interpolation methods have to be investigated and tested for minimal data quality requirements to prove accurate results. Furthermore the discretization method and the adequate modeling to generate a graph are issues that have to be investigated. The forest road optimization can not be formulated as a standard optimization problem. Thus the selection of appropriate existing and/or the development of new algorithms is a key issue of further research activities.

The main objective of future research activities is to develop a prototype of a SDSS to support forest road planning. In such a SDSS the user will be able to weigh different criteria according to needs specific to forest road planning. Such criteria are e.g. construction costs, road length, and size of accessible forest areas. This tool will allow the forest engineer to create alternative forest road networks and evaluate them, which in turn supports the decision making process at hand. Human resources, usually involved in forest road network planning, can therefore be used more efficiently.

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